CONTENTS

TABLE LIST

FIGURE LIST

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ABSTRACT

SWIMMING POOL WATER TREATMENT and OPERATIONAL PARAMETERS

Eray ERDİM

The scope of this study was to illustrate the basic principles of modern water treatment procedures and to explain the significance and effect of the chemicals currently used for disinfection, flocculation, pH adjustment and the maintenance of water balance in swimming pools. The ever increasing demands made on pools and spas make the monitoring of the water quality an essential part of the treatment programme.

Turkey has a great potential of tourism industry with several facilities located in Aegean Region and Mediterranean Region and hosts more than ten million people every year. To maintain the permanence of this great economic source the swimming pools in touristic locations should be well managed and operated. In this scope, the mechanical and chemical processes applied to maintain the pool water quality in desired limits were investigated. Different disinfectant alternatives were also determined and water balance parameters were assessed.

Water samples were taken from different pools at different periods and analyzed to check whether they provide the standards or not. The results indicated that chlorine was the most preferred disinfectant in swimming pools. Although the disinfection with chlorine provided the TSI standards mostly, sometimes it did not. A strict and continuous management programme should be applied in order to prevent health problems.

Keywords: Swimming pool, water treatment, chlorine, Turkey

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ÖZET

YÜZME HAVUZU SULARININ ŞARTLANDIRILMASI ve İŞLETME PARAMETRELERİ

Eray ERDİM

Bu çalışmanın amacı yüzme havuzlarında, modern su şartlandırma prosedürlerinin temel prensiplerini ve su dengesinin sağlanması, dezenfeksiyon, flokülasyon, pH ayarlaması gibi işlemler için kullanılan kimyasal maddelerin önemini açıklamaktır. Yüzme havuzlarına olan talebin giderek artması su kalitesinin sürekli izlenmesi gerekliliğini şartlandırma programının vazgeçilmez bir parçası yapmıştır.

Türkiye, Ege ve Akdeniz bölgelerindeki çok sayıdaki tesisiyle büyük bir turizm potansiyeline sahip olup her yıl on milyondan fazla kişiyi ağırlamaktadır. Bu büyük ekonomik girdinin sürekliliğinin sağlanabilmesi için turistik bölgelerdeki yüzme havuzları iyi bir biçimde yönetilmeli ve işletilmelidir. Bu amaçla havuz suyu kalitesinin istenen standartlara ulaştırılabilmesi için uygulanması gereken mekanik ve kimyasal prosesler incelenmiştir. Bunun yanında farklı dezenfektan alternatifleri de araştırılmış ve su dengesi parametreleri değerlendirilmiştir.

Çeşitli zamanlarda farklı havuzlardan havuz suyu numuneleri alınmış ve analiz edilerek standartları sağlayıp sağlamadığı belirlenmiştir. Elde edilen sonuçlar havuzlarda dezenfektan olarak en çok klorun kullanıdığını göstermiştir. Klorun çoğunlukla gerekli standartları sağladığı halde belli zamanlarda standartların altında kaldığı tespit edilmiştir. Su yoluyla bulaşabilecek sağlık problemlerini önleyebilmek için havuzlarda sürekli ve sıkı bir yönetim programının uygulanması şarttır.

Anahtar Kelimeler: Yüzme havuzu, su şartlandırma, klor, Türkiye

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1. INTRODUCTION

1.1. The Aim of the Study

Swimming has been the most popular participant sport in the world for years. The number of public and semi-public pools is increasing rapidly due to high tourism potential in our country. The various reasons people frequent pools are relaxation, fitness, competition and therapy. Ironically, pools are built to promote health and fitness but several risks and hazards are produced with the construction and improper management of swimming facilities. Hundreds of thousands of bathers visit public and semi-public pools every year. They swim in a relatively small volume of water, which has to be of good quality at all times **(Borgmann, 2003)**. Swimming pool water should be treated in order to keep the water free of pathogenic bacteria, keep the water free from algae growth, ensure the water is neither toxic nor irritating to swimmers, prevent the formation of undesirable smells or taste, prevent corrosion of the pool surround, fittings & equipment, prevent scale formation in the pool, filter or pipes, keep the pool always swimmable and keep the pool always a healthy ambience. A variety of illnesses ranging from minor and self-limiting to life-threatening has been reported as a result of using improperly maintained swimming pools. Reported illnesses which have increased over the past few decades can most likely be attributed to improved reporting techniques and to the increased popularity of spa pools and hot tubs. One of the most important factors in preventing outbreaks of illnesses at pools is adequate disinfection. Proper filtration and chemically balanced water are also essential in maintaining a healthful pool. All three factors work together to control the proliferation of pathogens and prevent disease.

A swimming pool is a dynamic system of moving water that continually flows from the pool for treatment and returns cleaned and disinfected. The pool can be described as a recycling system whereby the entire volume of water passes through a filtration plant several times each day. As the water travels through the filter, it is cleaned of suspended particles and sort of organic debris and before turning to the pool it must be sanitized using a strong disinfectant. Without filtration and disinfection the water in the pool turns cloudy and bacteria begin to grow thus become unsafe for all who enter **(Griffiths, 2003)**.

1.2. The Scope of the Study

The scope of this study is to illustrate the basic principles of modern water treatment procedures and to explain the significance and effect of the chemicals currently used for disinfection, flocculation, pH adjustment and the maintenance of water balance in swimming pools. The ever increasing demands made on pools and spas make the monitoring of the water quality an essential part of the treatment programme.

Turkey has a great potential of tourism industry with several facilities located in Aegean Region and Mediterranean Region and hosts more than ten million people every year. To maintain the permanence of this great economic source the swimming pools in touristic locations should be well managed and operated. In this scope, the mechanical and chemical processes applied to maintain the pool water quality in desired limits were investigated. Different disinfectant alternatives were also determined and water balance parameters were assessed.

Water samples were taken from pools at different periods and analyzed to check whether they provide the standards or not.

2. Swimming Pools

2.1. Classification of Swimming Pools

There are various classification methods for swimming pools related with geometrical shape, construction materials, volume and building techniques. For the purpose of this study, the classifications are defined as follows.

2.1.1. Public and sports pools

A public pool is usually a large pool with a surface area of more than 200 m^2 and a volume between 400-3000 m^3. These pools are owned or operated by some legal entities and they are available for anyone who pays entry fee. They can be constructed as both outdoor and indoor pools.

2.1.2. Residental pools

Residential pools are private pools that are not regulated by the health department or some other regulatory agencies. The major difference between residential and commercial pools is that while equipment and maintenance standarts are recommendary for residential pools they are mandatory for commercial pools. Residental pools are not intended for commercial use and are motly constructed as outdoor pools.

2.1.3. Water parks

Water parks form the biggest part of pool classification with a volume of more than 3000 m^3 and they are constructed as outdoor pools.

2.1.4. Hotel/motel pools

The volume of hotel/motel pools vary between 200-3000 m^3. They are constructed as both outdoor and indoor pools.

2.1.5. Semi-public pools

These pools are similar to public pools but have special entry restrictions like that of a hotel/motel or fitness center pool. Members have to pay fee for entrance.

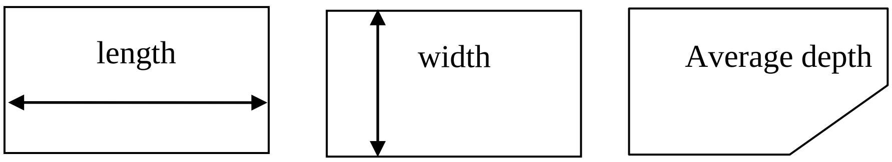
2.1.6. Spas and hot tubs

Spas and hot tubs are popular for their therapeutic value and low initial and upkeep cost. They are considered as the fastest growing segment of the water industry.

2.2. Capacity Calculations

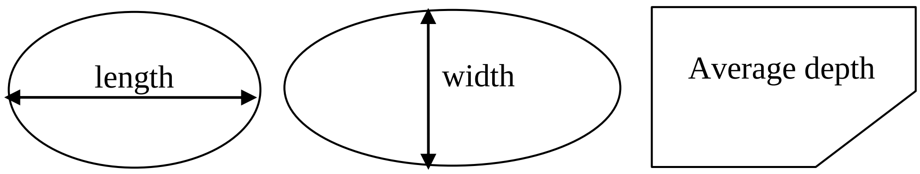
It is necessary to calculate the water capacity of the swimming pool in order to accomplish a full treatment program. The most important point that should not be overlooked is the balance tank water capacity. Also this volume must be added to the calculated pool volume. Average depth of a pool can be calculated approximately by the formula, (max.depth + min.depth)/2. Various formulas used for capacity calculations according to the pool shape are as follows.

2.2.1. Rectangular or square pools



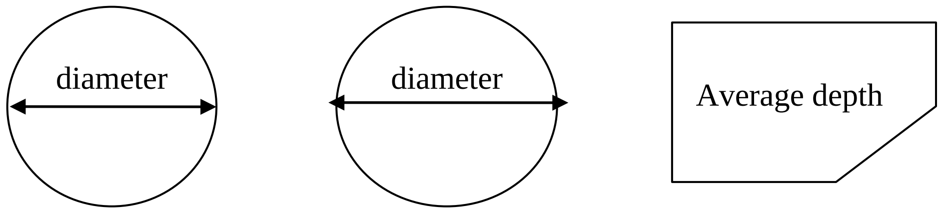
Volume (m^3) = Length * Width* Average depth

2.2.2. Oval pools



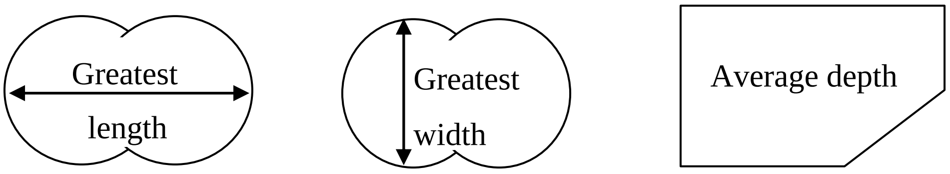
Volume (m^3) = Length * Width* Average depth* 0.89

2.2.3. Circular pools



Volume (m^3) = Length * Width* Average depth* 0.78

2.2.4. Free shape pools



Volume (m^3) = Length * Width* Average depth* 0.85

2.3 Circulation

To maintain a clear, high quality water in swimming pools an adequate understanding of filtration and chemical disinfection is a must. Considering the working of human body can be helpful in understanding how a swimming pool functions. The heart circulates blood in the body much the same way that a centrifugal pump recirculates swimming pool water. The kidneys remove toxic wastes from the blood just as filters remove debris from the pool water. Just as the veins and arteries carry blood to and from the heart, so do a series of influent and effluent pool pipes (Figure 2.1)**(Griffiths, T., 2003)**.

Swimming pool water must be circulated continuously through filters whenever pool is open for swimming, and for most pools circulation should be maintained 24 h a day. The circulation system must be capable of drawing water from the pool and then distributing treated water throughout the pool.

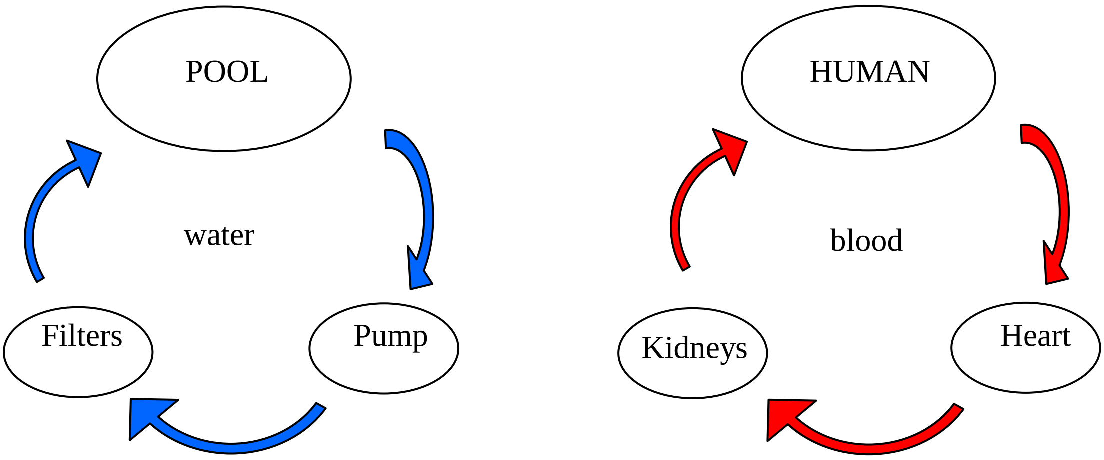


Figure 2.1 Similarities of swimming pool's and human body's circulation

The basic components of a swimming pool and its circulation system include the following.

1. Swimming pool basin
2. Balance tank(surge)
3. Pump
4. Hair and lint strainer (except on vacuum filters)
5. Filter/filters
6. Heater (optinal, if necessary)
7. Chemical disinfection system
8. Pool outlets
9. Pool inlets
10. Gauges, valves and meters.

2.4. Turnovers

The equipment mentioned above is responsible for circulation, however, they should maintain certain turnover requriments. Although many countries require 8 hour turnover period the trend is moving toward a 6 hour turnover. This means that water in a pool must pass through the filters every six hours, or 4 times a day. According to Gage and Bidwell's Law of Dilution, in fact, during one turnover, less than half of the water in the pool actually goes through the filter.

As shown in Figure 2.2 turnover rate is crucial to water clarity in swimming pool **(Griffiths, T., 2003)**. For example, % 95 of the pool water is filtered in three turnovers.

Only the pool volume and flow rate (filter rate) are necessary to determine a given pool's turnover rate. The equation 2.1. is used to calculate the turnover rate.

Turnover (h) = (Pool capacity, m^3) / (Flow rate, m^3/h) (2.1)

As water clarity depends on turnover rates, proper turnover rates are particularly important to pools with high swimmer loads. Swimming pool will not stay clear whether adequate turnover rates are maintained. Conversely, if the pool meets the turnover requirements but the water is still cloudy, the problem is probably a lack of chemical oxidation and not filtration.

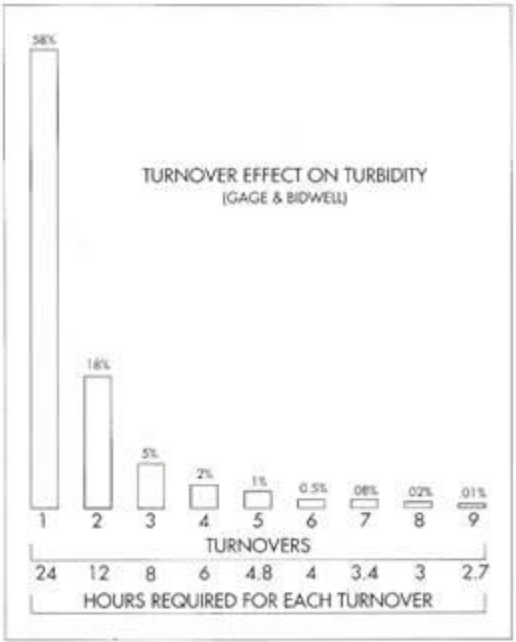


Figure 2.2 Turnover effect on turbidity **(Gage&Bidwell)**

Some suggested turnover rates are shown in Table 2.1..Besides, some commercial corporations have published turnover/flow rate graphs for pools and spas to determine the turnover rates easily.

Table 2.1. Some suggested turnover rates **(Griffiths, 2003)**

	Light-Moderate Swimmer Loads	Heavy Swimmer Loads
Public pools	6-8 h	4-6 h
Residential pools	8 h	6 h
Residential spas	< 30 min	< 30 min

2.5. Dilution with fresh water

Disinfection of the water and the filtration process will not destroy or remove all of the pollutants present. A programme of dilution of the pool water with fresh water is desirable to reduce the build-up of pollutants from bathers and the by-products of the disinfection process. To some extent dilution is carried out by the sheer nature of back washing the filter where the water flushed to drain must be replaced. Unfortunately it is observed that this is not frequent enough to maintain the concentration of pollutants at an acceptable level. Although some pollutants can be reduced by dilution, organic chloramines for example cannot be broken down by chemical means. It is recommended that up to 30 litres of water per swimmer be added every day **(Lovibond, 2002).**

2.6. The balance tank and the pool pump

Pool outlets are the exit points through which water leaves the swimming pool. Gutters and skimmers are both used for removal of water from the surface of the pool but they are significantly different in design. Gutters are troughs that are installed continuously around the perimeter of the pool where skimmers are individual exit ports located intermittently around the pool. Pools with gutters should have balance tanks which are designed to hold a large volume of displaced swimming pool water in reserve **(Griffiths, 2003)**.The benefits of balance tanks can be thought as to hold a reserve capacity of water when a large number of bathers enter the water and to protect the pumpm by maintaining a water level in the tank that is above the suction port of the pool pump. Balance tank capacity should be capable of taking the total displacement of at least maximum design bather load and preferably the total displacement of maximum safe bather load.

Maximum safe bather load is simply determined from the surface area of the pool and the number of bathers who can safely be allowed to use a facility of a given surface. Table 2.2. shows the required areas per bather in swimming pools versus depth of water to determine the maximum safe bather load.

Table 2.2. Required areas per bather in swimming pools

Required area	Depth of water
1 bather per 2.2 m^2	shallow water (under 1 m deep)
1 bather per 2.7 m^2	standing water (1 – 1.5 m deep)
1 bather per 4 m^2	deep water (over 1.5 m deep)
1 bather per > 4 m^2	very deep water (over 2 m deep)

The maximum design bathing load can be calculated by the Equation 2.2.

$$\text{Maximum design bathing load } (m^3/h) = (\text{ Pool circulation rate } / 1.7\ ) \qquad (2.2)$$

To maintain clean, clear swimming pool water, a pump must move the water through the pipes and filters. The pool pump system is the most important part in the management of a swimming pool One of the many types of centrifugal pumps are used swimming pools exclusively.

2.7. Filters

The filter is the piece of pool or spa equipment that strains impurities out of water that is pumped through it **(Tamminen, 2001)**. The filters are used to remove suspended solids from the water, which is essential in reducing turbidity and increasing water clarity. The filter surface area or bed creates small pores where dirt lodges and is unable to pass through. The important point that should be taken into consideration is that dirt can trap also additional dirt thus reducing the effectiveness of the filter. When the flow of water through the system is no longer efficient because of the accumulated dirt, the filter media must be cleaned or replaced.

The effectiveness of any type of filtration system depends on several factors as the flow rate, the filter media, the amount of filter area, and the turnover rate. Filter medias can be divided into two types: Permanent and temporary media.

Permanent media is a filter media that can be reused and does not have to be replaced on a regular basis. Sand is the most common permanent filter media used in pool industry. Temporary media is a filter media that must be replaced after each filter cleaning or backwashing. The most popular temporary media is Diatomaceous Earth (DE). Filters which do not allow particles of 15 microns or larger to pass through provide the clarity in a pool.

2.7.1. Sand filters

Although sand filters are the most widely used filters in swimming pool industry because of their easy use, they are the least efficient in trapping the dirt. The reasons for their wide use are the permenance of the sand as a media and the ease of backwashing. It is usual to achieve high water quality when they are maintained properly. The faster the water travels through the filter, the lower the filtration efficiency. Sand filters include pressure and sand gravel, pressure high rate sand, vacuum sand, and rarely gravity sands. Pressure and sand filters are not preferred recently because of their large sizes, installation costs and the extensive amount of water required for backwashing.

Backwashing refers to cleaning pressure filter systems by reversing the flow of water in the filter tank and pushing the accumulated dirt out. An extremely dirty filter will be accompanied by a significant pressure increase inside the tank and a drop in the filter flow rate. When the pressure difference between the influent pressure and the effluent pressure reaches a predetermined point, the filters should be backwashed **(Pope, J.R.)**. Flocculants are sometimes added to the top of the sand and gravel filters to assist in the filtering process. Flocculants like aluminum sulfate create a gelatinous mass that floats ontop of the filter and collects additional dirt. Flocculants are used only in conjuction with pressure sand and gravel filter systems.

The top layer of sand in pressures and filter system may encounter problems most of which are caused by ineffective backwashing flow rates. Channelling is caused by holes in the sand bed that can result and lead to poor filtration. Calcification of the sand layer may also occur when the pool water is not balanced, particularly regarding high levels of calcium hardness and total alkalinity. In order to prevent these problems, the sand should be raked clean and inspected once a year.

It is recommended to change the sand after 10 years at maximum. By maintaining balanced water and proper washing rates the problems can be avoided.

2.7.1.1. High rate sand

High rate systems became popular in the late 1950s because of reduction in both size and cost of equipment. Because of high filtering rates, less sand in smaller tanks is required. These filters use depth filtration which the entire sand bed is used to trap the dirt. Cartridge and D.E. filters use only the surface of the media. Sand and gravel filters use the 20 mm. of sand. Types of pool filters are shown in Figure 2.3.

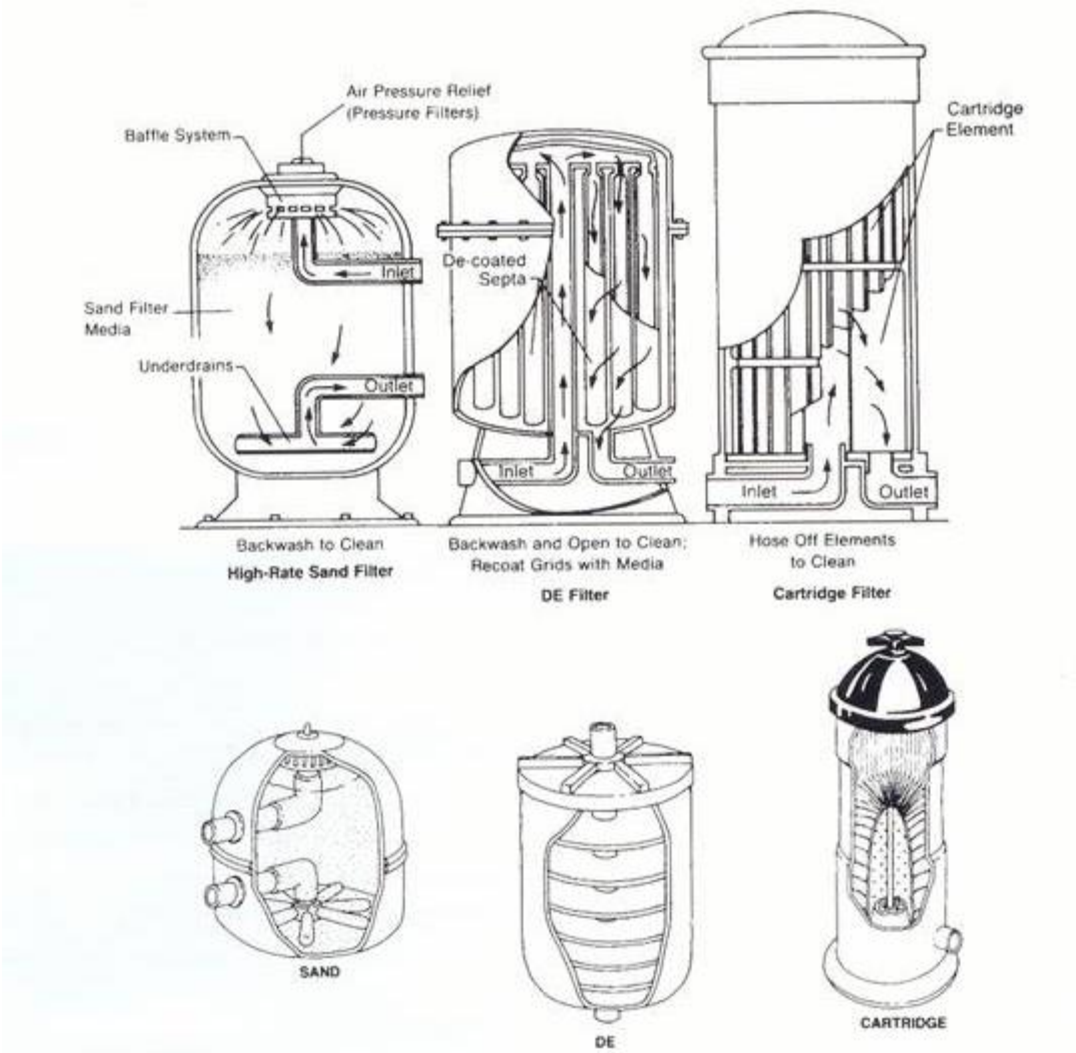


Figure 2.3 Types of pool filters (NSPI,1992)

2.7.2. DE filtration

DE filtration produces superior water clarity because of the ability of this irregular shaped filter media to screen out the smallest of particles. Unlike sand, DE filters dirt by trapping dirt within DE pores and holes, as well as between particles. Although DE produces great water clarity, its disadvantage is that DE is a temporary which needs to be replaced often. Many DE filters require a new batch of DE after every backwashing. In addition, the filter septa to which the DE filter cake clings must be cleaned periodically.

2.7.3. Cartridge filters

Cartridge filters utilize an artificial media. the filter element is composed of a pleated polyster or cloth or other synthetic fabric that traps dirt. One of the main advantages of cartridge filters is that they are cleaned by hand and do not require much water to clean, therefore they conserve water. Besides, cartridge filter systems are very simple to disasemble, analyze, repair and replace. Catridge filtration systems require little space and eliminate much of the valving and piping requirements. However, the difficulty in cleaning them is one of the disadvantages. Moreover, it is observed that only 65 % to 75 % of the cartridge filtering capacity is recovered after each cleaning.

2.7.4. Alternatives to sand filtration

Zeolites and recycled gas are two new exiting alternatives which have been introduced to sand filter industry. Zeolite collects more dirt and in addition traps ammonia existing in the media. Lacking ammonia in the pool means significiantly less chloramines production in the swimming pool **(Griffiths, 2003)**. Besides, zeolite filtration improves water clarity and reduces chloramines significiantly.

Recyled gas is also becoming popular as a replacement for sand because it is lighter and it is supposed that the sharper edges of the glass catch more dirt.

3. SWIMMING POOL WATER TREATMENT

3.1 Disinfection and Alternative Sanitizers

Swimming pool water needs to be disinfected to keep swimmers from infections caused by microbial pathogens **(Powick, 1989).** Disinfection can be defined as the process of destroying living microorganisms and bacteria to prevent transmission of diseases. Bathers contaminate the water with large amounts of micro-organisms. From the skin alone hundreds of millions of bacteria are rinsed during swimming. Other sources are saliva as well as the flora of intestines and genitals. These micro-organisms can cause various illnesses, for example eczema, infections of ears or the gastro-intestinal tract **(Borgmann-Strahsen, 2003)**. In order to provide efficient and continuous control the disinfectant must have residual properties. Residual properties mean to maintain minimal levels of active, available, chemical disinfectant in the swimming pool at all times. Disinfectant residuals in swimming pools that have been suggested in various countries are shown in Table 3.1.

Table 3.1 Recommended disinfectant residuals (mg/liter) in swimming pool water(WHO,2000)

Disinfectant	UK	EC	USA	Germany	Italy
Free chlorine (hypochlorous acid and hypochlorite)	1–2		1.0–3.0	0.3–0.6 0.7–1.0 (spas)	0.6–1.2
Bromine	1.5–3.5		2–4		
Chlorocyanurates	2.5–5.0 (free chlorine)				
Chlorine dioxide		0.2–0.3			0.3
Ozone	0	<0.1	0.1 (0.05 mg/m^3 air)	0.05	0.03
BCDMH (Bromochloro dimethylhydantoin)	4–6 (as Br) 200 (max. as BCDMH)				
Copper	1				

The hardiness of an organism when exposed to a specific disinfectant can be quantitatively expressed by the formula CT, where C is the concentration in mg/L of the disinfectant and T is the time in minutes of exposure. This value typically represents the concentration of a particular disinfectant and the time required to inactivate 99.9% of the organisms. Depending on the organism and disinfectant, this can vary from low to high levels of disinfectant for short to long periods of exposure time.

One of the most frequently isolated organisms found most often in spa pools, is *Pseudomonas aeruginosa*. These hardy thermophilic bacteria are encapsulated with a slimy coating that makes them more resistant to disinfectants. *P. aeruginosa* is most often responsible for outbreaks of folliculitis and skin dermatitis but can also cause otitis, pneumonia, and urinary tract infections. The amount of time spent in the contaminated water is an important factor in determining whether or not a person will become ill. Most outbreaks can be traced to lack of proper disinfection, inadequate filtration, and/or lack of proper pool maintenance and cleaning practices. Although testing has shown that *P. aeruginosa* is susceptible to low concentrations of free chlorine, it has been recovered from spas containing free chlorine residuals of 2 mg/L or greater. Exact numbers at which these organisms need to be present to cause illness is not known. It appears, however, that a level of 2 mg/L of free chlorine prevents the proliferation of the bacteria. Outbreaks in the past suggest that relatively large numbers of *P. aeruginosa* are needed to cause illness, and there have been few, if any, outbreaks observed at pools with adequate disinfectant levels.

Another group of bacteria that are commonly found in swimming and spa pools are *Staphylococci*. These bacteria originate from the pool user's skin and oral and nasal tracts. The coagulase positive varieties, e.g. *Staphylococcus aureus*, can cause serious skin infections as well as conjunctivitis, odds, and upper respiratory and urinary tract infections. Relatively low levels of free chlorine (<1.0 mg/L) are adequate to inactivate the bacteria in a short time.

In 1994, an outbreak of Legionnaires' disease was reported, but superchlorination and proper cleaning of filter devices successfully ended the outbreak. A Vermont study in 1983 indicated that *Legionella pneumophila* was isolated from three out of seven whirlpool spas located at local inns. In 1982, 14 out of 23 Michigan church group members became ill with flu-like symptoms after using a spa pool.

The illness was identified as Pontiac Fever, a milder form of Legionnaires' disease. Legionella, which have been identified as causing Legionnaires' disease and Pontiac Fever, were isolated from the spa water.

Legionella can be found in both raw and treated water. These bacteria are thermophilic and can survive temperatures up to 50°C. Legionella may often be found in the plumbing systems of hospitals with no apparent cases of Legionnaires' disease, indicating that some strains are more virulent than others. The United States Environmental Protection Agency (EPA) recommends free chlorine residuals of 8 mg/L to control Legionella in hot water plumbing systems. The EPA also reports that in some cases, a level of 1.5-2.0 mg/L is sufficient to control the organism.

Shigellosis is an acute bacterial illness involving the large intestine and is characterized by diarrhea, fever, nausea, and sometimes, vomiting, cramps, and toxemia. It is caused by bacteria of the genus Shigella. An outbreak of *Shigellosis* occurred at a recreational swim area in Los Angeles County in 1985. The water for the lake was supplied by a deep underground well that was used to replace water lost through evaporation and drainage. Bather loads during weekends were typically high and the swim area lacked any appreciable circulation. The recreational swim area had a chlorination system in place at the time of the outbreak, but it was not in use. Within one week following exposure at the recreational site, 68 persons had onset of diarrheal illness, including seven persqns who required hospitalization. It was theorized that the outbreak was caused by direct bather contamination of the swim area which was caused by heavy bather load, inadequate restroom facilities, poor water exchange, and the absence of disinfection. In the setting of a swimming poo1 with continuous filtration and chlorination, Shigella are quite susceptible to low levels of chlorine disinfectants and can be inactivated at levels less than 1.0 mg/L.

A variety of viruses have been implicated in disease outbreaks at public pools including adenovirus, enterovirus, and Hepatitis A virus. Adenovirus type 4 was identified as causing an outbreak of pharyngoconjunctival fever at a swimming pool in Georgia and a summer camp in North Carolina. A major factor in both outbreaks was inadequate chlorination. Laboratory tests have shown that low levels of free chlorine (0.2 mg/L) are effective in inactivating adenovirus type 3 and type 4. In a 1981 study, municipal and wading poo1s in the Houston area were tested for viruses.

Viruses, including enterovirus, echovirus, coxsackievirus, adenovirus, and poliovirus, were isolated in 10 out of 14 samples. Two of the pools that contained enterovirus had free chlorine residuals that exceeded 0.4 mg/L. The study suggested that viruses were generally more resistant to chlorine than coliform bacteria. Coliform bacteria are commonly used as indicator organisms to determine water quality. The study concluded that a higher free chlorine residual should be considered for public pools.

Of great concern in the last decade have been outbreaks of illness caused by species of Giardia and Cryptosporidium. Both organisms are protozoans and are transmitted from person-to-person through oral-fecal route. Giardiasis is caused by several species of Giardia that infect the upper portion of the small intestine. While frequently asymptomatic, it may cause diarrhea, abdominal cramps, fatigue, and weight loss. The disease is spread by ingestion of cysts from the feces of infected individuals. An outbreak of Giardiasis occurred at a public swimming pool in New Jersey in fall 1985. The source of the contamination was most likely a handicapped child who had a fecal accident in the pool. Records indicated that no chlorine reading had been taken on the day of the contamination, and the following day the chlorine level was zero. Giardia cysts are somewhat resistant to chlorine, especially at colder water temperatures (<10°C). At temperatures normally maintained in pools (>20°C), inactivation of Giardia cysts occurs at free chlorine concentrations of 1.5 mg/L for 10 minutes or a CT value of 15.

It has been demonstrated that rapid and high rate sand filters cannot be relied on to effectively remove oocysts. While diatomaceous earth filters can remove oocysts, it generally takes at least three turnovers of pool water to eliminate 95% of the pollutants. Cryptosporidium oocysts are extremely resistant to chlorine, and it has been reported that a CT value of 9,600 is required to inactivate them. Another study indicated that exposure of oocysts to 80 mg/L of free chlorine at 25°C for 90 minutes produced a 99% inactivation rate resulting in a CT value of 7,200.

Many illnesses, some very serious, can be transmitted through improperly maintained swimming pools and spa pools. With the exception of Cryptosporidium, current information indicates that most pathogens in pool water can be inactivated or at least controlled with a minimum free chlorine residual of 2.0 mg/L or an ORP of 650 mV.

Although the role of disinfection is extremely important, it is quite easily achieved. Oxidation of organic pollutants (hair, lint, body oil, urine, etc.), however, might require much higher levels of chemical disinfectant in pool water. Chemicals that do not have residual properties may not be used as primary swimming pool disinfectants or sanitizers.

Many swimming pools use some form of chlorine as a disinfectant. Chlorine and chlorine containing agents are used on a large scale for the disinfection of water. Its first use goes back to 1850s, when chlorine was used for drinking water disinfection after a cholera epidemic in London. Since then the use of chlorine has considerably contributed to the reduction of water-borne diseases **(Borgmann-Strahsen, 2003)**.

Alternative disinfectants most of which are referred to as 'chlorine-free' sanitizers include iodine, ozone, ultraviolet light (UV), hydrogen peroxide, ionization, potassium monopersulfate and polymeric biquanide.

3.2 Chlorination

The disinfection of swimming pool water is mainly done with chlorine or chlorine containing agents. The use of this agent against pathogenic micro-organisms has proved to be very effective in swimming pool water. Additionally, the chlorine containing agents are important for the degradation of pollutants in swimming pool water **(Borgmann-Strahsen, 2003)**. More than 90% of all pools in the United States use some type of chlorine. Although there is a strong movement away from chlorinated pools by experimenting with alternative sanitizers, chlorine still offers an effective and economical way of keeping pool water clean and safe.

A major advantage of chlorine is that it provides three important functions simultaneously:

1. Disinfection of bacteria, viruses, algae and other pathogen oxidation of organic pollutants and swimmer waste.

2. Oxidation is an important function that assists the filtering process by oxidizing solid waste particles in the water. Many alternative sanitizers offer disinfection without oxidation, resulting in additional chemical need.

3. The chlorine remains in the water for extended periods in order to be available to disinfect and oxidize as the need arises with increased swimmer loads.

Chlorine provides both disinfection and oxidation. Killing bacteria is a relatively easy task for chlorine; only small amounts of free chlorine (0.4 ppm) will destroy many pathogens. In a study carried out to investigate the presence of bacteria belonging to the *Legionella* genus in the pools, samples were taken from 12 swimming pools located in Italy. Two of the samples of which the free chlorine levels were 0.31 and 0.28 mg/l, respectively were found to be positive for *Legionella spp.***(Leoni, 2001)**. On the other hand, a more difficult responsibility of chlorine is to destroy particulate organic matter. This often calls for higher chlorine levels because heavy swimmer loads create a larger amount of organic pollution. For oxidation purposes, free chlorine levels can vary greatly but are often between 2.0 ppm – 10.0 ppm. Dull-looking pool water is often blamed on poor filtration, when in reality; insufficient oxidation is the main reason **(Griffiths, 2003)**.

The active substance of chlorine and the chlorine containing agents in water is hypochlorous acid (HOCl). Chlorine reacts with water to produce hypochlorous acid, which in turn disinfects through an electrochemical process. Regarding the disinfection mechanism different theories exist. Central in all mechanisms is the fact that hypoclorous acid reacts with enzymes. Because of the inactivation of enzymes the functioning of cells is affected, causing the death of the microorganism **(White, 1992)**.

3.2.1. The chemical processes of chlorine

Chlorine, in any form, mixed with water forms hypochlorous acid which is very effective as a disinfectant, an algaecide and an oxidizer. Used at proper levels, hypochlorous acid does not taste, smell or burn. Formation of HOCl is presented in Equation 3.1.

$$Cl_2 + H_2O \longrightarrow HOCl + HCl \qquad (3.1)$$

HOCl is a mild acid which disinfects and oxidizes swimming pool water and is the active, killing agent produced by chlorine's reaction in water. HOCI is referred as free chlorine (FC). HCl is hydrochloric acid, which is powerful acid.

The important point in this reaction is that as pH rises, HOCI disassociates as presented in Equation 3.2.

$$HOCl \longrightarrow H^+ + OCI^- \quad (3.2)$$

H^+ refers to the hydrogen ion and OCI^- represents hypochlorite ion. The hypochlorite (OCI^-) is not very active, and its killing power is insignificant. The higher the pH, the less HOCI available to disinfect and oxidize. At higher pH levels, more HOCI is required, plus bacteria and algae will take longer to kill. The likelihood of swimmer infections, like swimmer's ear and sore throats may also increase. As pH levels decrease, the effectiveness of HOCI increases (Fig.3.1).

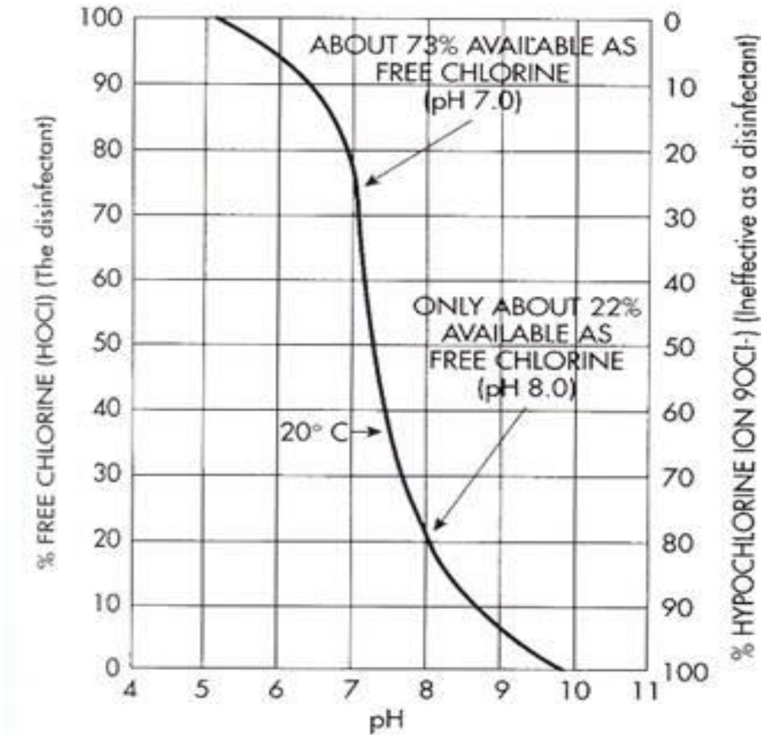


Figure 3.1 Dissociation of HOCl at high pH. (NSPI: Basic pool and spa technology, 1992)

To prevent HOCI from losing its killing power, pH levels should be maintained between 7.2 and 7.8. Below a pH of 7.2 HOCl becomes corrosive. In Fig. 3.2, at a pH of 7.5, about 50% of the free available chlorine is actually active HOCI. At the elevated pH 8.0, a mere 21% of the free chlorine is active HOCl.

3.2.2. Chlorine demand

Chlorine demand can be defined as the amount of any chlorine product (in any form) needed to kill all the bacteria present in the water.

3.2.3. Chlorine availability

Chlorine in its various forms combines with other elements present in the water, meaning some of the chlorine is unavailable for oxidizing bacteria, while some is available for that sanitizing purpose.

FREE AVAILABLE CHLORINE

$$FAC = HOC1 + OC1^- + CyaC1$$

(HOC1: hypochlorous acid; $OC1^-$: hypochlorite ion)

FORMATION OF HYPOCHLOROUS ACID

$$C1_2 + H_20 \longrightarrow HOC1 + HC1$$

(chlorine + water → hypochlorous acid + hydrochloric acid)

DISSOCIATION TO HYPOCHLORITE ION AT HIGH Ph

$$HOC1 \underset{\text{low pH}}{\overset{\text{high pH}}{\rightleftharpoons}} H^+ + OC1^-$$

ypochlorous acid (MORE ACTIVE DISINFECTANT) — hydrogen ion — hypochlorite ion (LESS ACTIVE DISINFECTANT

Pool pH:	% CHLORINE AS $OC1^-$ (hypochlorite ion)	% Chlorine as HOC1 (hypochlorous acid)
6.0	3.5%	96.5%
6.5	10.0%	90.0%
7.0	27.5%	72.5%
7.5—IDEAL	50.0%	50.0%
8.0	78.5%	21.5%
8.5	90.0%	10.0%

Figure 3.2 The effect of pH on the killing powder of chlorine. (NSPI: Basic pool and spa technology, 1992)

3.2.4. Forms of chlorine

Chlorine is available in three basic forms: gas, liquid, and solid. Within these three forms many varieties are commercially available.

3.2.4.1. Gas chlorine (Cl_2)

Gas chlorine is the most cost effective form of all the chlorines because it consists of 100% available chemical. Because it is pure chlorine, there are no by-products added to the water when using it. Although it is the cheapest and strongest of all chlorines, it is the most potentially dangerous. Gas chlorine, a green-yellow gas that is 2.5 fold heavier than air, is extremely toxic and can be lethal. The National Association of Gas Chlorinators provides the facts shown in Table 3.2.

Table 3.2. The effects of chlorine gas on health at certain levels (Tamminen, 2001)

Effect	Chlorine concentration in air by volume
Slight symptoms produced at	1 ppm
Detectable odor	3.5 ppm
Maximum exposure level over 1 h without symptoms	4 ppm
Danger level in 30-60 min	40-60 ppm
Kills rapidly	1000 ppm

Gas chlorine is compressed into large metal cylinders where it liquefies under pressure. In the liquid form, it is 1.5 times heavier than water. When released from the tank, the chlorine returns to the gaseous state. For every 0.435 kg of chlorine used, about 0.435 kg of hydrochloric acid is produced, which in turn lowers the pH. As a result, for every 0.435 kg of chlorine added to pool water, an additional 0.435 kg of soda ash must be added to maintain the pH in the ideal range **(Pope, 1991)**. In addition to lowering the pH, the HOCl that chlorine gas produces dissipates quickly in sunlight. To combat this loss of chlorine, cyanuric acid (CYA) is added to stabilize the chlorine. It can be concluded that aquatic facilities in the south part of the world tend to need stabilized chlorine more than those in the north. The most important disadvantage of gas chlorine is the specialized equipment needed to prevent and escape a gas leak. Because of the safety requirements being mandated for the safe handling and transportation of chlorine, the expense of constructing a gas chlorine storage room and injection system is too much. When handled and managed properly, gas chlorine can provide the cheapest and best disinfection and oxidation to swimming pool water but it should not be used in residential pools.

3.2.4.2. Sodium hypochlorite (NaOCl)- liquid chlorine

Sodium hypochlorite is the most popular liquid form of chlorine. The greatest advantage of NaOCl is in its convenient and safe handling. Sodium hypochlorite (12% to 15% active chlorine) is most referred to as either liquid chlorine, sodium hypo or simply bleach. Sodium hypochlorite is available in a clear, yellow liquid that is normally stored in large plastic drums.

This type of liquid chlorine is introduced to the pool by a chemical feeder. Although sodium hypochlorite is more expensive than gas chlorine, it is usually much less expensive than other chlorines. Sodium hypochlorite's greatest disadvantage is in its short shelf-life. As storage temperatures increase, the percentage of available chlorine decreases caused by auto decomposition. The chemical reaction taking place for liquid chlorine in swimming pool water is similar to that of gas chlorine as shown in Equation 3.3.

$$NaOCl + H_2O \longrightarrow HOCl + NaOH \qquad (3.3)$$

When NaOCl is mixed with water, hypochlorous acid, which is a disinfectant and oxidizing agent, is produced. Another by-product of the reaction is sodium hydroxide (NaOH) which is a strong base and raises the pH. As a result, whenever NaOCl is used for disinfection in swimming pools, an acid or CO_2 gas must be used in order to decrease the pH to the desired levels. Muriatic acid, also named hydrochloric acid, can be used since it is cheap and effective in lowering the pH for public pools. Residential pools or smaller swimming pools may prefer sodium bisulfate, a safe and convenient acid, which is more expensive.

As a basic rule it is convenient to add 4 liters of hydrochloric acid for every 15 liters of NaOCl **(Griffiths, 2003)**. Acids used for lowering pH should be diluted before adding them to cool water in a clean, clear plastic container.

Sodium hypochlorite is a readily available and easy to handle disinfectant but its shell life is very short as mentioned before. It must be stored in a cool, dark room. Large quantities of sodium hypochlorite should not be stored for long periods of time as it decomposes very quickly. Like gas chlorine, the HOCl produced by sodium hypochlorite is unstable. It may be stabilized with cyanuric acid to prevent loosing its strength in sunlight.

One of the other disadvantages of sodium hypochlorite is the effect it causes on the pH of pool water. When sodium hypochlorite is used, a strong acid must also be added to maintain pH within the ideal range. Another problem associated with the use of sodium hypochlorite is that it tends to clog chemical feeders pumping it into the pool. This occurs because of the scale produced by the high pH that sodium hypochlorite contains.

Sodium hypochlorite has also a strong tendency to raise the Total Dissolved Solids (TDS) that can accumulate in pools. High TDS values give a dull and cloudy appearance to the water.

3.2.4.3. Calcium hypochlorite

Calcium hypochlorite is a white solid and is available in granular and tablet form. It has been the leading solid form of chlorine in recent years and is popular for its relatively low cost and convenience of use. Calcium hypochlorite contains 65% available chlorine, has a long shelf-life, and is easily stored. The chemical reaction that takes place when calcium hypochlorite enters the pool water is as in Equation 3.4.

$$Ca(OCl)_2 + H_2O \longrightarrow 2HOCl + Ca(OH)_2 \tag{3.4}$$

In this case two molecules of HOCl are produced and provide the disinfection and the oxidation. $Ca(OH)_2$, calcium hydroxide, a moderate alkaline by-product is responsible for slightly increasing pH and calcium hardness. It is often claimed that calcium hypochlorite clouds the water and elevates the calcium hardness, but when cloudiness occurs, the water clears quickly.

Any organic material added to calcium hypochlorite can cause combustion. Soda, oil, sweat, paper, soap, other chemicals will cause fire in this case. For this reason calcium hypochlorite should be stored separately to prevent other chemicals from being accidentally mixed with it.

Calcium hypochlorite is unstable and will dissipate in sunlight quickly. Granular calcium hypochlorite also serves as an excellent algaecide on pool decks and pool bottoms, particularly sloped areas. Calcium hypochlorite is often used as a shocking agent **(Griffiths, 2003)**.

3.2.4.4. Lithium hypochlorite

Lithium Hypochlorite is powdered chlorine that is extremely soluble in water. It is approximately 35% effective, and dissolves quickly making it ideal for superchlorination. Although lithium hypochlorite is intended to be used as primary disinfectant, it is often used just for superchlorination because it is very expensive. The storage and handling of lithium hypochlorite is easy as it is not flammable.

Some times lithium is preferred due to its non calcium content. Lithium Hypochlorite is usually dissolved in water first and then pumped into the recirculation system. It is also an unstable chlorine, being lost rapidly in sunlight.

3.2.5. Stabilized chlorines

All of the chlorine forms mentioned before were unstabilized forms. To explain detailed, these chemicals last longer in indoor pools than outdoor pools because the deteriorating UV rays of the sun dissipate chlorine. To stretch chlorine in outdoor pools, cyanuric acid has been added to some chlorine compounds. It must be taken into consideration that stabilized chlorine products represent a somewhat controversial type of chlorination. Cyanuric acid or the compound of chlorinated cyanurates are commonly employed in swimming pools to reduce the loss of free chlorine by UV radiation. Up to 90% of the chlorine residual may be lost within several hours when exposed to sunlight. The addition of cyanuric acid may reduce this loss to only 10% to 15% of the total chlorine residual **(Sommerfeld, 1982)**. Several investigations have been conducted to ascertain the effect of cyanuric acid on the bactericidal properties of chlorine.

It was observed that in laboratory experiments, increased concentrations of cyanuric acid resulted in the requirement for greater quantities of chlorine to achieve the same degree of bactericidal activity as lower chlorine concentrations without stabilizer.

The studies carried out by **Sommerfeld (1982)** to determine the influence of cyanuric acid on the algicidal efficiency of chlorine concluded that in the presence of cyanuric acid, the toxicity of free chlorine to selected pool algae is reduced slightly, although in some cases significantly. Besides, increasing cyanuric acid concentration (from 25 to 200 ppm) did not result in a proportional or additional reduction in the algicidal efficiency of chlorine.

Chlorine can be stabilized in two ways:

- Cyanuric acid can be added to a chlorinated pool
- Prestabilized chlorine can be purchased from pool suppliers in the form of chlorinated isocyanurates.

Whether adding cyanuric acid to chlorinated pool water or using stabilized chlorinated isocyanurates, the process of protecting chlorine from the sun's UV rays is the same. Cyanuric acid is a ringlike molecule that latches onto HOCl molecules to form a more stable atomic structure. This combination of CYA and free chlorine delays chlorine loss but can not stop it altogether. Stabilized chlorine lasts longer than unstabilized chlorine in outdoor pools.

The main problem associated with the use of stabilized chlorine is that CYA levels in the water will increase as the stabilizer continues to be used. In most states of USA, CYA levels more than 100 ppm is prohibited. The greater the CYA, the less effective HOCl will be. According to some experts it is said that if the CYA level is raised it results with subtraction in the free chlorine level. Once the CYA level reaches 100 ppm, the only way of lowering cyanuric acid in the pool is by draining water from it. This is particularly a problem for Trichlor users because this stabilized chlorine consists of 50% CYA and the limit is attained quickly **(Griffiths, 2003)**.

It is recommended to keep the CYA levels between 30 to 40 ppm by many experts. At that high range HOCl is being protected from the sun, but it still remains an effective killer. Some health officers in USA believe that high cyanuric acid levels in the water may be hazardous to humans. Since swimming pool water can be swallowed and absorbed by the skin, high levels of cyanuric in the body may lead to liver and kidney problems.

3.2.6. Types of stabilized chlorines

The two most popular types of commercially available stabilized chlorines are named as dichlor and trichlor.

3.2.6.1. Sodium dichloroisocyanurate ($C_3O_3N_3Cl_2Na$)

Dichlor (sodium dichloro-s-triazinetrione) is a stabilized chlorine commercially produced by combining soda ash, cyanuric acid and chlorine. This stabilized chlorine is sometimes referred to as sodium dichlor. Dichlor is 56% or 63% effective and is available in granular form only.

Since it has a neutral pH (1% water solution : 5.5-7.0) it has little effect on pH levels in pool water.

If dichlor is used as a primary sanitizer, an unstabilized chlorine should be used for superchlorination in order to prevent high levels of CYA in water. Dichlor is easily stored and handled, and it dissolves quickly. It is usually predissolved and introduced to the pool through a liquid chlorinator.

3.2.6.2. Trichloroisocyanuric acid ($C_3O_3N_3Cl_3$)

Trichlor (trichloro-s-triazine-trione) is another type of stabilized chlorine that is produced commercially and is available in tablets, sticks and granules. Unlike dichlor, trichlor dissolves slowly and as a result can be introduced into pools through floaters, skimmers. Trichlor's popularity can be probably due to this fact; when trichlor is introduced into pool water chlorine will be found in the pool regardless of the amount of sunlight. The most important point that should be taken into consideration about trichlor is that it is highly acidic and lowers the pH of swimming pool water (1% water solution : 2.7-2.9). Trichlor is powerful, having an available chlorine content of almost 90%.

The stabilized chlorines, dichlor and trichlor are often called organic chlorines. Inorganic chlorines are those that are unstabilized and lost easily in sunlight. Stabilized chlorines should be used in only in outdoor pools. Stabilized chlorines were developed to increase chlorine's longevity in the sunlight. Because indoor pools have no deteriorating UV rays, stabilized chlorines are inappropriate for indoor pools. As mentioned previously, although CYA protects chlorine from the sunlight it also reduces chlorine's ability to disinfect.

Although stabilizer is an additional cost, it saves significant sums of money by saving chlorine and reducing service costs. Constantly monitoring and controlling CYA levels is a major concern. Table 3.3.presents the properties of chlorine products used in swimming pools.

Table 3.3. Properties of chlorine products (NSPI, 1992 & Tamminen, 2001)

Chlorine product	Form	Available chlorine	pH	Stability in water	Uses
Gas chlorine, $Cl_2(g)$	Gas (liquefied)	100%	0-1	Very unstable	Disinfection, shocking
Sodium hypochlorite	Liquid (bleach)	10-15%	13	Unstable	Disinfection, shocking
Calcium hypochlorite	Granular	65-75%	8.4-11.8	Stable	Disinfection, shocking, cleaning
Sodium dichlor	Granular	56-62%	6.8-7.0	Very stable	Disinfection, shocking, algae spots
Trichlor	Tablets, granular	90%	2.8-2.9	Very very stable	Disinfection, scrubbing algae spots
Lithium hypochlorite	Granular	35%	1.07	Unstable	Disinfection, scrubbing algae spots

3.2.7. Comparative cost for chlorine forms

Cost is one of the important evaluation factors of which type of sanitizer to use. The delivery system, labor involved, transportation costs and pH neutralizers needed all must be factored in the real cost of the sanitizer. Although gas chlorine is the cheapest and most effective sanitizer, it is the most dangerous and difficult to use. In order to compare sanitizers with each other, equal sanitizing capacities are assumed, not equal volumes or weights. As a rule of thumb a general guideline is given by **Tamminen (2001)** in Table 3.4.

Table 3.4. Cost comparison of different forms of chlorine

Liquid chlorine	Costs **2** times the equivalent amount of gas
Calcium hypochlorite	Costs **3** times the equivalent amount of gas
Trichlor	Costs **3** times the equivalent amount of gas
Lithium hypochlorite	Costs **5** times the equivalent amount of gas
Dichlor	Costs **5** times the equivalent amount of gas

3.3. Superchlorination and Breakpoint Chlorination

Hypochlorous acid is a by-product produced when chlorine is added to water. It is an excellent disinfectant and oxidizer as mentioned before. In chlorine chemistry literature the sum of HOCl and OCl^- is referred to as free available chlorine (FAC). As HOCl is the more effective form in disinfection, pool operations would be simplified if the free HOCl produced remained free and active in the water.

Free available chlorine combines with contaminates like algae, dust, pollen, urine, perspiration, and other ammonia-nitrogen compounds (urine, sweat) to form combined available chlorine (CAC). The sources of ammonia (NH_3) existing in the pool are,

- Make – up water
- Perspiration from the swimmers
- Urea coming from swimmers urine
- Bacteria’s chemical structure
- Algae’s chemical structure

A number of nitrogen compounds can be eluted from the skin (Table 3.5). The nitrogen content in sweat is around 1 g/liter, primarily in the form of urea, ammonia, amino acids and creatinine. Depending on the circumstances, the composition of sweat varies within extremely broad ranges. Considerable amounts of nitrogen compounds can also reach pool water via urinary discharges (Table 3.5). The urine release into the swimming pool water of indoor pools has been estimated to be between 25 and 30 ml per bather **(Gunkel & Jessen, 1988)** and as much as 77.5 ml per bather **(Erdinger et al., 1997)**.

Table 3.5. Nitrogen-containing compounds in sweat and urine (Jandik, 1977)

Nitrogen-containing compounds	**Sweat**		**Urine**	
	Mean content (mg/litre)	Portion of total nitrogen (%)	Mean content (mg/litre)	Portion of total nitrogen (%)
Urea	680	68	10240	84
Ammonia	180	18	560	5
Amino acids	45	5	280	2
Creatinine	7	1	640	5
Other compounds	80	8	500	4
Total nitrogen	992	100	12220	100

The distribution of total nitrogen among relevant nitrogen compounds (Table 3.5) has been calculated from statistically determined means of values obtained for 24-h urine samples. Although more than 80% of the total nitrogen content in urine is present in the form of urea, and although that of ammonia, at approximately 5%, is comparatively low, swimming pool water exhibits considerable concentrations of ammonia, which evidently are formed secondarily by urea degradation following chemical reactions with chlorine. The ammonia reacts rapidly with hypochlorous acid to form monochloramine, dichloramine and trichloramine **(Hailin et al., 1990),** whereas nitrogen-containing organic compounds, such as amino acids, may react with hypochlorite to form organic chloramines **(Taras, 1953; Isaak & Morris, 1980)**. The organic nitrogen compounds found in urine and sweat are also possible precursors for chlorination by-products, such as THMs **(Ueno et al., 1996)**.

Free chlorine reacts with NH_3 to kill the bacteria and oxidize NH_3 so that combined chlorine forms. The reactions involved between free chlorine and ammonia are presented in the Equation 3.5, 3.6, and 3.7.

$$HOCl + NH_3 \longrightarrow \underset{\text{monochloramine}}{NH_2Cl} + H_2O \qquad (3.5)$$

$$HOCl + NH_2Cl \longrightarrow \underset{\text{dichloramine}}{NHCl_2} + H_2O \qquad (3.6)$$

$$HOCl + NHCl_2 \longrightarrow NCl_3 + H_2O \quad (3.7)$$

trichloramine

The unpleasant chlorine odor found at many pools is not caused by free chlorine as generally known, but rather combined chlorine or chloramines. Chloramines not only smell but also burn eyes and skin and cause cloudy water. In fact, the swimmers who complain about chlorine irritation and odor are the cause of it because of the ammonia compounds they naturally carry with them into the pool. The chlorine smell is caused by too little, not too much chlorine. In aquatic facilities that have been effectively superchlorinated, there will be no detectable chlorine odor, even with high free available chlorine levels.

Chloramines are perhaps the most important problem facing indoor, heavily used chlorinated pools. As swimmer loads increase, so does the chloramine formation. Chloramines are not effective disinfectants. The more traditional way to remove chloramines from a pool is by adding an amount of new chlorine that is 10 times greater than the existing combined chlorine concentration. More recently, new techniques and products have been developed to remove ammonia from the water so that chloramines cannot be produced. In outdoor pools, chloramines are still a problem but often go unnoticed, because the outside air and breezes wisk the chloramines away before they can be really noticed. A DPD test kit is typically needed to determine the free chlorine and total available chlorine levels. A much improved way of testing for chloramines is the titration method. More specifically, Taylor Technologies refers to this as FAS-DPD Titrating for chloramines.

When this test kit is used, a white powder is applied to the pool sample in a test vial to turn the water pink in the presence of free chlorine.

3.3.1 Reactions of superchlorination

Superchlorination usually refers the intentional elevation of free chlorine periodically maintained in the pool to prevent algae, odors, irritation, and cloudiness. In this case free chlorine is often raised to between 3 and 10 ppm. Superchlorination is more of a preventive measure, keeping the water clear and comfortable by elevating free chlorine and not allowing problems to develop.

Breakpoint, on the other hand, refers to a very specific and measurable point at which all organic impurities are oxidized. Maintaining breakpoint chlorination is slightly different and refers to keeping free chlorine levels sufficiently high so that ammonia and nitrogen compounds are oxidized as they are introduced into the pool.

In this case, organic materials are immediately oxidized, and therefore chloramines are unable to develop. Theoratically it is mentioned in the literature that in order to break the chloramines minimum 7.5 – 8 times free chlorine dosage more than combined chlorine level have to be added. Practically this 7.5 – 8 times level can be considered as 10 times. If there is 0.6 ppm combined chlorine present in the pool, minimum 6 ppm of free chlorine must be added in order to make it zero. If the formation of combined chlorine is high, fresh water must be added continuously.

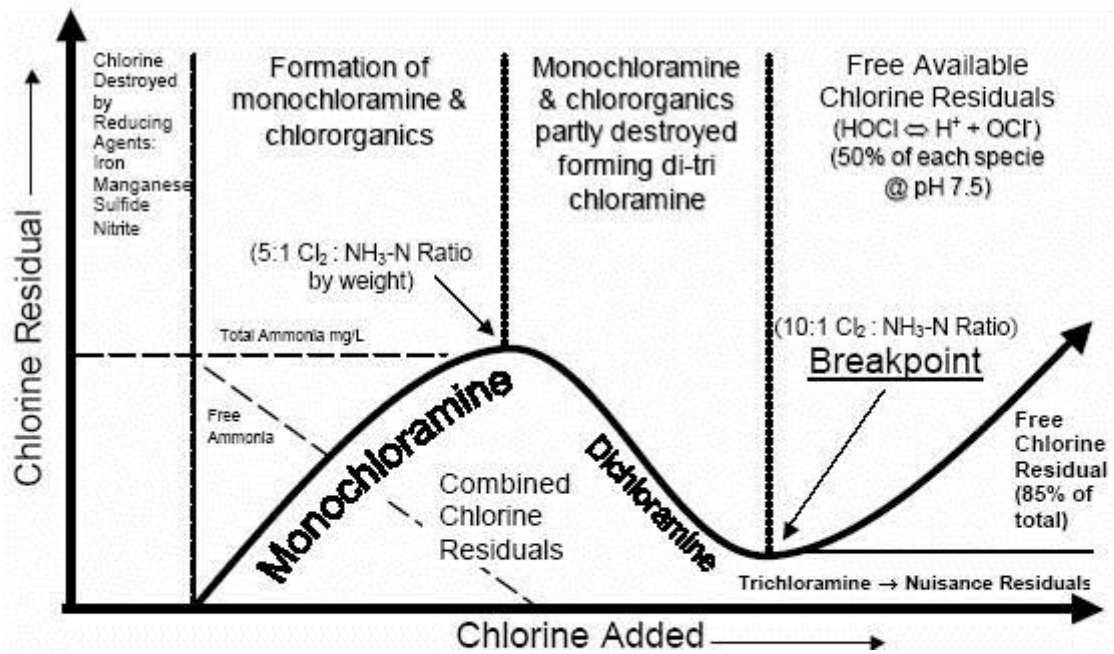


Figure 3.3. Breakpoint chlorination

Breakpoint chlorination (Figure 3.3) eliminates chloramines and other reductants which cause an increased chlorine demand. In order to achieve breakpoint, a quantity of 7.6 molecules of free chlorine are used to break apart each molecule of combined chlorine. Several chemical reactions take place. Chlorine reacts with ammonia (NH_3) to form monochloramines (NH_2Cl). Free chlorine reacts with monochloramines to form dichloramines ($NHCL_2$). Free chlorine reacts with dichloramines to form trichloramines or nitrogen trichloride (NCl_3) and nitrates before the breakpoint is achieved.

Nitrogen trichloride forms when the HOCl to nitrogen molecular weight ratio is 12 to 1, and oily, insoluble colloidal particles will appear, cloud the water, migrate toward the water surface, and may be released into the ambient air, further contaminating the natatorium environment. Reaching the breakpoint is an all-or-nothing reaction. If breakpoint is not reached, the problem will be worse.

When the chemical bond with ammonia is broken, free chlorine, nitrogen, water and inorganic chloride (salt) remain. Superchlorination of pool water should be done periodically, as needed, when the level of chloramines present in the water is greater than 0.2 ppm. Products used for superchlorination include chlorine in any form, however, stabilized chlorine products, or isocyanurates (trichlor or dichlor), should not be used for superchlorination since excess cyanuric acid would be added to the water solution concurrently. Before attempting breakpoint chlorination, the pH should be lowered to 7.2 to 7.4 to increase the percentage of hypochlorous acid which forms, and make sure the water is chemically balanced. Shocking a pool with unbalanced water, particularly with a high (basic) pH or high total alkalinity, will result in the formation of a white carbonate precipitate which will cloud the water. However, some operators prefer to raise the pH when using acidic chlorine products like elemental gas chlorine for superchlorination since more offensive forms of chloramines develop rapidly at a very low pH. To calculate breakpoint in order to superchlorinate, a DPD (N,Ndiethyl- p-phenelynediamine) or FAS (ferrous ammonium sulfate) test kit is used use to find both the free and total available chlorine levels. If the free available chlorine (FAC) is subtracted from the total available chlorine (TAC) the combined available chlorine (CAC) level is found. Multiplying the combined available chlorine by the factor 10, although only 7.6 is actually needed, the dose of chlorine that must be introduced into the pool in order to reach the breakpoint can be found.

Ten is used as a factor because most pool operators are not sure of the precise amount of water in their pools, or of the exact percentage of available chlorine in the chlorine compound being used. Ten is used as a factor to err on the side of caution and so that enough chlorine is left over after breakpoint has been achieved to satisfy the chlorine demand and leave an adequate residual.

Once breakpoint is accomplished, the pool should remain closed until the free chlorine levels drop to an acceptable level (3.0 to 5.0 ppm) on its own.

Also, the addition of sodium thiosulfate may be used to neutralize excessively high amounts of free chlorine when the pool needs to be reopened to the public shortly after shocking.

3.3.2. Alternative chemicals for superchlorination

3.3.2.1. Monopersulfate

Monopersulfate is an alternative agent to superchlorination. Monopersulfate is also known as potassium peroxymonosulfate or monopotassium persulfate. Monopersulfate is an oxygen-based shocking chemical that oxidizes like chlorine but without the disadvantages associated with superchlorination. Some of the drawbacks

of shocking with chlorine include closing the pools for eight to 10 hours, and misjudging breakpoint, therefore adding too much, or too little chlorine. Monopersulfate destroys all chloramines and organic wastes without having to climb to a predetermined breakpoint. Monopersulfate comes in both 42% and p, 32% active ingredient. Overdosing does not result in high levels of chlorine and underdosing does not result in additional chloramine formation. Underdosing with monopersulfate kills some but not all of the chloramines. The greatest advantage of monopersulfate is that swimmers can return to the water within 15 minutes of shocking. This advantage of nonchlorine shocking agents becomes even more important during large competitive swimming events, when a shocking may be required but closing the pool is not possible. Nonchlorine shocking agents like monopersulfate are expensive.

3.3.2.2.Granulated activated carbon filters

When regular shocking has failed repeatedly in a facility, adding a secondary granulated activated carbon (GAC) filter may be used to remove ammonia.

This system is not used to filter all the pool water but rather, a smaller slip-stream of water drawn off the main circulation line, or by treating just the source water being added to the pool. The GAC filter helps to remove the ammonia in the pool and chloramines that are produced. It should be pointed out that municipal water authorities are now using ammonia and/ or chloramines more often in drinking water to prevent trihalomethane which worsens the chloramine problem in pools.

3.3.2.3. Zeolites

Zeolites are a family of granular, extremely porous volcanic materials capable of removing ammonia from the waters as well as trapping particles down to five microns in size. Zeolites with a high (80%) percentage of clinoptilolite can be used an alternative filter media instead of silica sand in typical sand filter systems. The organic zeolite material has an affinity for ammonia therefore any ammonia deposited in the water by swimmers stays in the filter media and is unable to form chloramines in the pool. The product works extremely well and when it does become saturated with ammonia in the filter tank, the filter bed is shocked with a saltwater solution to reduce the ammonia instead of shocking the pool. This regeneration process that includes backwashing as well as the saltwater bath must be performed at least every six months but perhaps more in a heavily used facility.

3.4. Alternative Disinfectants

There are many alternatives to chlorine, although none are as widely used or as easy to use.

3.4.1. Bromine

Bromine, like chlorine, is a member of the halogen family with excellent disinfection and oxidation properties. Elemental bromine is a difficult and dangerous liquid to handle. Elemental bromine reacts with water as in the Equation 3.8.

$$Br_2 + H_2O \longrightarrow HOBr + HBr \qquad (3.8)$$

Rather than producing HOCl like chlorine, bromine produces two disinfecting agents. HOBr or hypobromous acid is the primaty disinfectant, while HBr or hydrobromic acid reduces pH levels. The primary source for bromine is sea water and potash mines. While elemental bromine is used successfully in Europe, the United States has switched to sodium bromide salts in combination with other compounds like chlorine to increase its effectiveness and ability to be handled.

This two-part system includes an oxidizer that activates the bromine. Bromine in this form is available in sticks or tablets. The oxidizer is of ten chlorine or potassium monopersulfate, a non-halogen oxidizing agent, and in some cases, ozone.

The bromine/potassium monopersulfate combination is usually reserved for smaIl pools that can be hand-fed. The more popular combination is bromine/chlorine. The combination of bromine and chlorine produce hypobromous acid (HOBr) as the primary disinfectant and hypochlorous acid (HOCI), which serves as a regenerative catalyst and also assists with disinfection and oxidation. The use of bromine has several advantages. Perhaps the: greatest advantage is that combined bromine or bromamines does not irritate, burn, or smell the way combined chlorines or chloramines do. Along those lines, chloramines must be "shocked" out of the water, where as bromamines break down on their own. Bromine is more stable at elevated temperatures than chlorine so its use in hot water is preferable to chlorine. This explains why bromine is the preferred disinfectant in hot tubs and spas. Combined chlorines and bromines are produced quickly in hot water environments due to the relatively high swimmer load and the increased amounts of perspiration in the water due to the heat.

Bromamines are effective as disinfectants, whereas chloramines are not, giving bromine the advantage in hot water. Since it is a fairly strong oxidizer (but not as strong as chlorine), bromine is combustible like chlorine and must be stored carefully. Bromine may also smell, turn the water green, and cause staining and sudsing if not maintained at appropriate levels **(Kowalsky, 1991)**. Generally, it is more expensive than chlorine. Another disadvantage of bromine is that it is unstable and will be lost rapidly in sunlight. Unfortunately, cyanuric acid cannot be used to stabilize bromine. Bromine's best application is in hot tubs and spas while chlorine should be reserved for larger pools.

3.4.2. Iodine

Iodine is a cheap, tasteless, odorless disinfectant. However, iodine is in insufficient quantity to oxidize bacteria in pool water. Moreover, iodine does not kill algae.

3.4.3. Ultraviolet light (UV) / Hydrogen peroxide

A combination of UV light and hydrogen peroxide is a good disinfectant, particularly for smaller pools, hot tubs and spas. Mercury vapor lights are used in a chamber through which swimming pool water passes.

The lights radiate sufficient energy to sterilize water in the chamber or tube. Two basic methods of UV disinfection are used for swimming pool disinfection: shell-side flow and tube-side flow. In the shell-side flow, water flows over quartz sleeves housing a UV lamp. The tube side flow passes water through a UV transmittable material. In both cases the UV disinfection is a point source application without any residual disinfecting properties. In addition, UV radiation does not provide oxidation. If the organic matter content of the water is too much, the UV disinfecting process will be greatly hindered. Hydrogen peroxide is used as oxidizing agent as it is an effective oxidizer with a measurable residual but is a weak disinfectant. H_2O_2 levels should be maintained between 30 to 40 ppm **(Griffiths, 2003)**. The disadvantages of hydrogen peroxide are its capability of causing combustion as it is a strong oxidizer, difficulties in storing and handling, and high cost.

3.4.4. Ozone

Basically, ozone is a form of oxygen that is produced when ultraviolet (UV) rays react with oxygen in the earth's atmosphere. During electrical storms, ozone is often produced when lightning moves through oxygen molecules. Some experts refer ozone as "energetic oxygen." Ozone is a powerful disinfectant and oxidizer, and in some respects is even more powerful than chlorine. Ozone is very effective in killing many types of bacteria and viruses. For instance, ozone kills the *E. coli* bacteria 25 times faster than hypochlorous acid, which is produced by chlorine.

Ozone kills virtually all bacteria algae, mold, and viruses on contact. Ozone also produces an odorless, tasteless pool because chloramines are not produced during ozonation. Ozone has the unique ability to completely destroy urea introduced by swimmers, thereby eliminating the formation of obnoxious chloramines. Ozonation supposedly reduces the need for additional chemicals by 50% to 90%.

Ozone is very unstable and as a result does not last long in pool water. Therefore ozone must be produced on- site and then added to the swimming pool circulation system. Ozone has a half-life of 22 minutes. This means that half the ozone produced will decompose and be rendered useless every 22 minutes. As a result, ozone must be constantly produced and reintroduced to the pool. There are two basic methods of ozone production: Corona discharge and UV generation.

1. Corona-discharge: Corona-discharge ozone generation is the more traditional and larger of the two methods of producing ozone. It requires continual supply of high-voltage electricity that produces large quantities of ozone at high concentrations. A special chamber is needed to house the corona- discharge equipment, which reacts with specially dehumidified air. Once the ozone is manufactured, it is introduced into the pool by utilizing either a venturi-suction system or an air compressor. The trend in ozone delivery appears to be away from compressors and more toward venturi injectors. In both cases ozone bubbles are mixed with swimming pool water that is returning to the pool. The corona- discharge equipment can be very expensive, and professional installation is a must because of the required combination of water and electricity. For large aquatic facilities the Corona Discharge method is preferred.

2. UV ozone generation: This system uses UV lamps, which produce law levels of ozone, which in turn attack oxygen molecules as air is passed in front of the lamps. Air dryers and compressors are sometimes added to the UV system to increase ozone production. UV lamps require little power, but they generate far less ozone than the older corona- discharge method. As a result, UV ozone applications are better suited for smaller aquatic facilities.

Ozone must be used as a supplementary sanitizer only because a minimum level of halogen residual is required to ensure water disinfection. Chlorine or bromine must also be added to ozonated pools because algae growth is actually encouraged in the presence of ozone. Only small residuals need to be maintained in this case, but still, two forms of disinfectants are required when ozone is used as the primary disinfectant. Also, although ozone is safer on pool walls and floors than traditional disinfectants, it does corrode copper and some other metals. Ozonation systems are extremely expensive to install. As technology improves and the cost of installation decreases, ozone as a primary pool disinfectant may gain popularity.

3.4.5. Ionization

lonization is an electrochemical process of converting electrically neutral atoms, molecules, or compounds into electrically charged ions. These ions, which are either positively (+) or negatively (-) charged, have disinfecting properties in pool water. In the swimming pool industry, ionization is usually accomplished by the use of copper and silver electrodes to produce copper and silver ions.

Both copper and silver serve as alacrities and bactericides. The advantages of using an ionization disinfection system for swimming pools include reduced chemical usage, no effect on pH, and little maintenance or monitoring of disinfecting chemicals. Ionization with copper and silver does not provide oxidation. As with ozone generators, ionizers can not be used as the only sanitizer but it will reduce the need for chemicals significiantly. As a result, an oxidizer is needed to deal with organic contaminants, and many health departments still require a halogen residual regardless of the disinfection system. It must be emphasized that both the copper and silver electrodes must be cleaned and changed often. Another drawback of ionization is green and black staining that may result from using copper and silver.

Some pool experts claim that ionization is more appropriate for smaller, low usage pools rather than high load public aquatic facilities.

3.4.6. Polymeric Biquanide

A relatively new sanitizer, biquanides, is a general term referring to a disinfectant polymer. It is an effective sanitizer but not an oxidizer so it can not be used alone. Polymeric biquanide is a chlorine-free swimming pool disinfectant and algaestat. As a polymer aids in filtration by electrostatically clumping smaller particles together, making them easier to trap. Unlike halogen sanitizers, it is not affected by sunlight, temperature, or pH fluctuation. It is usually used in private pools with capacities less than 200 m^3. Hydrogen peroxide is added for oxidation and a quaternary ammonium based algaecide is also necessary. Biquanicide concentrations should be kept between 30 to 50 ppm.

Biquanicides should not be mixed with chlorine products otherwise, water becomes chocolate-brown color and stains occur on the plaster. It is very important to first neutralize other chemicals and remove any metals that may be present in the water if it is decided to change a chlorine treated pool to Biquacinide. They also react with household detergents and trisodium phosphate (TSP) so care should taken with any cleaning products in a pool that uses biquanicides. Biquanides gain more popularity as consumers and health offices continue to search for chlorine-free pool disinfectants.

3.4.7. Potasium monopersulfate

Potassium monopersulfate is a very efficient oxidizer used most often in products sold for superchlorination. It is also an effective catalyst for bromine and is sometimes found in small quantities in bromine tablets.

3.5. Disinfection By-Products

The formation of by-product chemicals associated with disinfection of pool waters varies with the chemical. Disinfectant by-product chemicals are produced by reactions between disinfectants and other substances present in the pool. These disinfectant by-product precursors may be both inorganic, especially bromide ions (such as may be found in a saltwater pool), and organic, such as amino acids and proteins. Input of reactive organic precursor chemicals is continuous and a function of the number of swimmers, who are contributing urine, perspiration, oils, cosmetics, soap residues and insoluble detritus, which can be reactive.

Many chemical by-products associated with disinfection of pool waters are produced at levels that are at least comparable to those produced in drinking-water disinfection. In fact, as initial and make-up water entering the pool has in most cases already undergone drinking-water treatment and contains disinfectant and by-products, and as typical pool waters are recycled and additional precursors and disinfectant are added, the levels of disinfectant by-products found in disinfected pool water could easily exceed drinking-water levels. Two key disinfection by-products in swimming pools are trihalomethanes and chloramines, whose health impacts have been subjected to much study over the years **(Judd, 2003)**.

Although most of the disinfection agents are chlorine containing agents and have proven to be worthwhile in practice, the formation of trihalomethanes (THM's) and the irritant effect of chloramines are disadvantages of these products. Such by-products are developed by the reaction of hypochlorous acid with organic contaminations introduced by the bather (i.e., urine, perspiration). Good cleaning of the swimming pool water and an optimization of the biocide dosage solves most of the problems **(Borgmann-Strahsen, 2003).**

Traditionally sodium hypochlorite has been widely used for disinfection purposes in swimming pools due to its moderate stability.

However, the use of this compound has been reported to produce various halogenated organic compounds collectively called disinfection by-products (DBPs) **(Kim et al., 2002)**. The levels of DBPs, mostly trihalomethanes in indoor swimming pools reported by some researchers showed a tendency of wide variation. The chloroform concentrations in Modena, Italy were 115, 33 and 37 μg/l with ranges of 62-179, 17-47, and 19-94 μg/l respectively **(Aggazzotti and Predieri, 1986)**. The variations in the concentrations of DBPs in pool waters have been suggested to depend on several factors:

1. The number of swimmers in pools
2. The chlorine dose
3. The bromide content
4. The extent of outgasing of volatile DBPs.
5. The use of DBPs-containing water (mostly chlorine-treated surface water) for pool water supply **(Heller-Grossman et al., 1993)**.

THMs were formed in a pool model system when human urine analogues containing sodium chloride, urea, creatinine, citric acid, hippuric acid, and ammonia were treated with HOBr or HOCl at 30°C. The concentrations of urine and the disinfectant significantly influenced the formation of THMs. The major products of the disinfection using HOBr and HOCl were bromoform ($CHBr_3$) and chloroform ($CHCl_3$) respectively **(Judd and Jeffrey, 1995)**.

The predominant disinfectants that are used in pool water treatment and some of the by-product chemicals that have been detected are summarized in Table 3.6. Unlike the other disinfectants, the major chlorine dioxide disinfectant by-products are derived from decomposition of the disinfectant as opposed to reaction with precursors.

Table 3.6. Predominant disinfectants used in pool water treatment and their associated disinfectant by-products

Disinfectant	**Disinfectant by-products**
Chlorine/hypochlorite	Trihalomethanes (THMs) haloacetic acids haloacetonitriles haloketones chloralhydrate (trichloroacetaldehyde) chloropicrin (trichloronitromethane) cyanogen chloride chlorate chloramines
Ozone	Bromate Aldehydes Ketones Ketoacids Carboxylic acids Bromoform
Chlorine dioxide	Chlorite chlorate
Bromine/hypobromite/BCDMH	THMs, mainly bromoform bromal hydrate bromate bromamines

Chlorate, chlorite and bromate measurements have been conducted in swimming pools in Germany **(WHO, 2000)**. Chlorate ranged in concentration from < 0.0036 to 147 mg/liter. Chlorite was not found in pool waters. Bromate ranged in concentration from < 0.0055 to 0.825 mg/liter. The highest bromate levels were found in swimming pools (e.g., saltwater pools) in which ozone had been used to treat bromide-containing pool water; the levels were above the provisional WHO drinking-water guideline value for bromate of 0.025 mg/liter **(WHO, 1993)**.

THMs, haloacetic acids, haloacetonitriles, haloketones, chloropicrin, chloral hydrate and bromal hydrate have all been detected in pool water. Concentrations of THMs, which are significant chlorine and bromine disinfectant by-products, have been measured the most frequently.

In general, the THM concentration in the pool water is directly dependent on the chlorine (bromine) dose, the organic content in the pool water, the chlorine (bromine) contact time and the temperature. The main constituent among THMs in freshwater pools is chloroform. In the water and air of seawater pools, the dominant THM is bromoform **(WHO, 2000)**. The other most commonly found THMs are bromodichloromethane (BDCM) and dibromochloromethane (DBCM). Table (3.7) provides an overview of the concentrations of these various disinfectant by-products measured in different pools.

Table 3.7 Concentrations of trihalomethanes measured in swimming pool water (WHO,2000)

Country	Disinfectant by-product concentration (µg/litre)								Pool type	Reference
	Chloroform		BDCM		DBCM		Bromoform			
	mean	Range	mean	range	mean	range	mean	Range		
Poland		35.9–99.7		2.3–14.7		0.2–0.8		0.2–203.2	indoor	Biziuk et al., 1993
Italy		19–94							indoor	Aggazzotti et al., 1993
	93.7	9–179							indoor	Aggazzotti et al., 1995
	33.7	25–43	2.3	1.8–2.8	0.8	0.5–10	0.1	0.1	indoor	Aggazzotti et al., 1998
USA	37.9								indoor	Copaken, 1990
		4–402		1–72		<0.1–8		<0.1–1	Outdoor	Armstrong & Golden, 1986
		3–580		1–90		0.3–30		<0.1–60	indoor	
		<0.1–530		<0.1–105		<0.1–48		<0.1–183	spa	
Germany	14.6	2.4–29.8							indoor	Eichelsdörfer et al., 1981
	43	14.6–111							outdoor	
	198	43–980	22.6	0.1–150	10.9	0.1–140	1.8	<0.1–88	indoor	Lahl et al., 1981

Germany		0.5–23.6		1.9–16.5		<0.1–3.4		<0.1–3.3	indoor	Ewers et al., 1987
		<0.1–32.9		<0.1–54.5		<0.1–1.0		<0.1–0.5	hydro-therapy	
		<0.1–0.9		<0.1–1.4		<0.1–16.4		2.4–132	hydro-therapy	
		3.6–82.1		1.6–17.3		<0.1–15.1		<0.1–4.0	Outdoor	
	94.9	40.6–117.5	4.8	4.2–5.4	1.8	0.78–2.6			indoor	Puchert et al., 1989
	80.7		8.9		1.5		<0.1		indoor	Puchert, 1994
	74.9		11.0		3.0		0.23		outdoor	
		3–27.8		0.69–5.64		0.03–6.51		0.02–0.83	indoor	Cammann & Hübner, 1995
		1.8–28		1.3–3.4		<0.1–1	<0.1		indoor	Jovanovic et al., 1995
		8–11							indoor	Schössner & Koch, 1995
	14	0.51–69	2.5	0.12–15	0.59	0.03–4.9	0.16	<0.03–8.1	indoor	Stottmeister, 1998, 1999
	30	0.69–114	4.5	0.27–25	1.1	0.04–8.8	0.28	<0.03–3.4	outdoor	
	4.3	0.82–12	1.3	0.19–4.1	0.4	0.03–0.91	0.08	<0.03–0.22	hydro-therapy	
	3.8	6.4 (max.)							spa	Erdinger et al., 1997
Denmark		145–151							indoor	Kaas & Rudiengaard, 1987
Hungary	11.4	<2–62.3	2.9	<1.0–11.4					indoor	Borsányi, 1998

4. Water Balance in Swimming Pools

4.1. Water Balance Parameters

Swimming pool water may be supplied from one of several sources including municipal water companies, wells, and surface run-off. Sources like lakes and reservoirs are the most common supplies. This source water used to fill swimming pools is usually called make- up water. Make-up water may not provide perfectly balanced water and may have components that are not compatible with aquatic facilities. Besides, many forms of pollutants may be introduced to the pool water from the environment which may affect the balance. Water balance refers to water that is neither corrosive nor scale-forming. The factors that determine the balance of water are pH, total alkalinity (TA), calcium hardness, total dissolved solids (TDS), and temperature. For swimming pool equipment to function effectively, balanced water is a must. Unbalanced water can destroy a pool shell and its plumbing in a few years. There are two major roles of pH in water chemistry. The firs one is, it buffers acidic disinfectants added to swimming pool water, thus enhancing bather comfort, and the second is that pH is the most significant determinate in water balancing. Most health departments are concerned with pH and chlorine readings. The reason why they are more concentrated on pH and chlorine values rather than other chemical components of water balance like total alkalinity and calcium hardness is that other components do not directly affect the health.

4.1.1. pH

pH is referred as the most important parameter in swimming pool water chemistry. Every chemical introduced to pool is either affected by or has an effect on pH. pH not only buffers disinfectants but also determines the water balance in the pool. Generally it is accepted that swimmers are comfortable in water that is lightly basic, pH between 7.2 and 7.8.

Water dissociates to form hydroxide (OH^-) and hydrogen (H^+) ions. The concentration of hydrogen ions determines the pH of the water. When the hydrogen ion concentration is equal to the hydroxide ion concentration the water is said to be neutral. Distilled water is neutral with a pH of 7.0 but this value is too acidic for pool water. The pH scale extends from 0 to 14 with values below 7 being acidic and values above 7 being basic. The pH of pool water is shown in Figure 4.1.

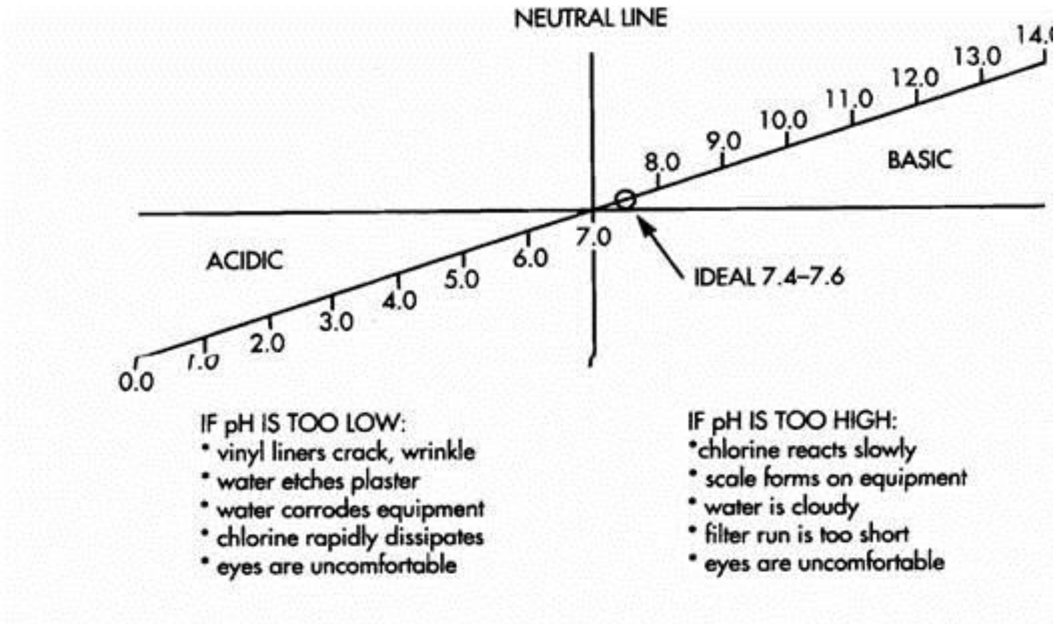


Figure 4.1 The pH of pool water

Acidic water is aggressive, whereas basic water is scale forming. Acidic water can deteriorate metal surfaces that include filter tanks, valves, pipes, heaters and other pool plumbing. Corrosive water can also burn skin and eyes. Scale has an opposite effect. Scale is referred as a white precipitate that occurs on pipes, pumps and other pool equipments making them less effective or nonfunctional. Basic water can also cause cloudy water and skin irritation. The higher the pH, the less effective the disinfectant becomes.

To raise pH, basic or alkaline compounds are used. The soda ash (sodium carbonate) is the most common substance used to increase pH. Soda ash is a fine white powder that is usually mixed with water first and then injected by a chemical feeder pump into the pool water. Soda ash feeders must be cleaned on a regular basis. Running a solution of muriatic acid periodically through the feeder often prevents clogging, but this must be performed regularly.

Soda ash can also be added directly into the pool but it should be mixed with water first, and it will cloud the water so it is best to use this technique at night, after the pool closes. In some pools sodium hydroxide (caustic soda) is used instead of soda ash. Sodium hydroxide is a liquid that is extremely effective in raising pH and less expensive than soda ash, but it is somewhat difficult to handle and freezes between 10° and 15° C. Although sodium bicarbonate also raises the pH it should be used to raise the total alkalinity.

When the pH needs to be lowered, an acid must be introduced into the water. The most common acid used for this purpose, particularly in larger, public pools is muriatic acid (hydrochloric acid). Muriatic acid is a corrosive acid that is relatively inexpensive but it must be handled carefully. Muriatic acid is often used to lower the pH when sodium hypochlorite is used as disinfectant. A safer alternative to muriatic acid is sodium bisulfate, which is often referred as dry acid, because it comes in a white granule. Sodium bisulfate is much easier to handle but it is quite expensive.

CO_2 gas is a relatively new method in lowering the pH. CO_2 also raises the total alkalinity as it lowers the pH, a big advantage for pool with low total alkalinity. This gas is not harmful for metals and does not emit corrosive gases. When CO_2 is mixed with water, it forms carbonic acid, which in turn liberates hydrogen ions that lowers the pH. If the total alkalinity tends to be high (130-150 ppm) because of CO_2 utilization, it should be avoided, because total alkalinity will rise to excessively high levels and then require the addition of muriatic acid which would defeat the purpose of changing to CO_2 **(Griffiths, 2003)**.

4.1.2. Total Alkalinity

Total alkalinity (TA) is a measure of the resistance of water to changes in pH and is measured in ppms. The higher the total alkalinity, the more difficult it is to change pH with either acid or soda ash. The lower the total alkalinity the more likely pH is to change; even slight changes in chemicals, swimmer loads, and weather can have a significant effect on pH or cause pH bounce. More specifically, total alkalinity is a measurement of alkaline components in the water. These components include carbonate ($C03^{-2}$), bicarbonate ($HCO3^{-}$), and hydroxide (OH^{-}) with some other alkaline materials making minor contributions. In the ideal pH range for pools (7.2 to 7.6), the bicarbonates make the greatest contribution.

pH and total alkalinity in swimming pools are closely related. When pool water has a low pH, all carbonate ions are converted to bicarbonates and no calcium carbonates are formed. As a result, without calcium carbonate available, the water becomes corrosive to the shell, equipment, and plumbing. Conversely, when pool water has a high pH, calcium precipitates out of the water and causes cloudiness.

Problems arising when total alkalinity is not in proper range are illustrated in Figure 4.2.

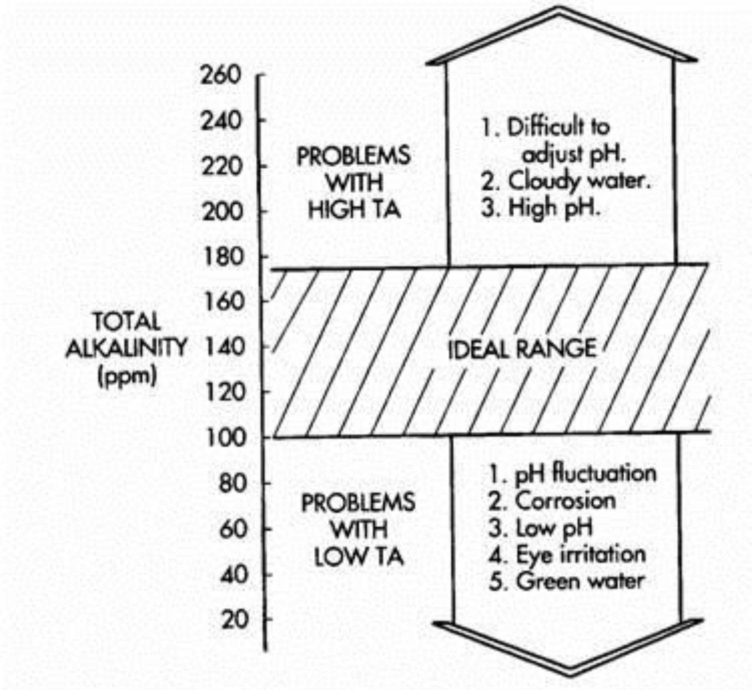


Figure 4.2. Total alkalinity levels in a swimming pool

Most pools should maintain the total alkalinity levels between 100 to 150 ppm. It should be noted that many health departments do not dictate ideal ranges for total alkalinity because they only affect pool plumbing and not people's health. Total alkalinity should not drop below 100 ppm, except in regions that have very high calcium hardness levels or when calcium hypochlorite is the primary sanitizer. In this case, when the calcium hardness in a pool is greater than 500 ppm, the total alkalinity may be allowed to drop to no less than 80 ppm. It should be noted that when cyanuric acid is added to pool water to stabilize chlorine, it artificially elevates the total alkalinity level. When the total alkalinity is low (less than 80 ppm), and cyanuric acid level is high (more than 60 ppm), one/third of the cyanuric acid reading should be subtracted from the total alkalinity level for a true total alkalinity level.

A low total alkalinity not only makes it difficult to maintain the ideal pH but may also lead to highly aggressive water, which could damage filters, pool shell and other equipment. Low alkalinity is also associated with green water and the etching of plaster. Very low alkalinity (< 50 ppm) can also be linked to eye burns. Sodium bicarbonate ($NaHCO_3$) which slightly affects the pH should be added to raise the total alkalinity. On the contrary, high total alkalinity causes the pH to stick at a certain level, making it difficult to change. Besides, it leads to scale forming and may cause cloudy water. Muriatic acid and sodium bisulfate are the two acids most commonly used for this purpose.

4.1.3. Calcium Hardness

Hardness is the term used to refer to the mineral content of water. All water supplies have varying amounts of calcium and magnesium that make water hard. In swimming pools calcium accounts for nearly 95% of the hardness. Although calcium and magnesium are the major contributors to hardness other elements like carbonates, chlorides, nitrates, sulfates and other mineral salts contribute to the hardness. Pool water must have a very high degree of hardness otherwise the pool itself and the equipments deteriorate. A swimming pool with less than 200 ppm calcium hardness is considered hungry for calcium and as a result dissolves any source of hardness. Low alkalinity also adversely affects the water balance in the pool.

Calcium hardness indicates Ca^{2+} content of the water. The recommended range for calcium hardness is between 200 and 400 ppm. Low calcium hardness combined with a low pH and low total alkalinity significantly increases the corrosiveness and aggressiveness of the water. As the aggressiveness of the water increases, the solubility of calcium carbonate also increases. Low calcium hardness also leads to corrosion of metal components in the pool plant, particularly in heat exchanges. Calcium carbonate usually provides a protective film on the surface of the copper heat exchangers and heat sinks. This thin layer prevents much water to metal interaction but does not adversely affect the heating process. Without the protective layer caused by low calcium hardness, heat exchangers and related parts can be destroyed **(Griffiths, 2003)**.

As water temperature increases, solubility of calcium carbonate decreases. Problems encountered when calcium hardness is not in proper range are illustrated in Figure 4.3.

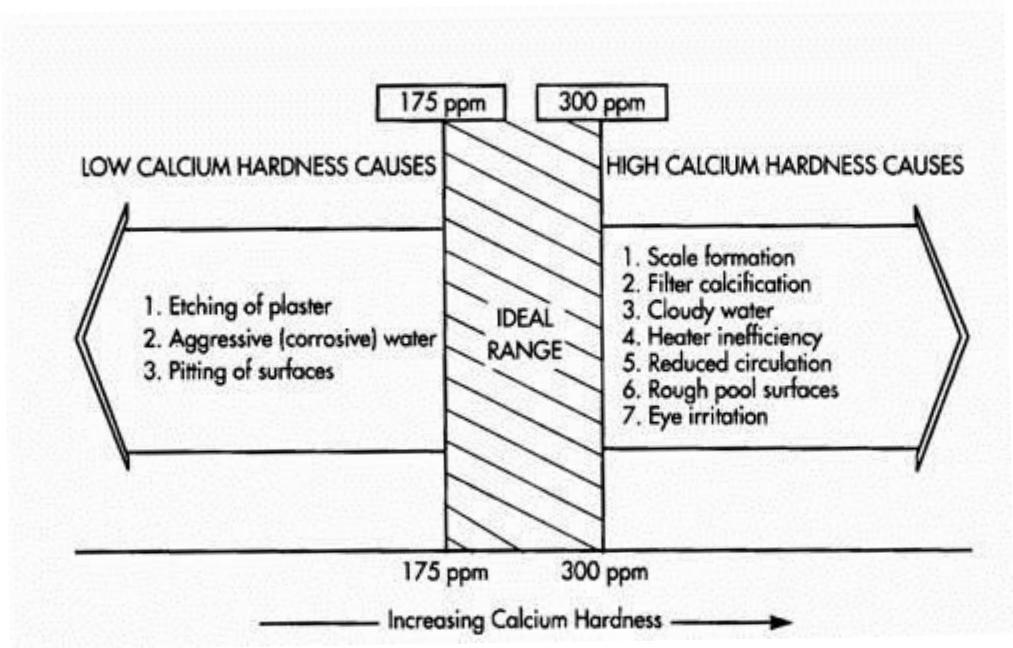


Figure 4.3. Problems encountered when calcium hardness is not in proper range (Griffiths, 2003)

High calcium hardness causes problems such as scale formation, filter calcification, heater inefficiency, rough pool surfaces and eye irritation. The practical way of removing calcium hardness from the water is to drain varying amounts of water from the pool. Another alternative is prolonging the backwash cycle. If the make-up water has exceedingly high calcium hardness, the pH and total alkalinity levels need to be lowered. However, the pH should not be allowed to drop below 7.2, nor should the total alkalinity be allowed to fall below 80 ppm.

4.1.4. Total Dissolved Solids

Total dissolved solids (TDS) levels are a general indicator of pool water quality. Pools with less than 1000 ppm TDS usually have good water quality, whereas pools with more than 3000 ppm may have poor water quality. Of the first signs of high TDS is a dull or cloudy appearance of water. Some of the dissolved material includes hardness, alkalinity, cyanuric acid, chlorides, bromides and algaecides. TDS also includes bather wastes, such perspiration, urine, body oil and others.

The more chemicals and people added to water, the faster the TDS levels will increase. New water in recently filled pools has low TDS values, whereas water that has been in a pool for a long time has high TDS levels.

High TDS levels can lead to some problems in the pool such as reduced chlorine efficiency, algae growth, aggressive water and cloudiness. Increased corrosion is due to the increased electrical conductance that a high TDS pool promotes, resulting in galvanic corrosion. TDS levels can be kept under control by adding fresh water on a daily basis.

4.1.5. Temperature

As temperature increases calcium carbonate becomes less soluble causing it to precipitate out of solution at higher temperatures. Besides, temperature is one of the five important parameters considered in the Langelier Saturation Index, but is the least significant one. As temperature increases the water balance tends to become more basic and scale forming. However, as temperature decreases, water becomes more corrosive. Temperature has also effects on algae growth, chlorination and evaporation.

4.2. The Langelier Saturation Index and Water Balance

In 1936 a scale was developed by Professor Langelier of the University of California to determine water balance. Perfectly balanced water is usually defined as water that is neither corrosive nor scale-forming. The corrosiveness or scaling properties of water can be determined by the use of Langelier's Index. This complicated scale was originally developed to better understand hot water chemistry so that boilers and heat exchangers would operate more efficiently in factories and housing projects. The main purpose of this index was to predict if the water analyzed will keep calcium carbonate in solution or will it precipitate out. Initially, the index had nothing to do with swimming pool water and has only been adapted for that purpose in recent years.

The original index has been simplified for swimming pool use. Pool owners and operators should note that chlorine and other disinfecting chemicals are not a part of water balance. Before examining the specifics of this index it would be wise to review two basic properties of water balance, corrosiveness and scaling.

4.2.1. Aggressive water

Aggressive (corrosive) water is "hungry" water that attempts to "eat" everything it comes in contact with. Aggressive water dissolves metals, particularly copper and iron. Aggressive water also dissolves and etches plaster. A swimming pool plant with corrosive water in it is being destroyed by the water. A saturation index with a minus (-) value indicates corrosive water.

4.2.2. Scaling Water

Scaling water is the opposite of aggressive water and does not corrode, but rather clogs by precipitating scale, cloudiness, or residue within the pool plant. Unlike aggressive water, scaling water may be considered overfed or overstuffed, containing too many components and inert materials. Scaling water will clog pipes and valves and calcify filter mediums. Basic water that is only slightly scaling may produce a beneficial protective coating on all pool parts. A saturation index with a plus (+) value indicates basic or scale-forming water.

4.2.3. Equilibrium

Perfect balanced water is said to be in equilibrium with calcium carbonate. Zero (O) on the saturation index indicates water in the state of equilibrium that will neither precipitate calcium carbonate in the form of scale nor dissolve the pool shell and equipment in an attempt to increase calcium carbonate.

Although the Langelier Saturation Index has been criticized over the years, it still has value in swimming pool applications. The following factors are needed to determine water balance:

1. pH
2. Total Alkalinity (TA)
3. Calcium Hardness (CH)
4. Temperature
5. Total Dissolved Solids (TDS)

Only pH, TA, and CH are normally adjusted to achieve water balance and are the most important contributors to water balance. Pool water will often be balanced if pH, TA, and CH are kept within the recommended ranges.

5. EXPERIMENTAL

5.1. Materials

Water samples were taken from several pools (indoor, outdoor, fun, relax, kid) of the 8 important plants, coded as Belek-1, Belek-2, Bodrum, Kemer-1, Kemer-2, Kemer-3, Kemer-4, and Marmaris-1 located at Aegean and Mediterranean Region. The samples were obtained at several time periods during the months May-June-July and August when the bather load is maximum.

5.1.1. Water sampling

The water sample should not be collected from the surface of a pool where the contaminants collect or in front of an inlet where chemical concentrations is high. In order to take representative samples, samples of water were extracted from 50 cm below and 20 cm away the pool surface and from several different locations around the pool. After mixing they were analyzed for pH, free chlorine, combined chlorine and cyanuric acid.

5.2. Analyses

The Lovibond test equipment is widely used by the water recreation industry and testing authorities. The following procedures outline the Lovibond 2000 equipment (Figure 5.1) and describe in detail the various tests. The Lovibond comparator method has been developed to determine various values by measurement of color intensity against predetermined color standards. It enables a large range of pool water characteristics.

Figure 5.1. The Lovibond test equipment

5.2.1. pH Measurement

Colorimetric test method using phenolsulfonephtalein (phenol red) was performed for pH measurement. Phenol red is usually a liquid reagent, although tablets are available. The sample color gets progressively darker as pH levels increase. The color of the water sample is compared to the color comparator provided with the test kit.

At lower levels of pH, phenol red will turn to yellow and then orange at slightly higher levels. Shades of red indicate proper pH levels; dark red often indicates excessively high levels of pH.

5.2.2. Free and combined chlorine measurement

Free and combined chlorine levels were assayed at the pool side by the conventional DPD test **(APHA, 1998)**. The most common test method for chlorine is the color comparison test with DPD reagent, which turns the water sample pink. DPD chemistry can determine two types of chlorine residuals: free chlorine and total chlorine. Once these levels are found, combined chlorine can be calculated by subtracting free chlorine from total chlorine. DPD no.1 is used to determine the free chlorine level once the free chlorine level is found; DPD no.3 is added to the treated sample to find the combined chlorine level. The first reading is subtracted from the second reading to find the combined chlorine level.

5.2.3. Cyanuric acid measurement

A simple turbidimetric method is available for monitoring cyanuric acid levels. The turbidimetric test is as follows; the tablet reagent is added to the water sample in a special double-tube assembly. Any cyanuric acid present will produce a cloudy solution which is measured by moving the inner tube until a black spot printed on its base just disappears from view. The result is then read off from a scale on the side of the outer tube.

Cyanuric Acid

The presence of cyanuric acid in pool water results from the use of chlorinated isocyanurates as disinfectants –see page 16.

It may be necessary to shock-dose the pool with free chlorine to kill any algae growth which may have appeared. In this case it is important to use either Sodium or Calcium Hypochlorite not more of the stabilised chlorine (Di-Chlor orTri-Chlor).

Chlorinated Isocyanurates (stabilised chlorine)

These are compounds of chlorine and cyanuric acid which are in world-wide use due to the fact that the cyanuric acid acts as a stabiliser in outdoor pools, reducing the chlorine loss due to the action of ultra violet rays from the sun.

Two compounds are available – sodium dichloroisocyanurate 'Di-Chlor' and trichloroisocyanuric acid 'Tri-Chlor'.

Di-Chlor

This is a granular material containing about 60% of available chlorine. It is a highly soluble compound which makes it ideal for direct application to the pool. Furthermore it has an almost neutral pH which means it will not have an effect on the pH of the pool water.

When dissolved in water Di-Chlor produces hypochlorous acid (free chlorine) and cyanuric acid and it is important to monitor the latter as well as the free chlorine as it’s concentration tends to build up in the pool water until a situation arises

when chlorine – lock occurs –see page 41.

17

Tri-Chlor

This contains about 90% of available chlorine and is normally supplied in the

form of large tablets. It is not particularly soluble which makes it ideal for flowthrough

erosion feeders, floaters or in skimmer basket applications.

It has a low pH – about 3 which may require pH adjustment with pH-increasing

chemicals like sodium carbonate (soda ash)

It produces hypochlorous acid and cyanuric acid in solution in a similar manner to

dichlor and the same potential problem applies over the build-up of cyanuric

acid.

As a general rule free chlorine residuals must be kept higher than with regular

hypochlorites because with Di-Chlor and Tri-Chlor a reduction in the rate of kill of

bacteria occurs with increasing concentrations of cyanuric acid. The level recommended

depends on the cyanuric acid content as indicated in the table:

Cyanuric acid mg/l	Minimum free chlorine mg/l
25	1.5
50	2.0
100	2.5
200	3.0

5.2.4. Bacteriological testing

In general, microbiological quality evaluation rests on the traditional indicators of faecal pollution and on microorganisms such as *Pseudomonas aeruginosa* and *Staphylococcus aureus* shed by bathers. Correlation of microbiological standards and physico-chemical quality parameters might permit the prediction of hygienic conditions of bathing water by determining certain parameters in a rapid, simple form **(Ibarleuzea, 1997)**.

Samples were collected and sent to certified laboratory as soon as possible not exceeding 24 hours. *Fecal coliform, Esheria coli, Fecal streptococci, Salmonella* and *Pseudomonas aeuroginosa* analyses were carried out.

5.3. Standards for Swimming Pools

In Turkey, preparation of swimming pool water, technical construction, control, operation and maintenance guidelines is provided by Turkish Standards Institute (TSI) with TS 11899. Table 5.1 presents the suggested standards for swimming pools according to TS 11899.

Besides TS 11899, NSPI standards are also accepted and used commonly world-wide.

Founded in 1956, the National Spa and Pool Institute (NSPI) is an international trade association of more than 5,300 manufacturers, distributors, retailers, service companies and builders in the pool/spa and hot tub industry. NSPI members adhere to a code of ethics and share a commitment to public health and safety in the installation, maintenance and operation of pools/spas and hot tubs. NSPI suggested chemical standards for swimming pools are presented in Table 5.1.

Since almost all of the touristy plants serve foreign guests in Turkey, the plant managers prefer NSPI standards because they have to report to the foreign authorities.

Table 5.1 TS 11899 and NSPI suggested chemical standards for swimming pools

Parameter	Limit values			
	NSPI		TS 11899	
	Minimum	Maximum	Minimum	Maximum
pH	7.2	7.8	6.5	7.6
Free chlorine, ppm	-	1-3	0.3*	0.6*
Combined chlorine, ppm	-	0.2	-	0.2

Cyanuric acid, ppm	10	150	NA	NA

* Higher concentrations may be required in case of microbiological quality necessity. However, upper concentration should not exceed 1.2 ppm.

5.4. Results of Experimental Study

5.4.1. Plant Belek

There are three pools named as indoor, fun and relax in this plant. Stabilized chlorine is being used as the disinfectant in this plant.

The volume of the indoor pool is 500 m^3. It has a balance tank of 50 m^3. The water circulation flow is 120 m^3/h. Sand filters are used and the entrance is reported as 400 persons/day.

The volume of the fun pool is 2500 m^3. It has a balance tank of 100 m^3. The water circulation flow is 390 m^3/h. Sand filters are used and the entrance is reported as 1500 persons/day.

The volume of the relax pool is 200 m^3. It has a balance tank of 20 m^3. The water circulation flow is 80 m^3/h. Sand filters are used and the entrance is reported as 300 persons/day.

5.4.1.1. pH variation at plant Belek

The change of pH with time in indoor, fun and relax pools is shown at Fig. 5.1.

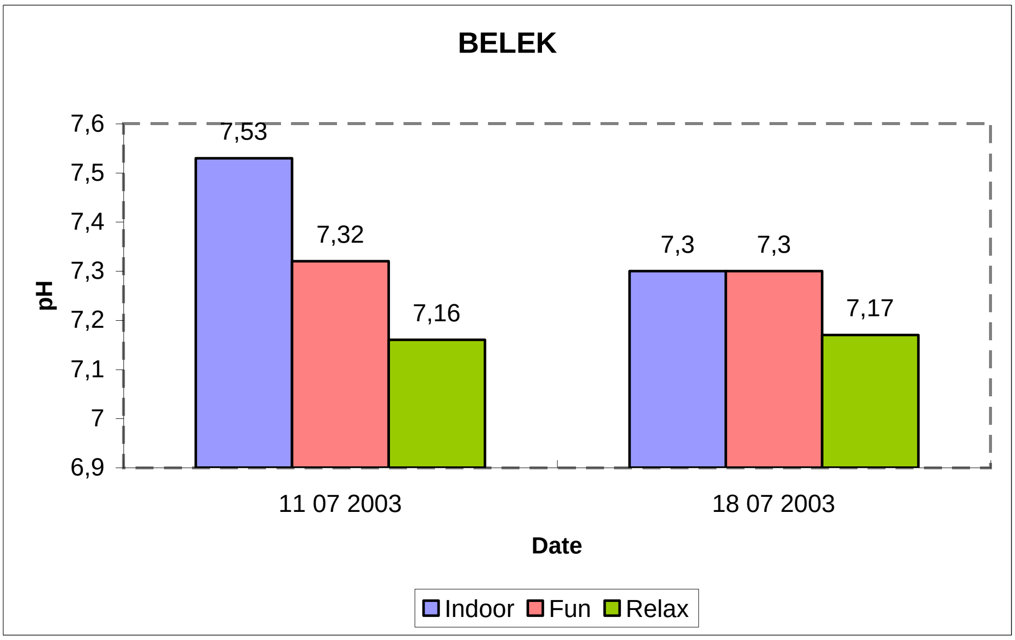


Figure 5.1. pH-time variation at plant Belek

For disinfectants based on chlorine to work properly and efficiently the pH value of the pool or spa water is critical. The normal recommendation is that the pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. The pH values of all the three pools seemed to be in limit ranges according to both TS 11899 and NSPI standards. However, pH value of 7.53 recorded in the indoor pool seemed to have a tendency to increase so a pH lowering solution was used.

5.4.1.2. Free chlorine variation at plant Belek

The change of free chlorine with time in indoor, fun and relax pools is shown at Fig. 5.2. Free chlorine measurements were tried to be carried out at noon day (about 13.00 ^{pm}) since the chlorine concentration decreases rapidly due to the action of ultra violet rays from the sun.

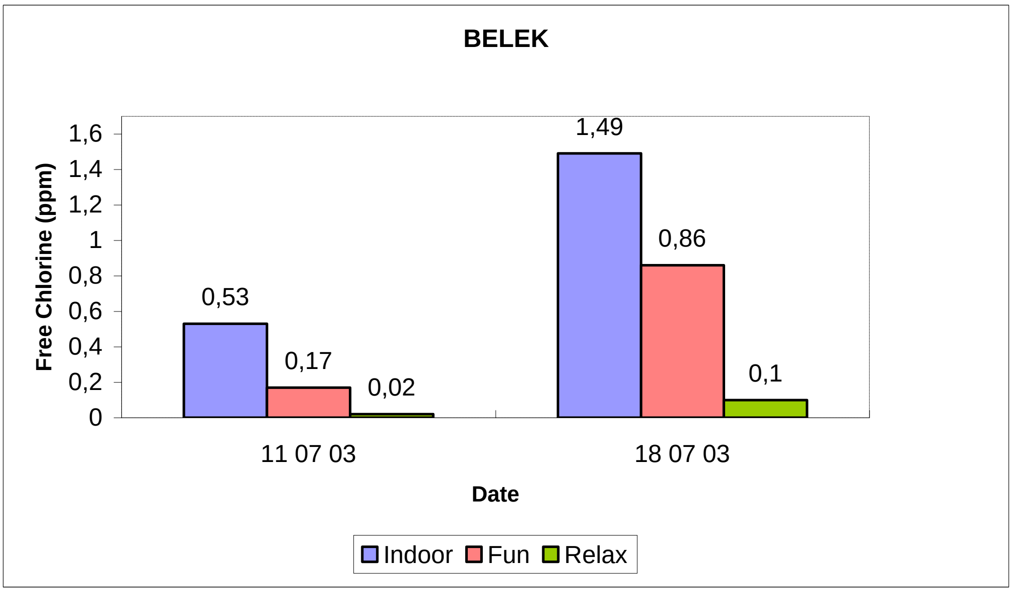


Figure 5.2. Free chlorine-time variation at plant Belek

As shown in Fig. 5.2., the free chlorine levels were fairly low at 11.07.2003, especially in the relax pool. The next week, it was observed that free chlorine concentrations were increased by chlorination process, however, it is thought that some microbiological risks still remained in the fun and relax pools.

5.4.1.3. Combined chlorine variation at plant Belek

The change of combined chlorine with time in indoor, fun and relax pools is shown at Fig. 5.3.

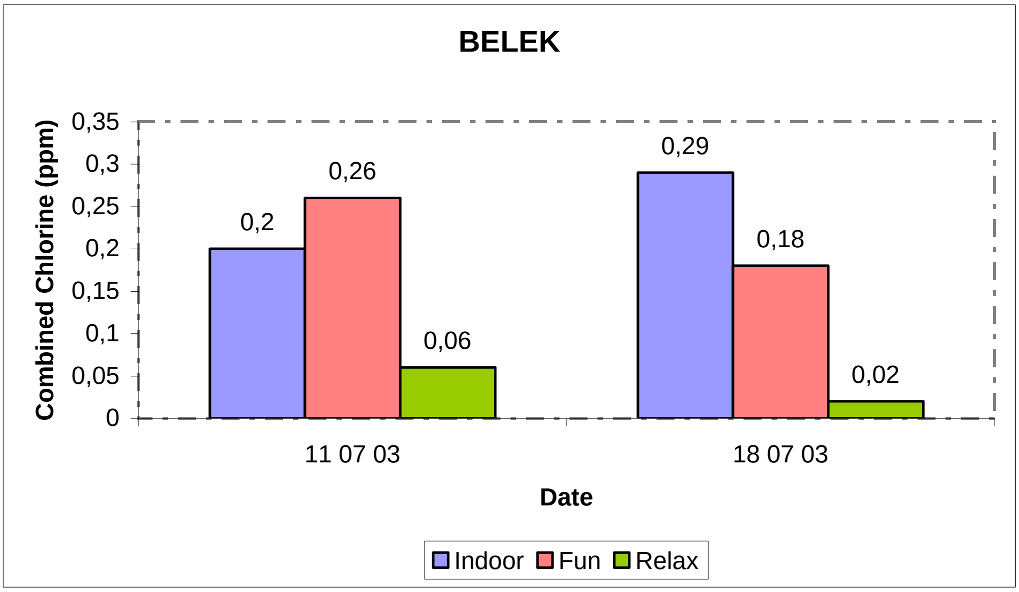


Figure 5.3. Combined chlorine-time variation at plant Belek

The combined chlorine levels generally seemed to be in limit ranges. But it is not desirable to measure concentrations above 0.2 ppm due to smell, irritation problems. Possibly, breakpoint chlorination process was applied to decrease the combined chlorine level in the fun pool at 11.07.2003.

5.4.1.4. Cyanuric acid variation at plant Belek

The change of cyanuric acid concentration with time in indoor, fun and relax pools is shown at Fig. 5.4.

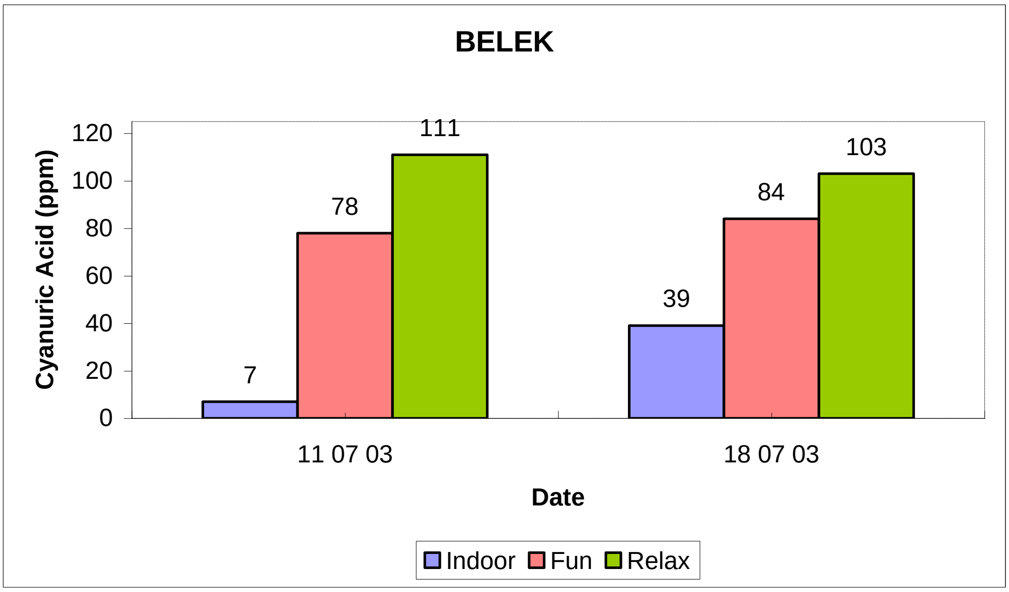


Figure 5.4. Cyanuric acid-time variation at plant Belek

In the process of disinfection, the chlorine becomes used up but the cyanuric acid molecule remains, and over time can build up to such a concentration as to cause what is popularly known as Chlorine-lock in the pool. Chlorine-lock usually occurs when the concentration of cyanuric acid in the pool water reaches levels of 150 mg/l and above. The water itself looks dull and lifeless and perhaps has a greenish tint and yet the DPD No.1 test for free chlorine still shows a good result – the water has become "over-stabilized" and the chlorine is locked in. Hot weather and extended periods of drought with perhaps water rationing promote elevated levels of cyanuric acid in pools treated with chlorinated isocyanurates. A level of 30 – 50 mg/l is satisfactory for stabilization and should the level rise to above 100 mg/l it is advisable to reduce it by dumping some of the water and topping up with fresh. This was applied to the relax pool at 11.07.2003 and the next week it was observed that the CYA levels decreased.

5.4.2. Plant Bodrum

There exist four pools named as indoor, outdoor, kid and relax in this plant. Stabilized chlorine is being used as the disinfectant in this plant.

The volume of the relax pool is 450 m^3. It has a balance tank of 50 m^3. The water circulation flow is 140 m^3/h. Sand filters are used and the entrance is reported as 300 persons/day.

The volume of the outdoor pool is 2600 m^3. It has a balance tank of 400 m^3. The water circulation flow is 450 m^3/h. Sand filters are used and the entrance is reported as 2000 persons/day.

The volume of the kid pool is 30 m^3. The water circulation flow is 25 m^3/h. Sand filters are used and the entrance is reported as 50 persons/day.

The volume of the indoor pool is 175 m^3. It has a balance tank of 25 m^3. The water circulation flow is 25 m^3/h. Sand filters are used and the entrance is reported as 50 persons/day.

5.4.2.1. pH variation at plant Bodrum

The change of pH with time in indoor, outdoor, kid and relax pools is shown at Fig. 5.5.

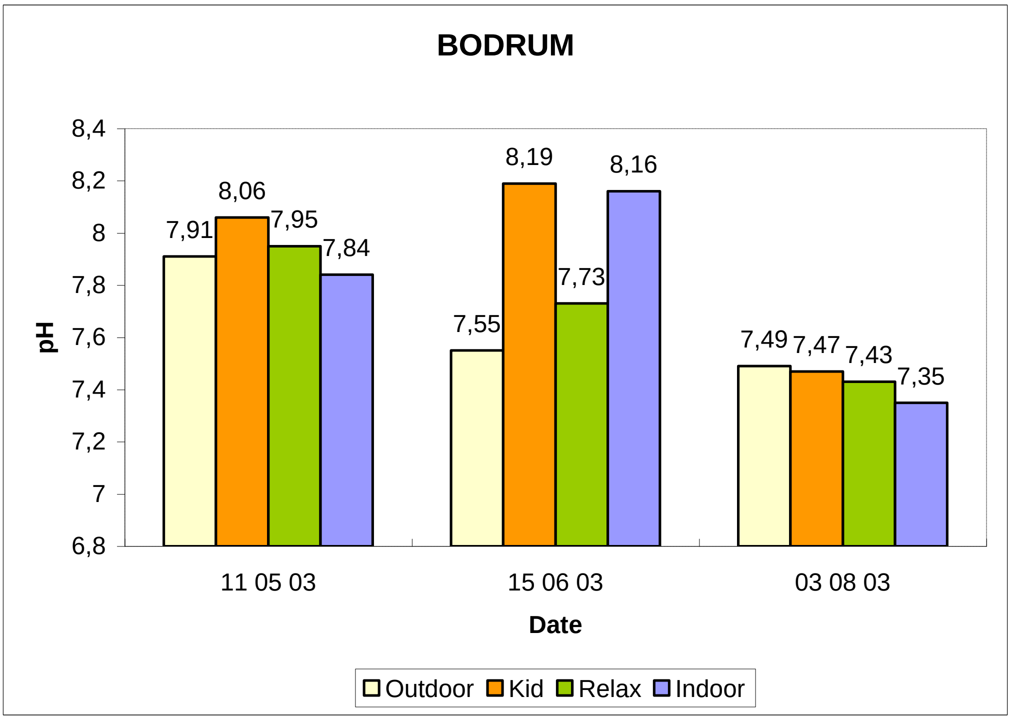


Figure 5.5. pH-time variation at plant Bodrum

The normal recommendation is that the pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. It was observed that pH levels were fairly high for all the pools in both of the measurements performed at 11.05.2003 and 15.06.2003. Then a pH lowering solution was used to decrease the pH.

5.4.2.2. Free chlorine variation at plant Bodrum

The change of free chlorine with time in indoor, outdoor, kid and relax pools is shown at Fig. 5.6.

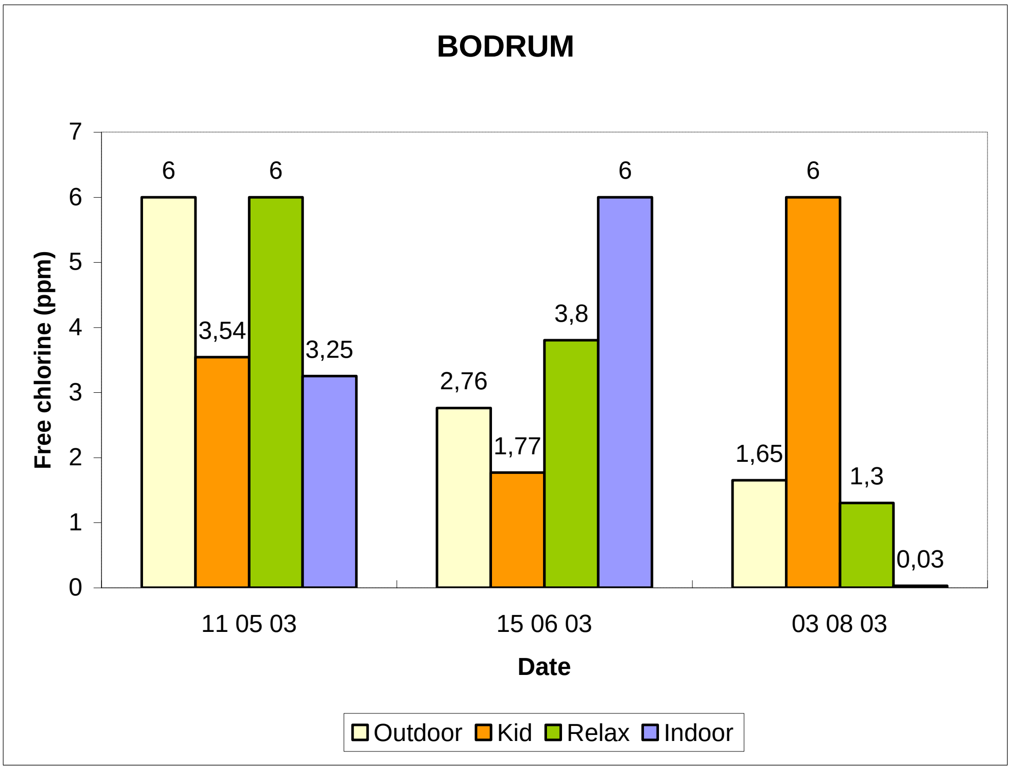


Figure 5.6. Free chlorine-time variation at plant Bodrum

It was observed that the free chlorine concentration was extremely high in all of the pools at 11.05.2003. This situation could be explained by the fact that it was the start-up period for the plant. However, similar results were observed for the relax and indoor pools at June. Possibly a shocking process, applied due to lack of chlorine, would be the reason or excess chlorine dosing by mistake might have caused this.

5.4.2.3. Combined chlorine variation at plant Bodrum

The change of combined chlorine with time in indoor, outdoor, kid and relax pools is shown at Fig. 5.7.

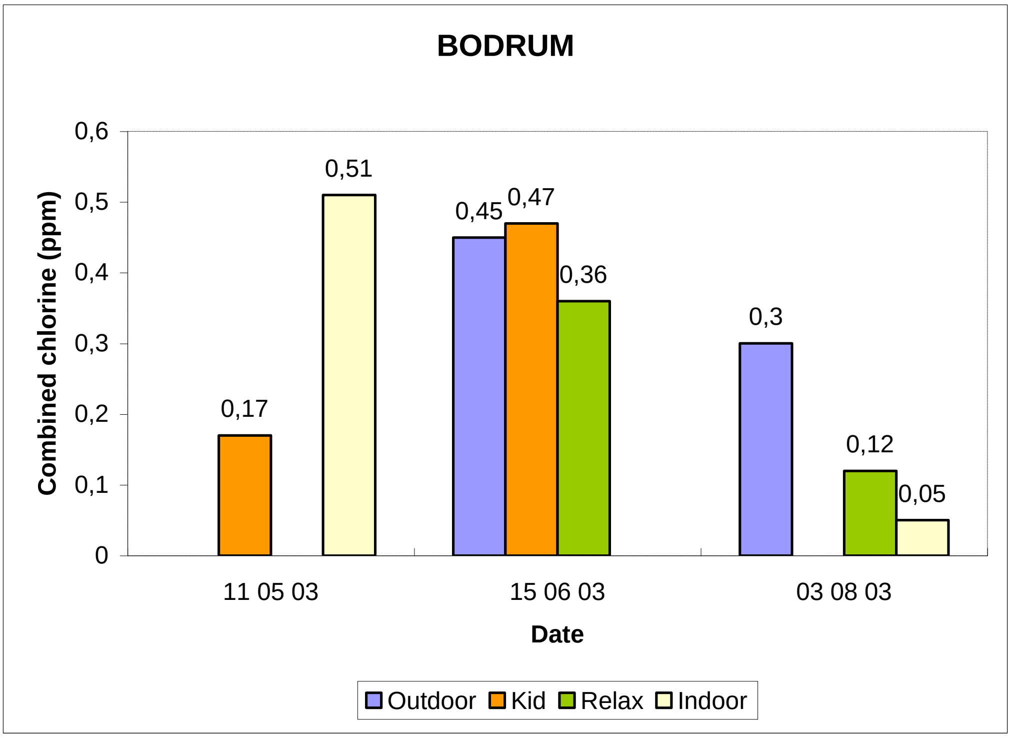


Figure 5.7. Combined chlorine-time variation at plant Bodrum

Generally it is not desirable to measure combined chlorine concentrations above 0.2 ppm due to smell, irritation problems. However, the measurements indicated fairly high concentrations in May and June months. Therefore, it was observed that the desired levels were achieved by breakpoint chlorination process in August.

5.4.2.4. Cyanuric acid variation at plant Bodrum

The change of cyanuric acid concentration with time in indoor, outdoor, kid and relax pools is shown at Fig. 5.8.

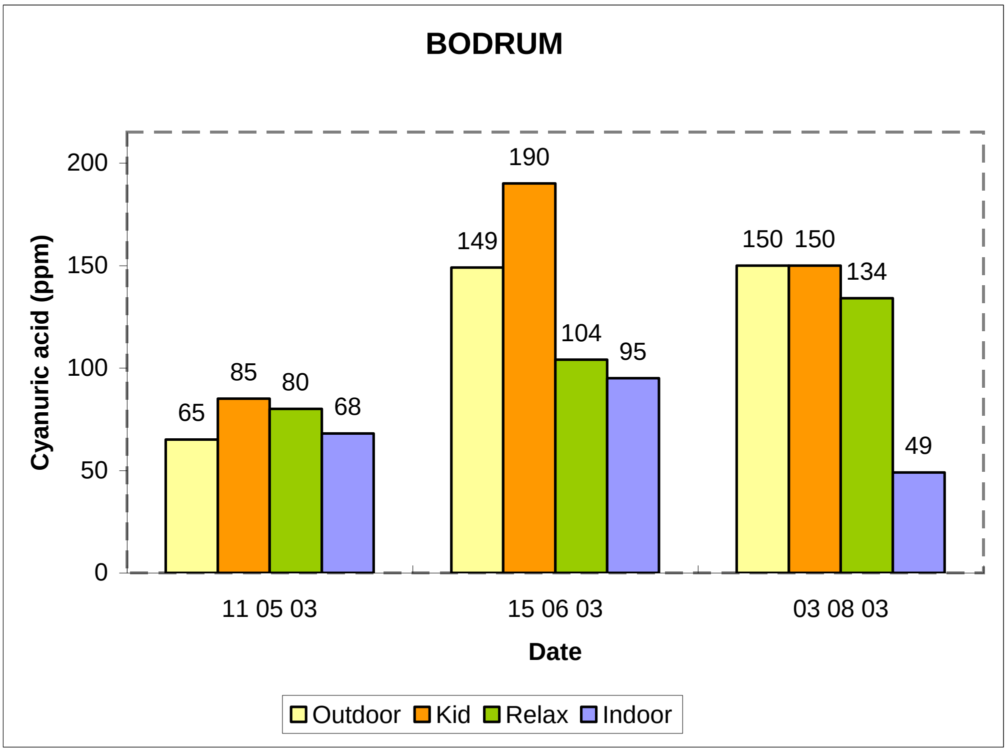


Figure 5.8. Cyanuric acid-time variation at plant Bodrum

As explained above chlorine-lock usually occurs when the concentration of cyanuric acid in the pool water reaches levels of 150 mg/l and above. So it should be reduced by dumping some of the water and topping up with fresh water.

5.4.3. Plant Kemer-1

There exist three pools named as indoor, outdoor, and fun in this plant. Stabilized chlorine is being used as the disinfectant in this plant.

The volume of the fun pool is 315 m^3. It has a balance tank of 20 m^3. The water circulation flow is 60 m^3/h. Sand filters are used and the entrance is reported as 300 persons/day.

The volume of the outdoor pool is 1000 m^3. It has a balance tank of 50 m^3. The water circulation flow is 200 m^3/h. Sand filters are used and the entrance is reported as 800 persons/day.

The volume of the indoor pool is 60 m^3. It has a balance tank of 5 m^3. The water circulation flow is 20 m^3/h. Sand filters are used and the entrance is reported as 50 persons/day.

5.4.3.1. pH variation at plant Kemer-1

The change of pH with time in indoor, outdoor, and fun pools is shown at Fig. 5.9.

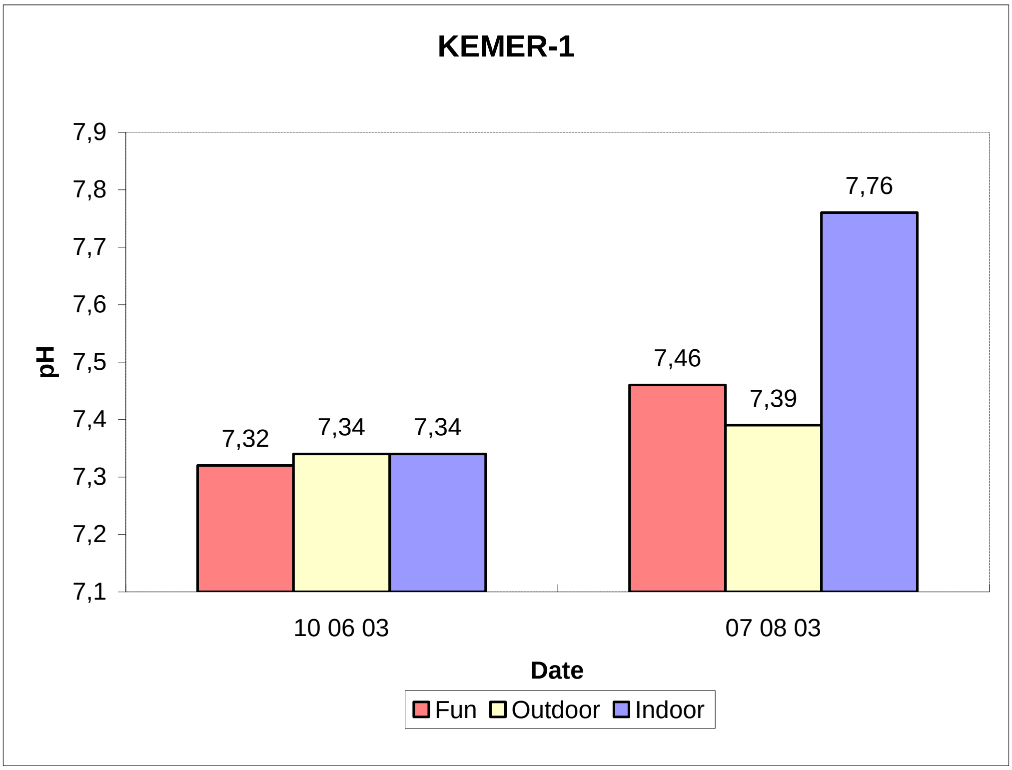


Figure 5.9. pH-time variation at plant Kemer-1

The pH value measured in the indoor pool at August is fairly high and needs to be decreased by appropriate solutions. The pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. Other measurements seem to be in limit ranges.

5.4.3.2. Free chlorine variation at plant Kemer-1

The change of free chlorine with time in indoor, outdoor, and fun pools is shown at Fig. 5.10.

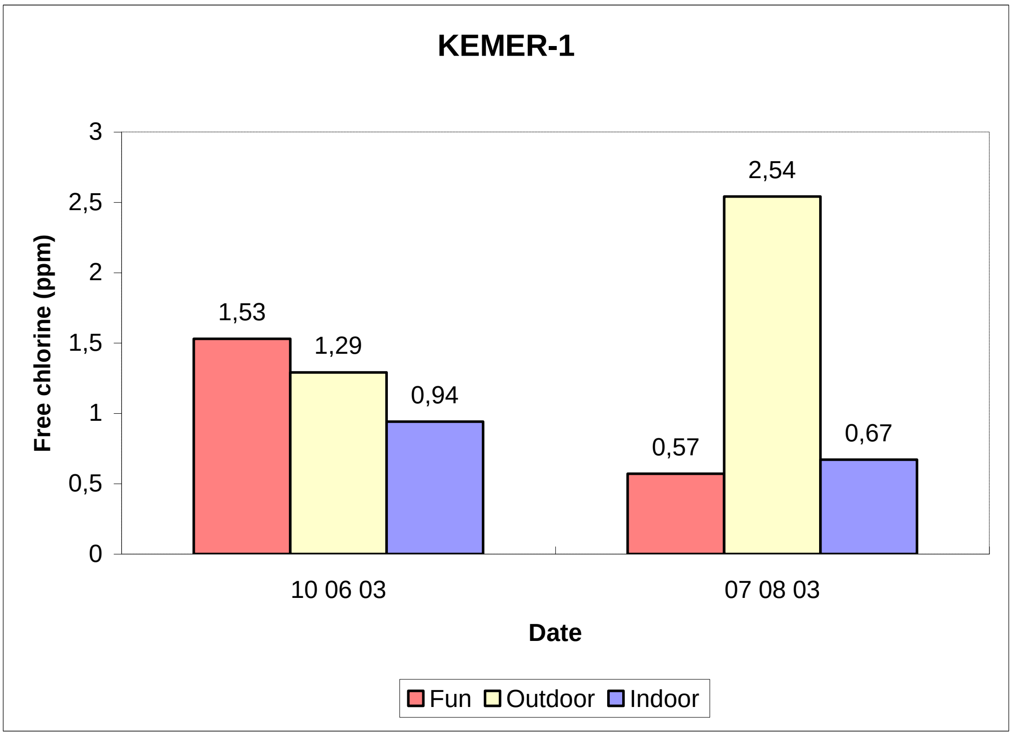


Figure 5.10. Free chlorine-time variation at plant Kemer-1

According to NSPI standards all of the pools seem to be in limit ranges by means of free chlorine concentration.

5.4.3.3. Combined chlorine variation at plant Kemer-1

The change of combined chlorine with time in indoor, outdoor, and fun pools is shown at Fig. 5.11.

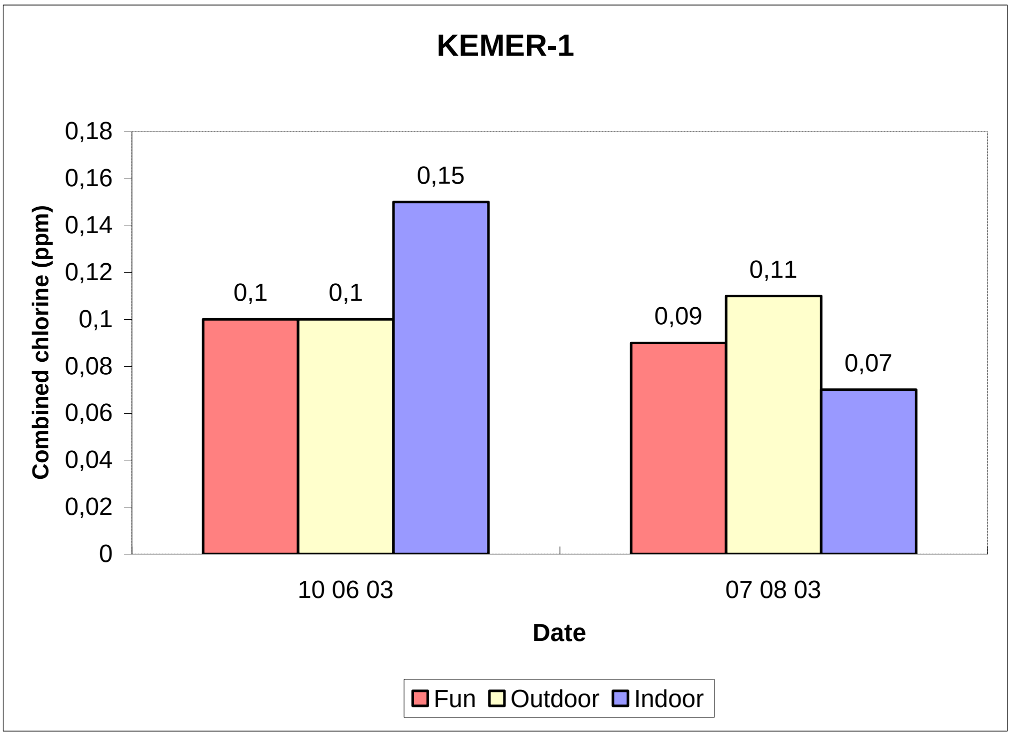


Figure 5.11. Combined chlorine-time variation at plant Kemer-1.

According to NSPI standards combined chlorine concentration are in the limit ranges in all of the pools.

5.4.3.4. Cyanuric acid variation at plant Kemer-1

The change of cyanuric acid concentration with time in indoor, outdoor, and fun pools is shown at Fig. 5.12.

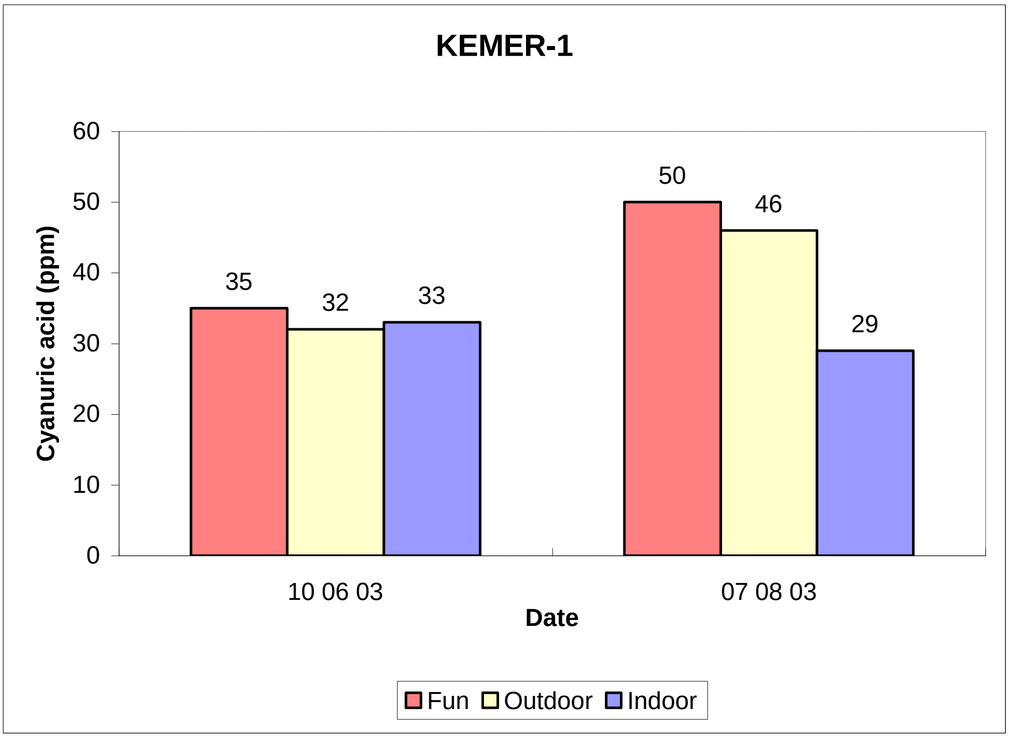


Figure 5.12. Cyanuric acid-time variation at plant Kemer-1

According to NSPI standards cyanuric acid concentration are in the limit ranges in all of the pools.

5.4.4. Plant Kemer-2

There are three pools named as indoor, outdoor, and fun in this plant. Stabilized chlorine is being used as the disinfectant in this plant.

The volume of the fun pool is 900 m^3. It has a balance tank of 50 m^3. The water circulation flow is 240 m^3/h. Sand filters are used and the entrance is reported as 700 persons/day.

The volume of the outdoor pool is 1400 m^3. It has a balance tank of 50 m^3. The water circulation flow is 240 m^3/h. Sand filters are used and the entrance is reported as 1100 persons/day.

The volume of the indoor pool is 185 m^3. It has a balance tank of 15 m^3. The water circulation flow is 60 m^3/h. Sand filters are used and the entrance is reported as 80 persons/day.

5.4.4.1. pH variation at plant Kemer-2

The change of pH with time in indoor, outdoor, and fun pools is shown at Fig. 5.13.

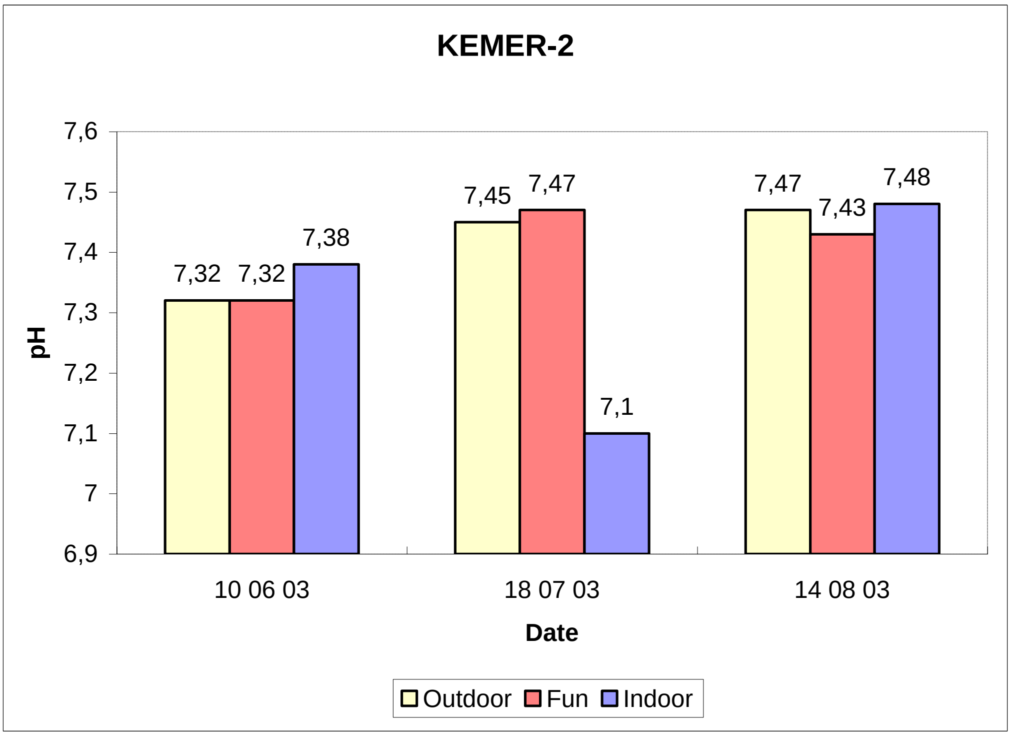


Figure 5.13. pH-time variation at plant Kemer-2

The pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. According to this criteria and NSPI standards all pH measurements are found between limit ranges in all of the pools at all dates.

5.4.4.2. Free chlorine variation at plant Kemer-2

The change of free chlorine with time in indoor, outdoor, and fun pools is shown at Fig. 5.14.

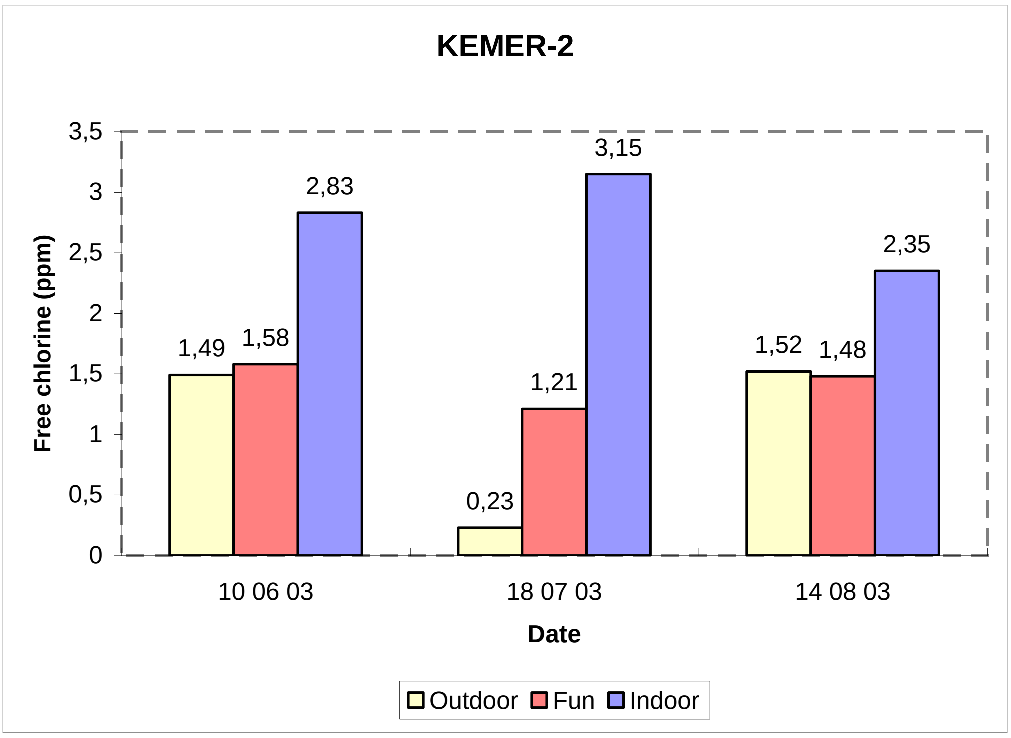


Figure 5.14. Free chlorine-time variation at plant Kemer-2

As NSPI standards suggest free chlorine concentration to be between 1-3 mg/l, measurements of month June indicate fairly good results. The free chlorine concentration measured at June in the outdoor pool is low. Chlorination process should be applied in order to prevent possible health risks. Measurements performed at July indicate that free chlorine concentrations are between limit ranges due to proper operation.

5.4.4.3. Combined chlorine variation at plant Kemer-2

The change of combined chlorine with time in indoor, outdoor, and fun pools is shown at Fig. 5.15.

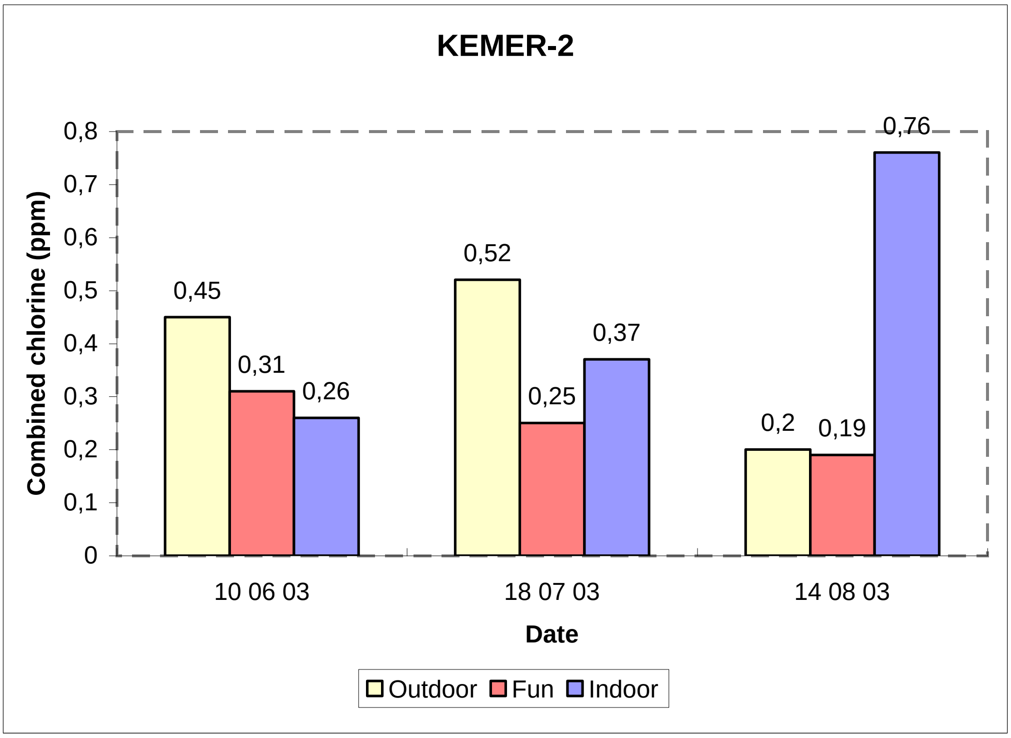


Figure 5.15. Combined chlorine-time variation at plant Kemer-2.

Combined chlorine is the general name given to the derivatives of chlorine which are produced when free chlorine reacts with nitrogen compounds like ammonia and urea from bathers. The products of the chlorine reactions are responsible for most of the complaints form bathers of skin and eye irritation. Trichloramine, more commonly called nitrogen trichloride, produced in the last reaction, is an unstable compound and being volatile comes off the surface of a pool as a gas with a nauseous odor. In addition, it is an extremely severe eye irritant. The chemical reaction does not proceed to completion at pH values above 5 so usually only very small amounts, if any are produced. The two chloramines we are most concerned with are monochloramine and dichloramine. In the DPD test they are usually determined together using the DPD No.3 tablet. The measurements performed at both June and July months indicate fairly high concentrations for combined chlorine concentrations. Breakpoint chlorination process is the only solution for desired levels. Anyway, in August, it was observed that combined chlorine concentrations were kept between limits by applying breakpoint chlorination process. However, there still existed some problems in the indoor pool. This would be explained by insufficient application.

5.4.4.4. Cyanuric acid variation at plant Kemer-2

The change of cyanuric acid concentration with time in indoor, outdoor, and fun pools is shown at Fig. 5.16.

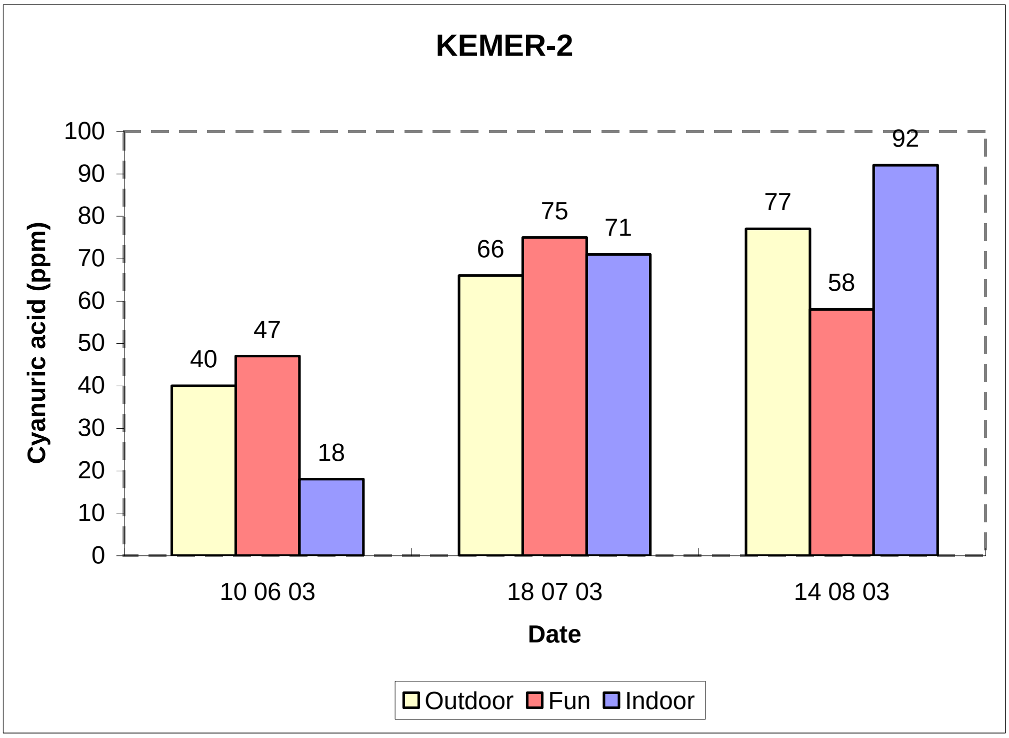


Figure 5.16. Cyanuric acid-time variation at plant Kemer-2

According to NSPI standards cyanuric acid concentration should be below 150 ppm. Considering this criteria it was observed that cyanuric acid concentrations were under limits in all of the pools at all dates.

5.4.5. Plant Kemer-3

There are two pools named as wavepool and fun in this plant. Stabilized chlorine is being used as the disinfectant in this plant.

The volume of the fun pool is 1750 m^3. It has a balance tank of 100 m^3. The water circulation flow is 320 m^3/h. Sand filters are used and the entrance is reported as 1500 persons/day.

The volume of the wavepool is 1400 m^3. It has a balance tank of 100 m^3. The water circulation flow is 120 m^3/h. Sand filters are used and the entrance is reported as 2500 persons/day.

5.4.5.1. pH variation at plant Kemer-3

The change of pH with time in wavepool and fun pools is shown at Fig. 5.17.

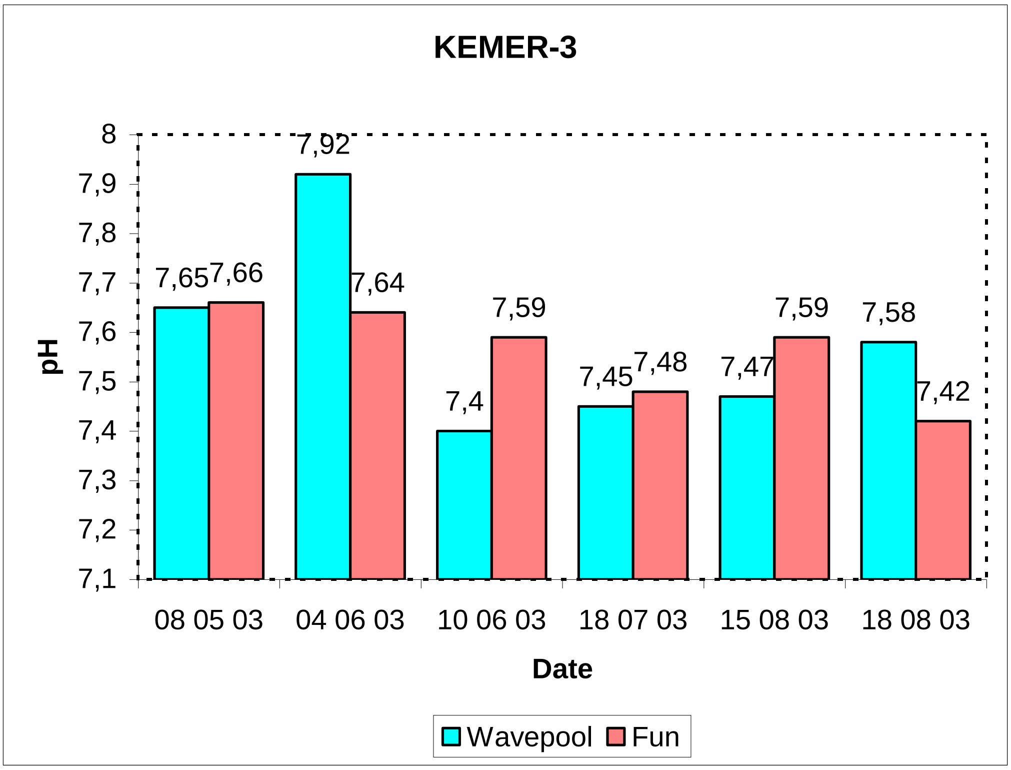


Figure 5.17. pH-time variation at plant Kemer-3

The pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. However, it was observed that almost all of the measurements were fairly high for pH and a tendency to increase existed. This would be explained by the fact that the pools were heavily used. Desired pH levels would be obtained by using a proper pH lowering solution.

5.4.5.2. Free chlorine variation at plant Kemer-3

The change of free chlorine with time in wavepool and fun pools is shown at Fig. 5.18.

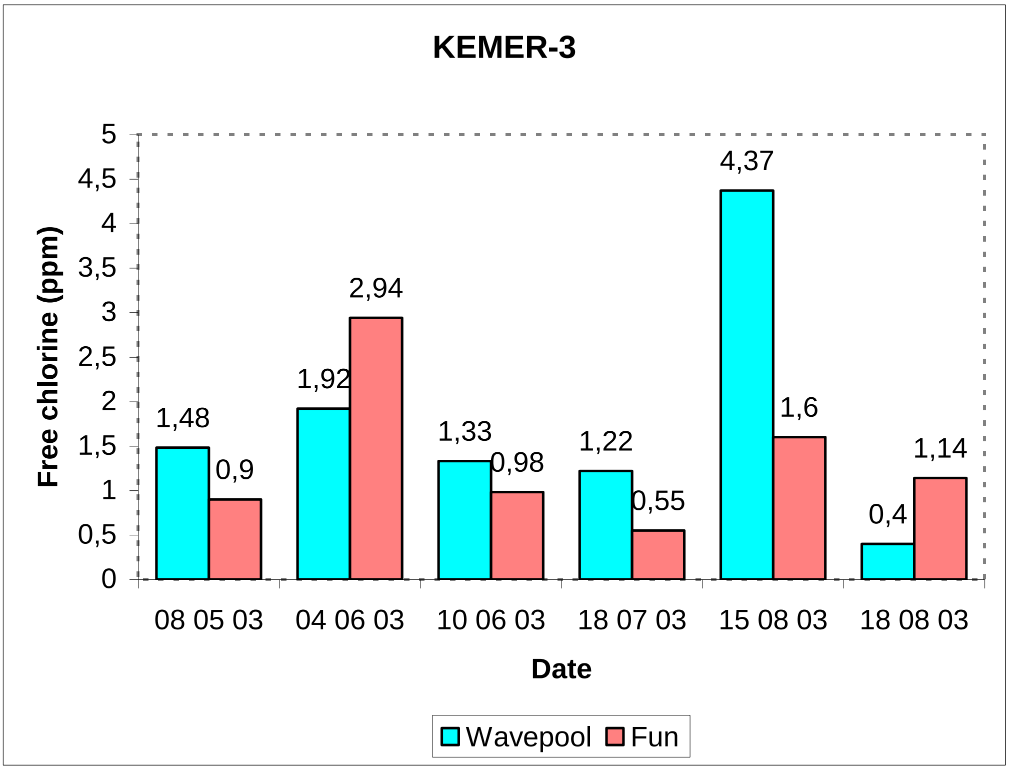


Figure 5.18. Free chlorine-time variation at plant Kemer-3

As NSPI standards suggest free chlorine concentration to be between 1-3 mg/l, it is possible to say free chlorine concentrations are between desired limits in all of the pools. Only the measurement in the wavepool at 15.08.2003 seemed to be high. Shocking process would be the possible reason for this situation.

5.4.5.3. Combined chlorine variation at plant Kemer-3

The change of combined chlorine with time in wavepool and fun pools is shown at Fig. 5.19.

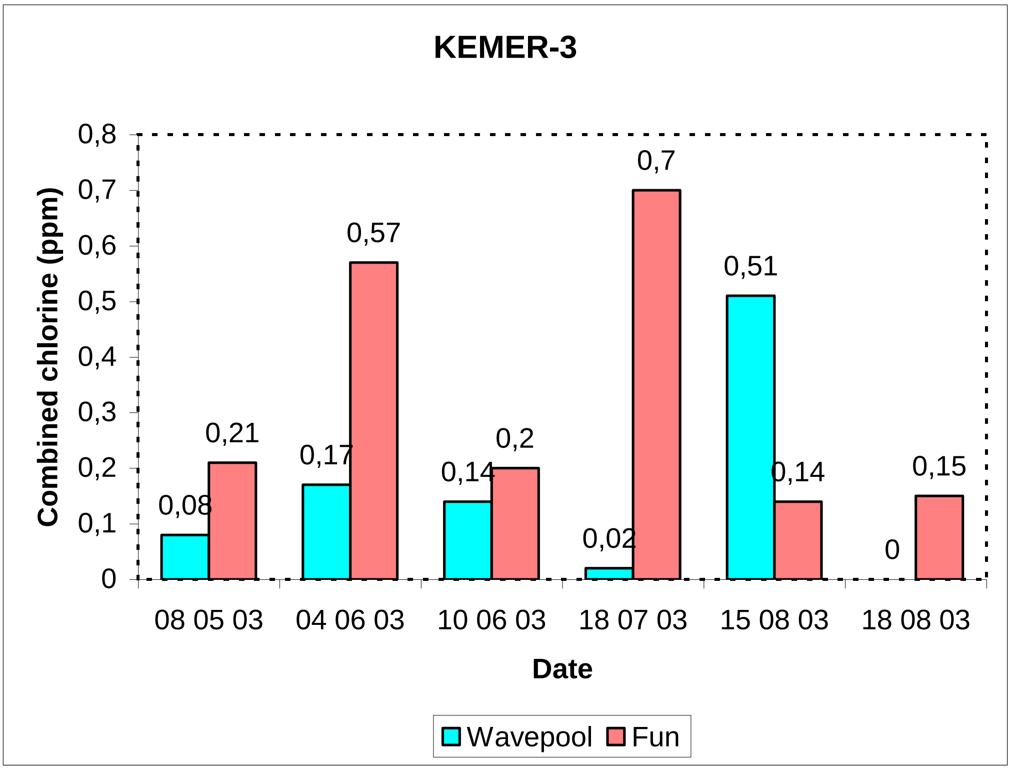


Figure 5.19. Combined chlorine-time variation at plant Kemer-3.

Since the products of the chlorine reactions are responsible for most of the complaints of skin and eye irritation, concentration over 0.2 ppm is not desired. Measurements at 04.06.2003 in the fun pool and at 15.08.2003 at wavepool are above the limits. Breakpoint chlorination should be applied to lower the levels.

5.4.5.4. Cyanuric acid variation at plant Kemer-3

The change of cyanuric acid concentration with time in wavepool and fun pools is shown at Fig. 5.20.

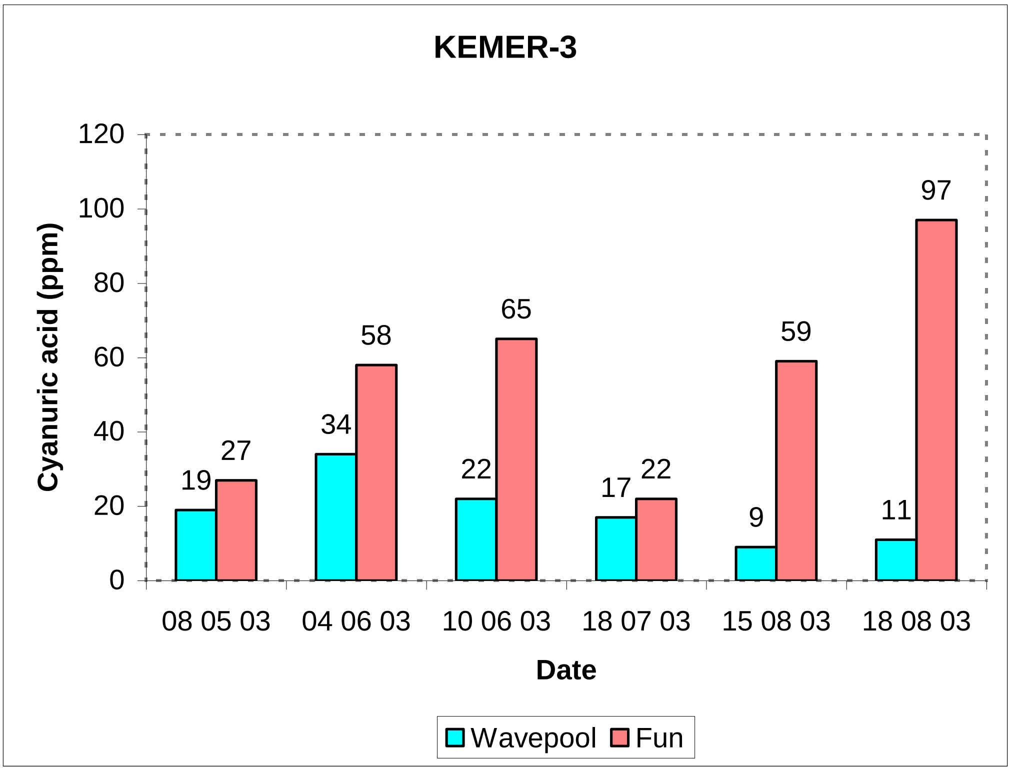


Figure 5.20. Cyanuric acid-time variation at plant Kemer-3

According to NSPI standards cyanuric acid concentration should be below 150 ppm. Considering this criteria it was observed that cyanuric acid concentrations were under limits in all of the pools at all dates.

5.4.6. Plant Kemer-4

There are three pools named as relax, outdoor, and fun in this plant. Stabilized chlorine is being used as the disinfectant in this plant.

The volume of the fun pool is 400 m^3. It has a balance tank of 30 m^3. The water circulation flow is 145 m^3/h. Sand filters are used and the entrance is reported as 2000 persons/day.

The volume of the outdoor pool is 3000 m^3. It has a balance tank of 100 m^3. The water circulation flow is 420 m^3/h. Sand filters are used and the entrance is reported as 5000 persons/day.

The volume of the relax pool is 250 m^3. It has a balance tank of 25 m^3. The water circulation flow is 50 m^3/h. Sand filters are used and the entrance is reported as 500 persons/day.

5.4.6.1. pH variation at plant Kemer-4

The change of pH with time in outdoor, relax and fun pools is shown at Fig. 5.21.

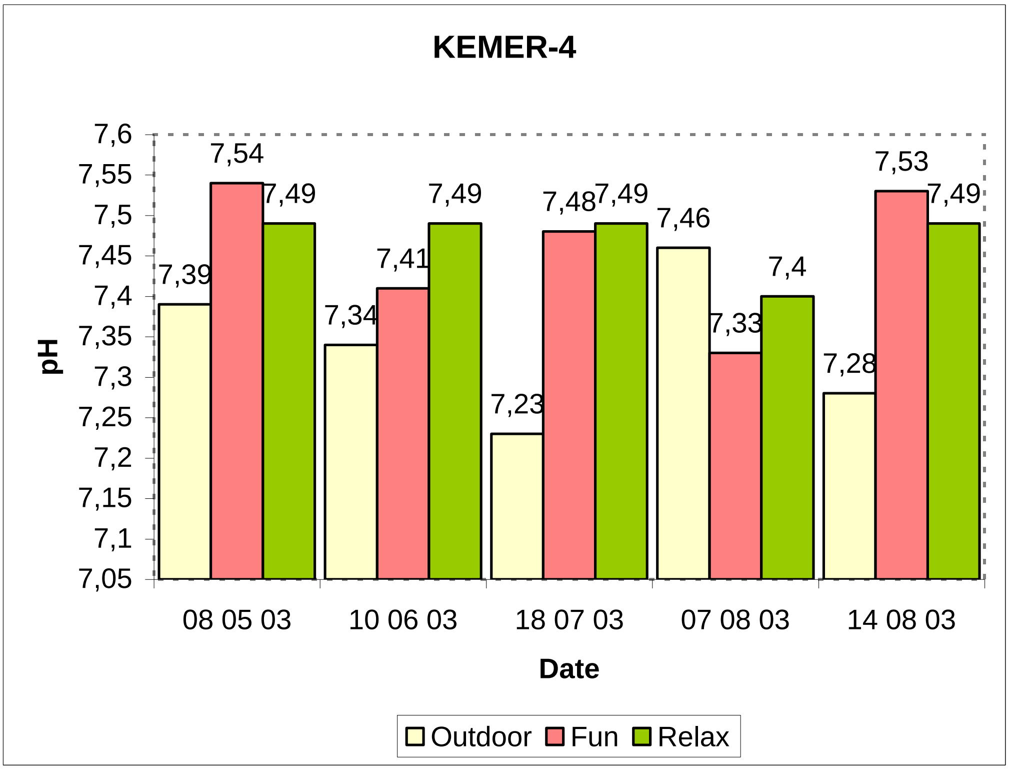


Figure 5.21. pH-time variation at plant Kemer-4

The pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. All of the pH measurements are between desired limits in all of the pools at all dates. This indicates good operation of the pools.

5.4.6.2. Free chlorine variation at plant Kemer-4

The change of free chlorine with time in outdoor, relax and fun pools is shown at Fig. 5.22.

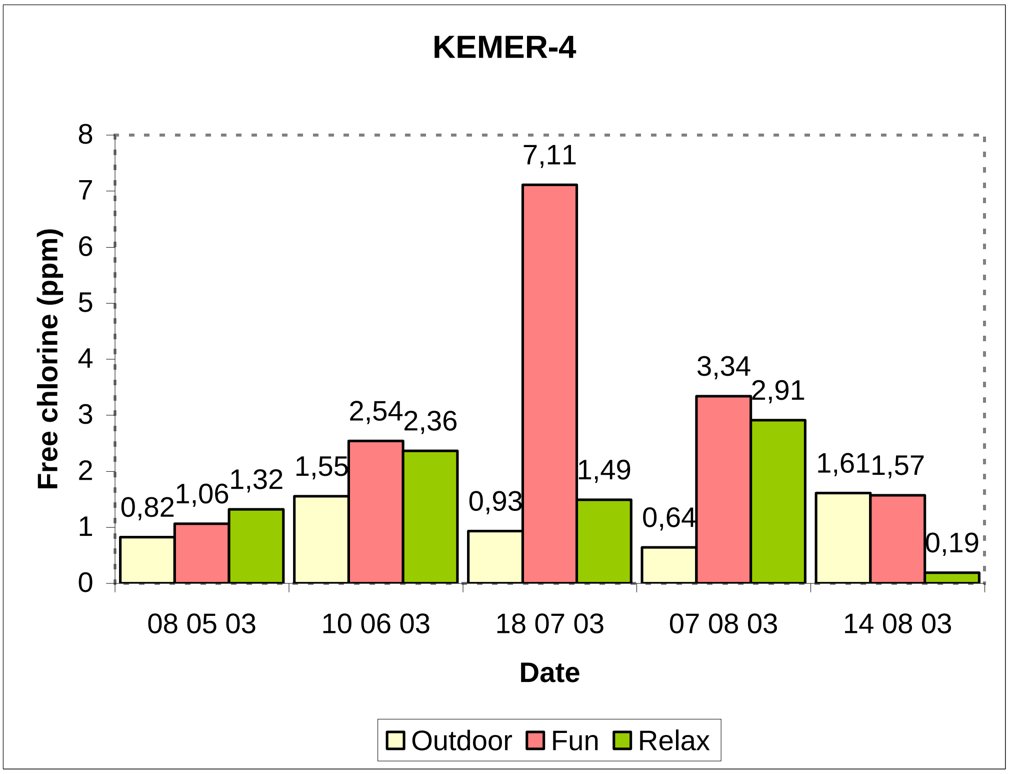


Figure 5.22. Free chlorine-time variation at plant Kemer-4

As NSPI standards suggest free chlorine concentration to be between 1-3 mg/l, generally all of the measurements seem to be in limit ranges. However, the value obtained for fun pool at 18.07.2003 is extremely high. The possible reason for this situation is that shock chlorination process was applied. Also, the decrease observed in the combined chlorine level in this pool for the same day supports this thesis.

5.4.6.3. Combined chlorine variation at plant Kemer-4

The change of combined chlorine with time in outdoor, relax and fun pools is shown at Fig. 5.23.

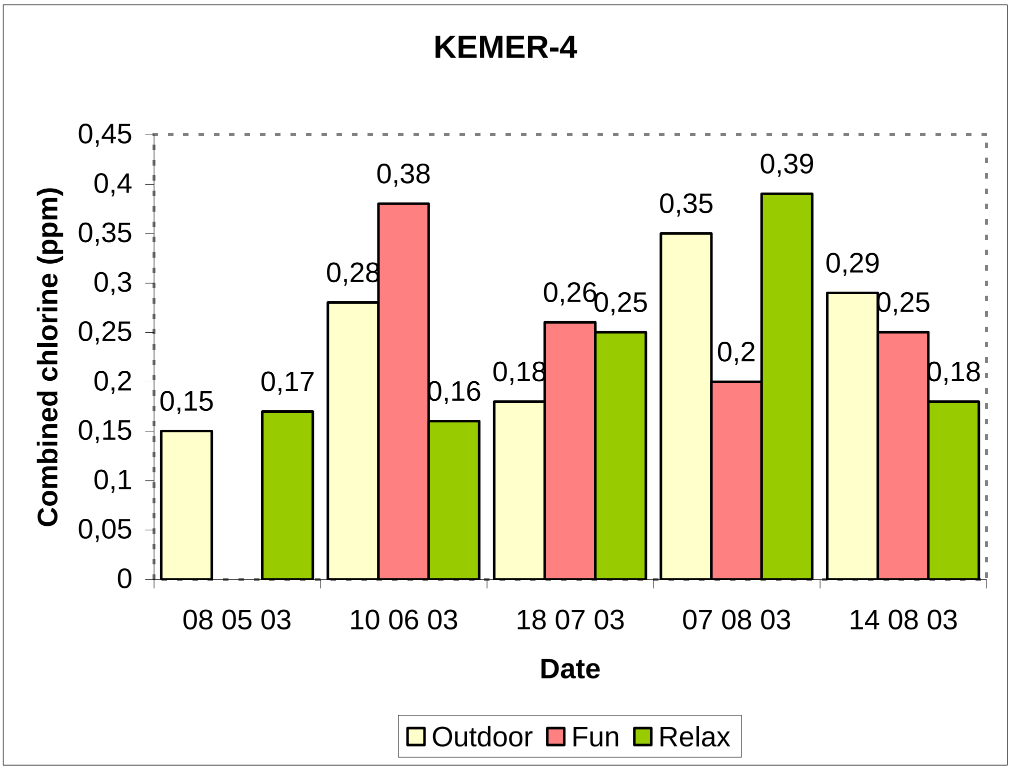


Figure 5.23. Combined chlorine-time variation at plant Kemer-4

Since the products of the chlorine reactions are responsible for most of the complaints of skin and eye irritation, concentration over 0.2 ppm is not desired. The measurements obtained for all of the pools at all dates are appropriate. This indicates that pools are operated successfully.

5.4.6.4. Cyanuric acid variation at plant Kemer-4

The change of cyanuric acid concentration with time in outdoor, relax and fun pools is shown at Fig. 5.24.

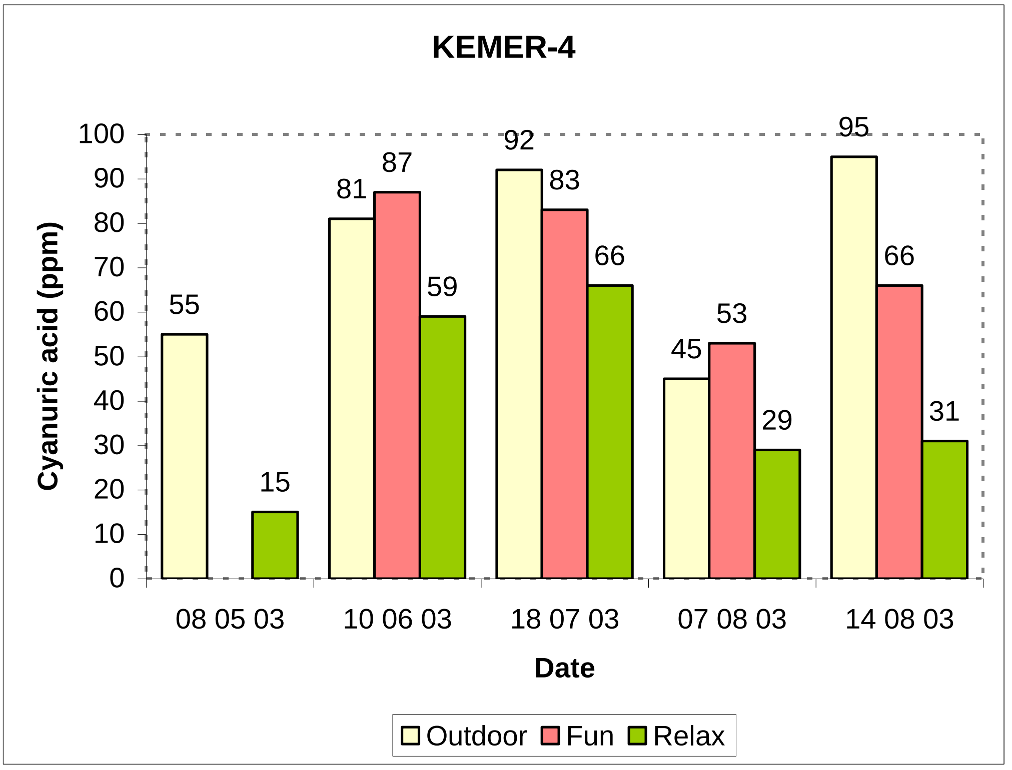


Figure 5.24. Cyanuric acid-time variation at plant Kemer-4

According to NSPI standards cyanuric acid concentration should be below 150 ppm. Considering this criteria it was observed that cyanuric acid concentrations were under limits in all of the pools at all dates.

5.4.7. Plant Marmaris-1

There are two pools named as relax and fun in this plant. Stabilized chlorine is being used as the disinfectant.

The volume of the fun pool is 550 m^3. It has a balance tank of 50 m^3. The water circulation flow is 100 m^3/h. Sand filters are used and the entrance is reported as 400 persons/day.

The volume of the relax pool is 400 m^3. It has a balance tank of 20 m^3. The water circulation flow is 60 m^3/h. Sand filters are used and the entrance is reported as 150 persons/day. An important point that should be taken into account about this pool is that there is a water loss of 100 m^3/day because of construction

5.4.7.1. pH variation at plant Marmaris-1

The change of pH with time in relax and fun pools is shown at Fig. 5.25.

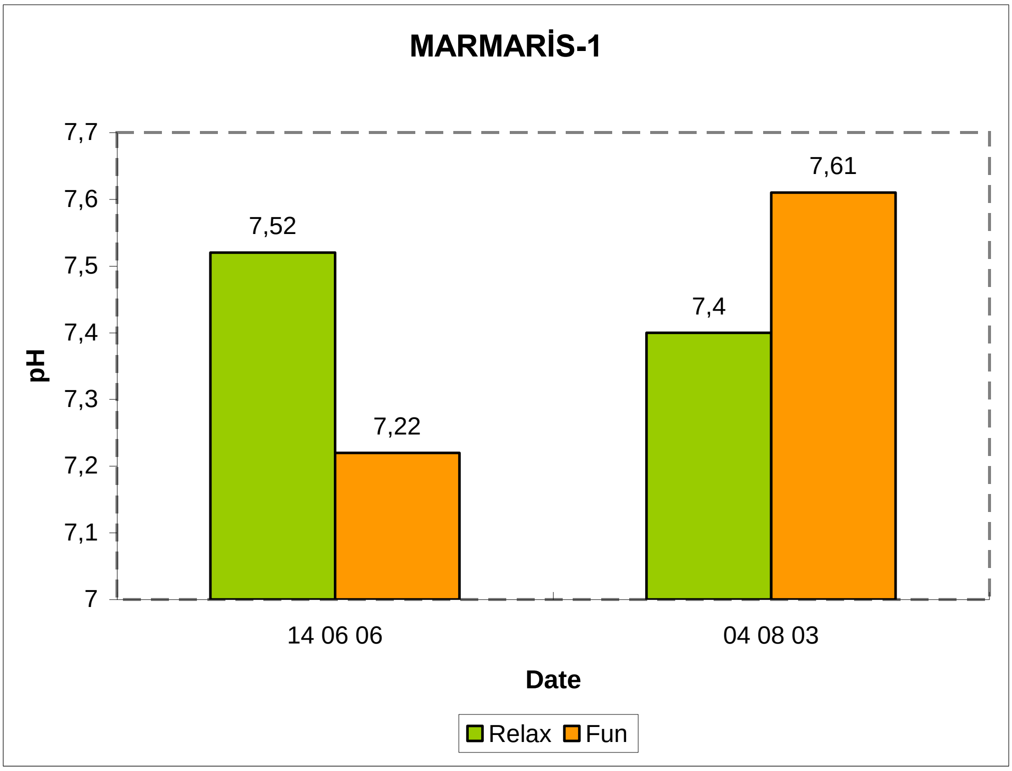


Figure 5.25. pH-time variation at plant Marmaris-1

The pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. All of the pH measurements are between desired limits in all of the pools at all dates. This indicates good operation of the pools.

5.4.7.2. Free chlorine variation at plant Marmaris-1

The change of free chlorine with time in relax and fun pools is shown at Fig. 5.26.

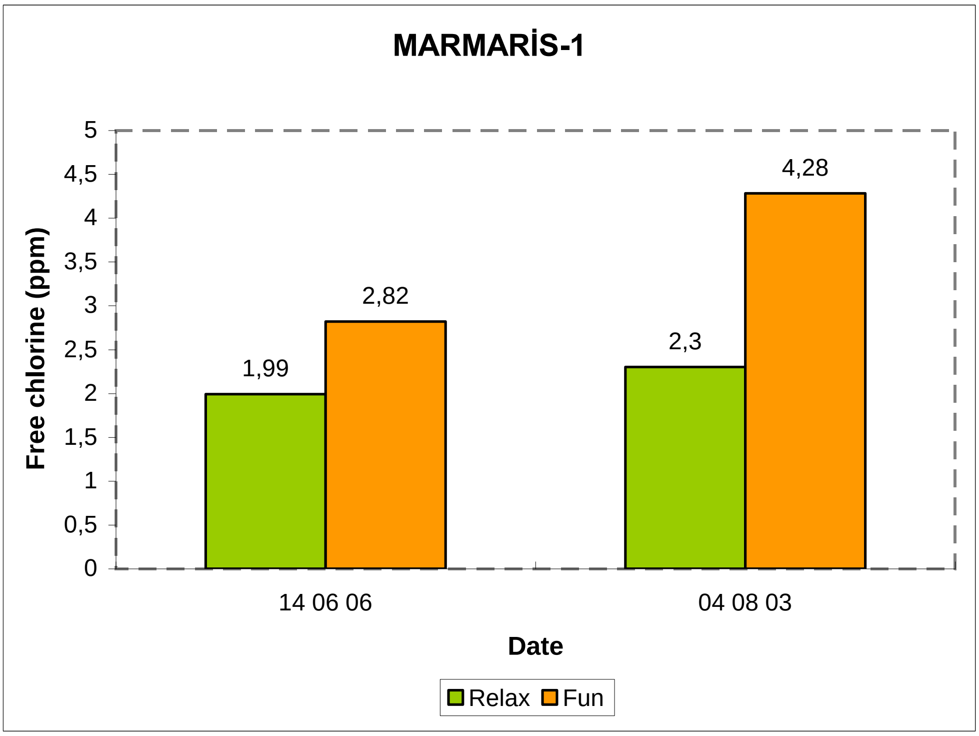


Figure 5.26. Free chlorine-time variation at plant Marmaris-1

As NSPI standards suggest free chlorine concentration to be between 1-3 mg/l, generally all of the measurements seem to be in limit ranges. However, the value obtained for fun pool at 04.08.2003 is high. The possible reason for this situation is that shock chlorination process was applied.

5.4.7.3. Combined chlorine variation at plant Marmaris-1

The change of combined chlorine with time in relax and fun pools is shown at Fig. 5.27.

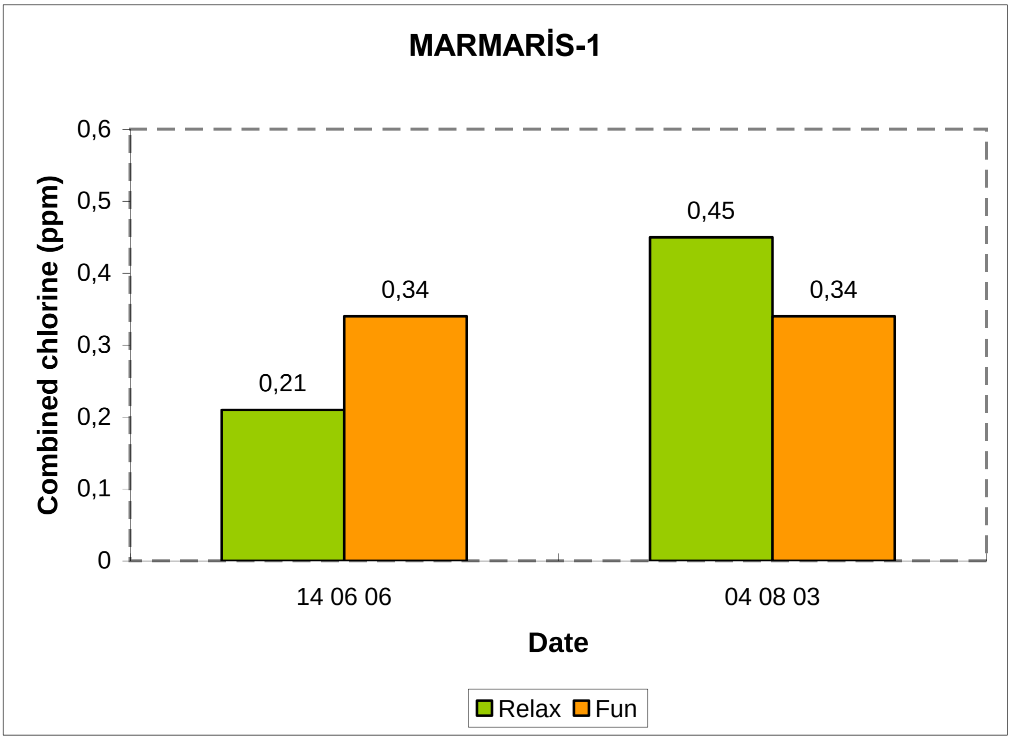


Figure 5.27. Combined chlorine-time variation at plant Marmaris-1

Since the products of the chlorine reactions are responsible for most of the complaints of skin and eye irritation, concentrations over 0.2 ppm is not desired. The measurement performed in the relax pool at 04.08.2003 is over the limits so breakpoint chlorination should be applied.

5.4.7.4. Cyanuric acid variation at plant Marmaris-1

The change of cyanuric acid concentration with time in relax and fun pools is shown at Fig. 5.28.

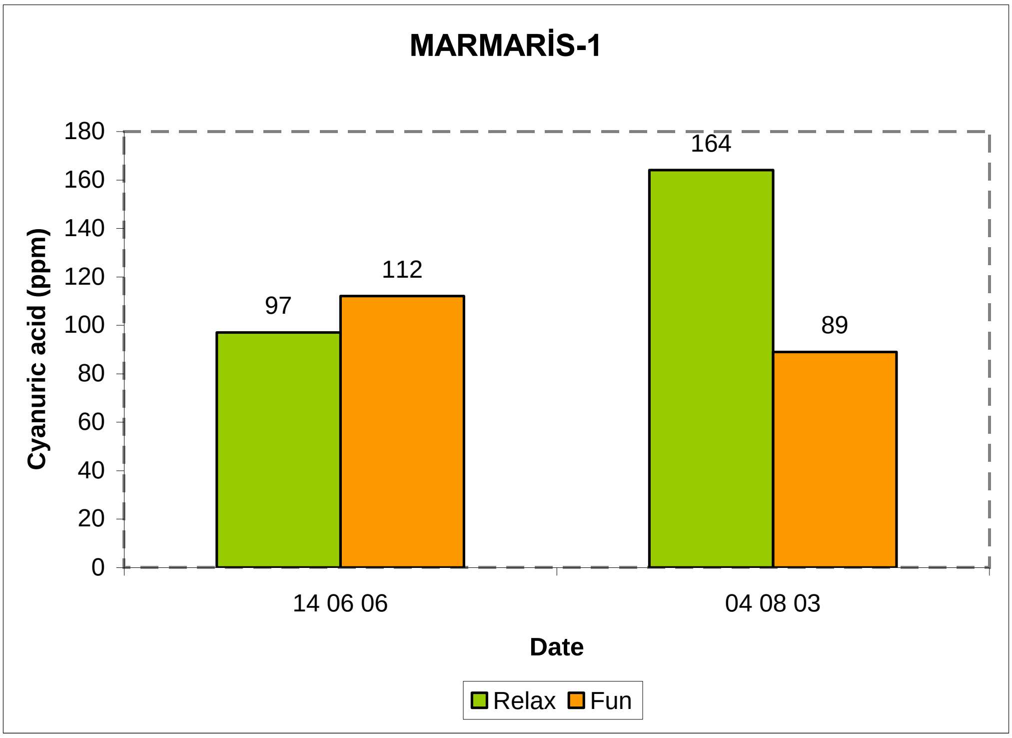


Figure 5.28. Cyanuric acid-time variation at plant Marmaris-1

As explained above chlorine-lock usually occurs when the concentration of cyanuric acid in the pool water reaches levels of 150 mg/l and above. So it should be reduced by dumping some of the water and topping up with fresh water for the relax pool.

5.4.8. Plant Belek-2

There are four pools named as relax, indoor, outdoor and fun in this plant. Stabilized chlorine is being used as the disinfectant.

The volume of the fun pool is 1000 m^3. It has a balance tank of 50 m^3. The water circulation flow is 240 m^3/h. Sand filters are used and the entrance is reported as 750 persons/day.

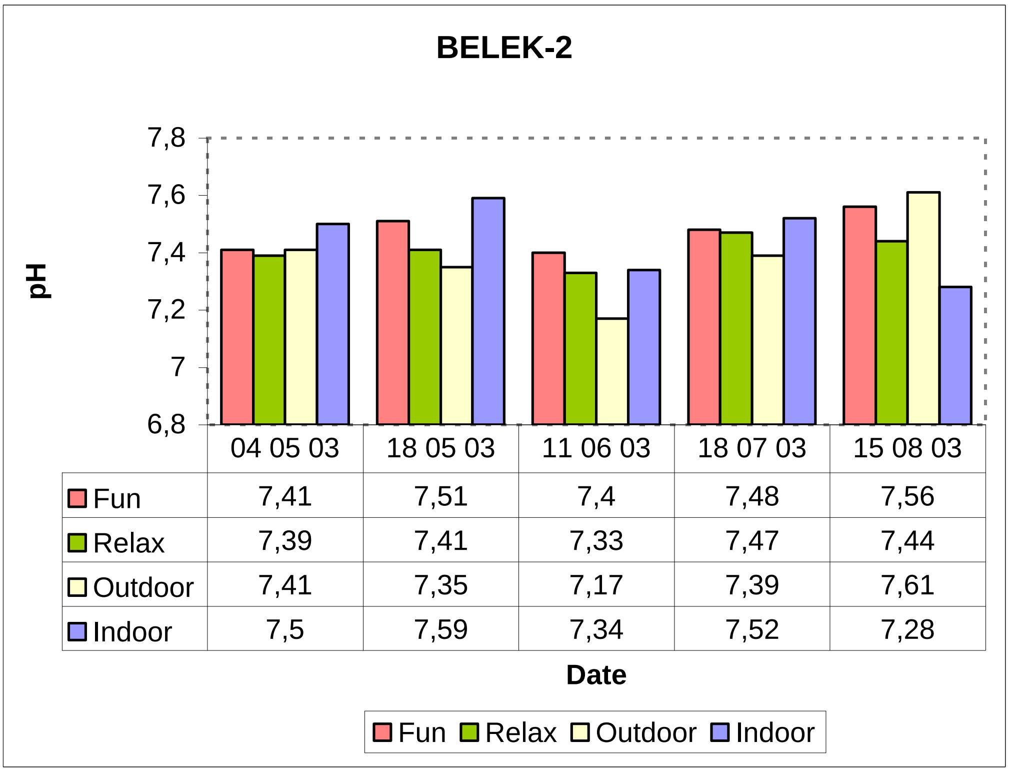
The volume of the relax pool is 1000 m^3. It has a balance tank of 50 m^3. The water circulation flow is 200 m^3/h. Sand filters are used and the entrance is reported as 600 persons/day.

The volume of the indoor pool is 150 m^3. It has a balance tank of 10 m^3. The water circulation flow is 30 m^3/h. Sand filters are used and the entrance is reported as 70 persons/day.

The volume of the outdoor pool is 1000 m^3. It has a balance tank of 50 m^3. The water circulation flow is 210 m^3/h. Sand filters are used and the entrance is reported as 850 persons/day.

5.4.8.1. pH variation at plant Belek-2

The change of pH with time in relax, fun, outdoor and indoor pools is shown at Fig. 5.29.



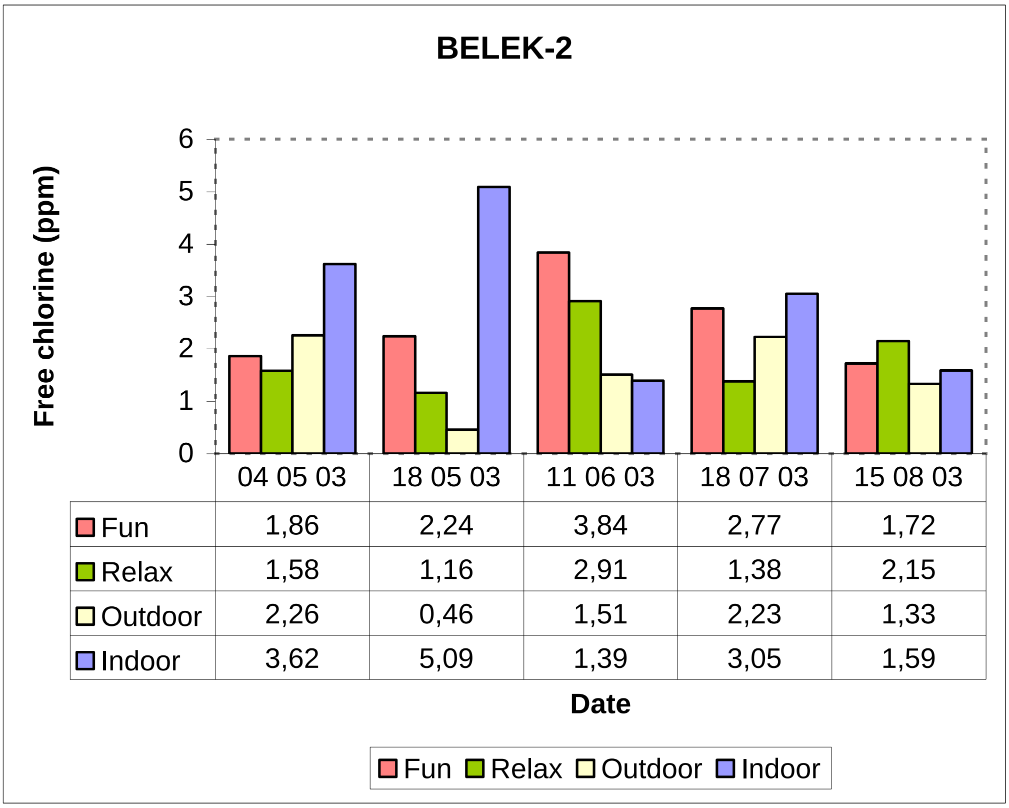
	04 05 03	18 05 03	11 06 03	18 07 03	15 08 03
Fun	7,41	7,51	7,4	7,48	7,56
Relax	7,39	7,41	7,33	7,47	7,44
Outdoor	7,41	7,35	7,17	7,39	7,61
Indoor	7,5	7,59	7,34	7,52	7,28

Figure 5.29. pH-time variation at plant Belek-2

The pH value should be maintained at between 7.2 and 7.6 with the target being 7.3 to 7.5, as disinfection will be more effective. All of the pH measurements are between desired limits in all of the pools at all dates. This indicates that pools are operated properly.

5.4.8.2. Free chlorine variation at plant Belek-2

The change of free chlorine with time in relax, fun, outdoor and indoor pools is shown at Fig. 5.30.



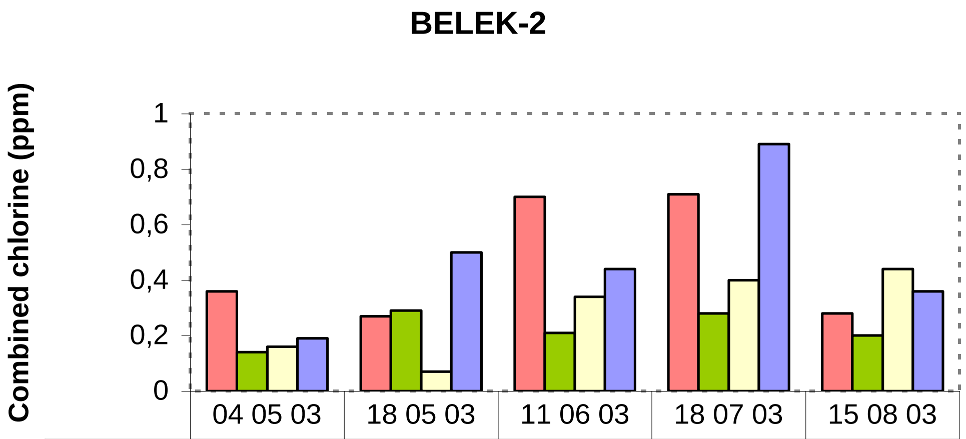
	04 05 03	18 05 03	11 06 03	18 07 03	15 08 03
Fun	1,86	2,24	3,84	2,77	1,72
Relax	1,58	1,16	2,91	1,38	2,15
Outdoor	2,26	0,46	1,51	2,23	1,33
Indoor	3,62	5,09	1,39	3,05	1,59

Figure 5.30. Free chlorine-time variation at plant Belek-2

As NSPI standards suggest free chlorine concentration to be between 1-3 mg/l, generally all of the measurements seem to be in limit ranges. However, the value obtained for indoor pool at 04.05.2003 is high. The possible reason for this result is that shock chlorination process was applied soon. Similarly, the free chlorine concentration measured in the indoor pool at 18.05.2003 is high. Again shock chlorination process might have caused this, but it is clear that the process was not successful enough because combined chlorine level is still 0.5 ppm. The same situation is valid for the measurement obtained at 11.06.2003 in the fun pool.

5.4.8.3. Combined chlorine variation at plant Belek-2

The change of combined chlorine with time in relax, fun, outdoor and indoor pools is shown at Fig. 5.31.



	04 05 03	18 05 03	11 06 03	18 07 03	15 08 03
Fun	0,36	0,27	0,7	0,71	0,28
Relax	0,14	0,29	0,21	0,28	0,2
Outdoor	0,16	0,07	0,34	0,4	0,44
Indoor	0,19	0,5	0,44	0,89	0,36

Figure 5.31. Combined chlorine-time variation at plant Belek-2

Since the products of the chlorine reactions are responsible for most of the complaints of skin and eye irritation, concentrations over 0.2 ppm is not desired. The measurements performed in both fun and indoor pools at 11.06.2003 and 18.07.2003 are over the limits so breakpoint chlorination should be applied. Similarly, there is a tendency to increase is observed in the outdoor pool at 15.08.2003 so breakpoint chlorination should be applied to decrease the level.

5.4.8.4. Cyanuric acid variation at plant Belek-2

The changes of cyanuric acid concentration with time in relax, fun, outdoor and indoor pools are shown at Fig. 5.32.

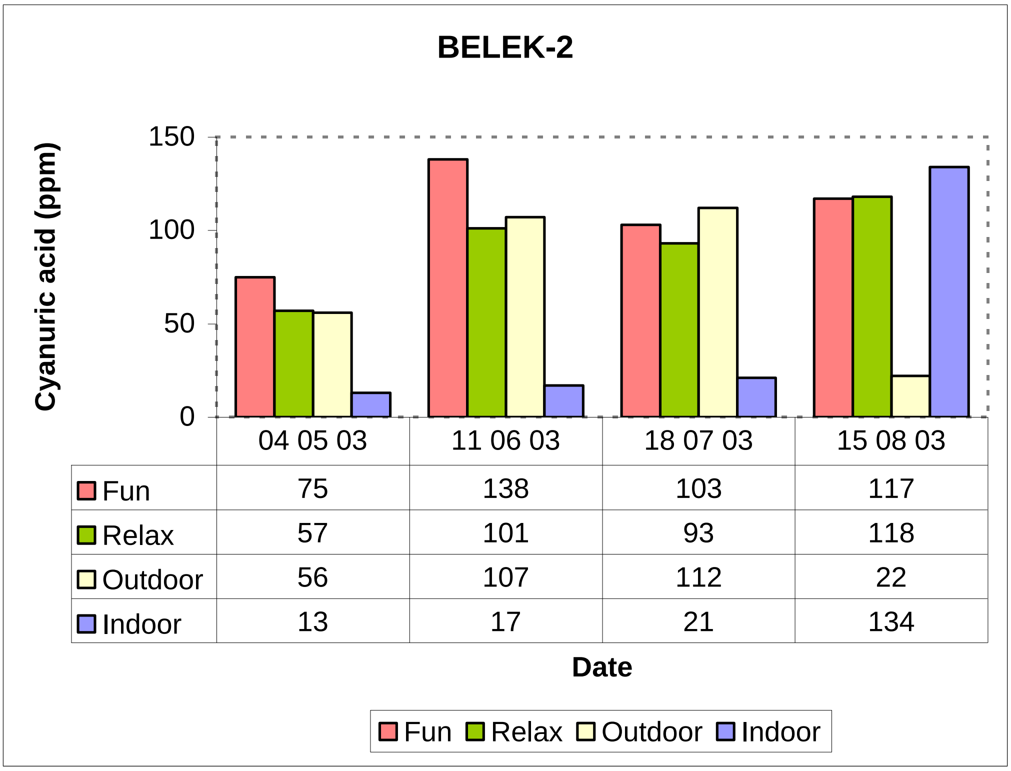


Figure 5.32. Cyanuric acid-time variation at plant Belek-2

According to NSPI standards cyanuric acid concentration should be below 150 ppm. Considering this criteria it was observed that cyanuric acid concentrations were under limits in all of the pools at all dates.

5.5. Results of Microbiological Analyses

In order to check the microbial quality of pool water samples, some of them were sent to a private laboratory. Samples were taken at different time periods and analysed immediately for *Fecal coliform*, *Esheria coli*, *Fecal streptococci*, *Salmonella* and *Pseudomonas aeuroginosa*. Table 5.? presents the results of microbiological analyses performed for Plant-1 located in Antalya.

Table 5.? Microbiological quality of swimming pool water of Plant-1

Date	20.05 2003	04.06 2003	16.06 2003	07.07 2003	21.07 2003	24.07 2003	11.08 2003
Fecal coliform	ND	ND	ND	ND	ND	ND	ND
Escheria coli	ND	ND	ND	ND	ND	ND	ND

Fecal streptococci	ND	ND	ND	ND	ND	ND	ND
Salmonella	ND	ND	ND	ND	ND	ND	ND
PseudomoNDs aeuroginosa	ND	ND	ND	ND	ND	ND	ND

ND: Not detected

However, fungi has been detected in samples taken from

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