A GUIDE TO SWIMMING POOL MAINTENANCE AND FILTRATION SYSTEMS

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An Instructional Know-How on Everything You Need to Know About Swimming Pools

E T Chan

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Foreword

As a sports enthusiast, I grew up playing a number of sports and naturally took an affinity to swimming. During those times, there were no swimming pools — it was the open seas, big flooded drains and sometimes murky rivers.

When I later became the Director of Facilities with the Singapore Sports Council, it coincided with the 'Sports for the masses' policy and campaign. I then had to lead in the formulation of the overall Master Plan for sports facilities in Singapore, which of course, included swimming pools for dedicated housing development areas. We did research, made study trips and engaged consultants — to design and construct swimming complexes, not only for recreational swimming for the masses but also for competitions, including meeting international competition standards. I wished then that I had a reference book that could take us through the complexities of pool construction.

My team and I spent many years, learning on the job, improving and perfecting the designs — for better and more efficient maintenance and operations of swimming pools.

Mr Chan Eng Teck, the author of this book, has had more than 30 years of experience in the construction and maintenance of swimming pools.

It is very noteworthy that he decided to pen down his life's work, experience and knowledge. It is invaluable for architects, engineers and pool maintenance technicians.

The book is clear, concise and presented in a very comprehensible manner. It serves as an excellent guide book for professionals involved in swimming pool designing, construction and maintenance. It contains details covering the required mechanical and electrical engineering as well as the application of swimming pool filtration system designs and analyses — in solving most of the practical but rather complex problems faced by the professionals in this industry.

Presently, consultants are appointed through a procurement procedure or public tender. Often, previous experienced consultants do not get reappointed again; there may be a problem in consistencies of standards without an 'official' reference.

This 'reference' book is thus, timely and invaluable in serving its purpose.

YEE WENG PHEI

Preface

When I first started business in this niche market more than 30 years ago, I conducted daily in-house training for my staff. I explained how equipment and piping had to be installed and why they had to be installed in a certain way to facilitate maintenance and for ease of operations. In those days, skilled labour was scarce and technical know-how was poor. The staff had benefitted immensely from these trainings and we were able to set the installation standards for others to follow.

In this book, I set out to put on record the experience and knowledge that I had garnered through these years. Some of the statements, opinions, events and observations mentioned and expressed in this book are frank and blunt, but bear no malice or mischief, with no intention to cause harm to any parties or to grind any axes. It is my fervent hope that readers can learn something from these experiences.

I am often appalled by the poor standards of installations that I was fortunate to have witnessed around the world and in Singapore. Such poor installations demonstrate that these installers, so proudly calling themselves “specialists”, are not taking their work seriously. To excel in any field, you must take pride in your work.

The commercial swimming pool market is relatively small as compared to other products. Most original pool equipment manufacturers for domestic pools are from Europe and USA. As China becomes the factory to the world, copies of these products from China are not uncommon. Due to the low commercial value and market size, the Japanese manufacturers do not seem to show much interest in this field.

Through these years, there has not been much innovation in the swimming pool industries, except for the disinfection process where ozonation is introduced in some countries, particularly in Germany, France and Switzerland. The additions of water features and interactive water play equipment to liven up the pool as a children's playground are the latest craze.

A few years ago, an acquaintance, a one-man operation, swimming pool service man, invited me to visit his store in a rented terrace house in Singapore. The car park porch of this house was converted for equipment storage.

On entering the premises, I was amazed by the quantity of used filters and pumps stacked in the store. Most of those used filter shells and pump housings were still in relatively good condition. My unscrupulous host bragged that he had managed to convince his unwary customers to replace them instead of having them repaired. As I left the premises, I felt a great sense of sadness and remorse for his clients.

Most of the equipment I had seen in this store could still provide years of useful service. Only the spider gaskets of the multi-port valves of the FRP filters had needed to be replaced to enable them to be put back to useful service. For the pumps, probably the mechanical seals would need to be replaced or the motors need to be rewound to enable them to be operational again.

Such unscrupulous swimming pool servicemen are a-plenty in the local swimming pool industry. They provide very low prices to maintain swimming pools, but schemed to increase their income with maintenance repairs and replacements. Most of these swimming pool servicemen have elementary technical knowledge of the filtration systems and the equipment. Their knowledge of pool water chemistry is confined only to chlorine addition and maintaining the pH of the pool water.

Probably, the pool owners deserved to be taken advantage of. They have selected the company or person, many swimming pool servicing companies in Singapore are one-man outfits offering the lowest price to maintain their pools, without due consideration of the other factors in the purchasing process. They leave the options of when and what ought to be done to the maintenance personnel.

Maintenance of the heart of the swimming pool -– the filtration equipment, and the other elements of pool water chemistry are forgotten as long as the pool water is not greenish and appears clean.

Through these years, I have also the privilege to witness both overly and under-sized filtration plant rooms that are sometimes even forgotten for its provision by the project architect. In every corner of the world, space is money in terms of land and construction costs. Many of our local engineers do not have the faintest idea of how to size a proper filtration plant room. Swimming pool drawings prepared for tenders are sub-standard.

It is the aim of this book to provide a clear concept to size every piece of equipment of the swimming pool filtration system including the sizing of the filtration plant room. It is my fervent intention to impart to those interested in this field some of the knowledge and experiences that I have accrued through these years.

The purpose of this book is to provide some fundamental ideas in the planning, design, maintenance and operation of swimming pools. Most of the information reflects the practices in Singapore. For other countries, local codes, formulae and methods should take precedence where a difference in opinion exists.

Although most of the information provided in the book reflects the practices in Singapore, it is also extremely relevant in countries that construct and maintain similar pools.

1: Introduction

Pool owners and operators often ponder about the causes of tiles detaching from the walls and floors of their swimming pools. Most will allude to these episodes as poor construction workmanship rather than failures to maintain correct pool water chemistry. Bathers are also often bewildered to find cuts inflicted on their hands and feet after their outings to swimming pools. Such obscure issues are explicitly unraveled and analysed in this book (see Chapter 12).

Swimming pool facilities provided must be well designed and maintained to benefit the users as otherwise they can be a vehicle for the breeding of water-borne diseases, inflicting unnecessary illnesses and injuries to the patrons. The best equipment installed will be rendered useless if the swimming pools and pool water chemistry are not correctly and properly maintained.

This book sets out the steps and procedures to ensure the filtration systems are properly and correctly designed. It enables readers to have a better understanding of every piece of equipment as illustrated by the author's experience and actual events. Concise explanations are provided on the importance of maintaining proper pool health (see Chapter 12) so as not to incur high repair and replacement costs.

Swimming is one of the most beneficial exercises, an effective and invaluable aid in muscular development, especially for those with physical limitations and for those who find other forms of exercise painful.

Water's buoyancy accommodates the fit as well as the unfit. Water cushions stiff joints or fragile bones that might be injured by the impact of land exercises.

According to Archimedes' principle, when a person is immersed in the pool water to the waist, 50% of his weight is displaced, immersed to the chest 65% to 75% of his weight is displaced, and to the neck

90% of his weight is displaced. This displacement of water by swimmers needs to be factored into the design of the pool circulation and filtration systems (see Chapter 9).

Construction of a Public Aluminium Pool
Figure 1-1

A swimming pool is a watertight receptacle containing circulated chlorinated water for recreation or training purposes. It can be of any shape and size. When they are of irregular shape they are termed as free-formed.

This receptacle can be fabricated with any material such as reinforced concrete, fibreglass, vinyl, acrylic, aluminium, stainless steel or any material that is structurally sound and water-tight. Ideally, to minimise and contain maintenance costs, the material of construction of the receptacle and all its related equipment should be capable of withstanding the corrosive environment. Figure 1-1 depicts an aluminium swimming pool under construction.

In non-earthquake zone countries, concrete pools are very common. Concrete, unless specially designed, will crack when subject to tremors. For this reason, a lot of swimming pools in Japan are fabricated with fibreglass, aluminium and stainless steel as they are more flexible and are good seismic structures. Figure 1-2 presents the completed aluminium pool. The biggest disadvantage of aluminium pools is the poor paint adherence. With advancement in technology, stainless steel swimming pools panels are laminated with PVC.

Public pools built by the government and country clubs provide inexpensive recreational activities and enable users to maintain their physical fitness. If a swimming pool is to be built for public use, its intended use should be the primary consideration for the designer as the depth of the pool to be constructed will vary with use. Will the pool be used for competition or strictly for leisure? If it is a training pool, will the pool be strictly used for training of swimmers or will it be used for training of water polo players? If a pool is designed for diving, it must have a certain depth for the safety of the divers. A swimming pool meant for water polo training must have, within the pool, a pool area of 30 metres length by 20 metres width with a minimum depth of 1.8 metres throughout the play area.

To comply to FINA (Federation Internationale De Natation Amateur) standards, an Olympic-size pool must be built with a nominal length of 50.0 metres with a tolerance of plus 0.03 metre minus 0.00 metre on both end walls at all points from 0.3 metre above to 0.8 metre below the surface of the water. Otherwise, swimming records set in the pool will not be recognised. For a half Olympic-size pool, the nominal length must be 25.0 metres with a tolerance of plus 0.02 metre minus 0.00 metre on both end walls at all points from 0.3 metre above to 0.8 metre below the surface of the water, with a depth of not less than 1.0 metre.

Completed Public Aluminium Pool
Figure 1-2

Residential pools are usually built to enhance the value of the property. Pools built in condominiums are intended for the identical reason. Residential pools are available as above-ground, part-in-ground or part above-ground or permanent-in-ground construction. Above-ground pools are not subject to municipal regulations as they are considered as movable properties. The other types of pool to be installed are subject to local municipal regulations. These regulations vary in every country.

Many types of proprietary-make swimming pools are available in the pool market. Many factors influence would-be residential pool owners on the selection of the type of pool. These factors include:

1. Space availability —— this will determine the size of the pool to be built;
2. Total investment and maintenance costs —— many would-be pool owners are unduly worried about the high cost of operation and maintenance;

3 Objective of pool ownership. Is it for the enhancement of the value of the property or for exercising? Is the pool meant for swimming only, or for swimming and diving;

4 Site conditions —— load bearing capacity of the site and the type of soil (sandy site will make guniting of concrete pool difficult);

5 Materials of construction of the pool;

6 Local regulations governing pool ownership;

7 Reputation of pool supplier or builder.

Most countries have their own building regulation and codes of practice regarding the building of swimming pools. The municipal code of practices is not a living bible to be adhered to naively and rigidly. The principal consideration should be the ability of the filtration systems to cope with the varying bathing loads.

Residential Skimmer-type Pool
Figure 1-3

In Singapore, swimming pools are classified under two broad categories. A swimming pool will be considered as a public or commercial pool if it is to be used by more than one family. Otherwise, it is termed as a residential pool. A public pool must be licensed with our Environmental Health Department (EHD). To license a swimming pool, the following must be complied with:

1. The “level-deck or surflo” circulation filtration system must be adopted. In this system, treated water enters the pool through inlet nozzles positioned in the pool floor. Contaminated water is drawn-off mainly at the surface using a high capacity scum drain. The pattern of recirculation is essentially upflow. A balancing tank is required between the scum drain channel and the circulating pumps. The swimming pool water level in surflo circulation system is similar to the pool deck. Skimmer-type filtration system is only permitted for residential pools. In the skimmer-type filtration system, the swimming pool water level is lower than the pool deck by about 150 millimetres as shown in Figure 1-3.
2. Shower and toilet facilities must be provided around the pool.
3. The turnover period for the main and children pools must not exceed 6 and 2 hours respectively. For a residential pool, the turnover period can be 8 hours or more.
4. A standby filter and circulation pump, either 50% or 100%, are required.
5. A proper chemical dosing system must be installed. For residential pools, chemicals can be manually dosed.
6. A proper daily record of the chlorine and pH level of the pool water must be maintained in the filtration plant room. Chlorine level in the pool water must be maintained between 1.0 and 3.0 ppm. The pH of the pool water must be maintained between 7.2 and 7.6.

7 Water sampling taps must be provided to the inlets and outlets of the filtration system.

8 Life buoys, pool rules, resuscitation chart and first aid kit must be provided around the pool.

9 For the safety of bathers, visible depth markers, at both sides of the swimming pool, must be provided at every change of depth of the pool.

10 Monthly water samples must be submitted to an EHD accredited laboratory to test the chlorine and pH level and for coliform and Escherichia coli count. One copy of the tests results will be mailed directly by the laboratory conducting the tests to EHD for their perusal and record.

11 The pool owner has to pay a yearly fee, currently at S$120.00, for the pool licence.

12 EHD is empowered to close the pool if the water samples fail repeatedly, or complaints are received from pool users.

From the above Singapore's EHD's requirements, it is important to note that it is essential to test for coliform and Escherichia coli count in the pool water. The consumption of contaminated water can cause bathers to become ill. Communicable disease can be spread by swallowing or having contact with contaminated water in swimming pools.

The greatest folly of Singapore's EHD is not requiring the water of interactive-water-play features to be submitted for coliform and Escherichia coli count. Such water poses the greatest risks and dangers for the spreading of water-borne diseases.

A few years ago, we installed a swimming pool filtration system to an exclusive high-end condominium in a prime Singapore area. To our dismay and disbelief, the uncouth residents enjoyed hurling their faeces into the swimming pool from their high-rise apartments. It was not a rare one-off incidence, but on more than six occasions during the defects-liability period of our one-year maintenance.

Bird droppings and people ill with diarrhea can contaminate pool water. The residual faeces on bottoms of average bathers can contaminate recreational pool water. A speck of stool of a person ill with diarrhea can contain millions of germs. If bathers swallow water that has been contaminated, they may become sick.

I am sure some of the readers must have witnessed disgusting behaviours of swimmers spitting, clearing their noses and young parents permitting their toddlers to pee into the overflow drains of swimming pools instead of doing it in the toilets. A lot of public behavioural education needs to be conducted on proper and correct usage of communal facilities. Posters of “Do not pee into the pool” or “Do not swim in your toilets” should be prominently displayed in all swimming complexes.

Many water-borne diseases can threaten the health and comfort of swimming pool users. Bathers can become ill by swallowing just a little of the contaminated water. Water-borne illnesses are commonly caused by swallowing, breathing mists or aerosol of or having contact with contaminated water in swimming pools. The most commonly reportedly water-borne illness is diarrhea. The list of communicable water-borne diseases includes the following:

- Escherichia coli which causes diarrhea ranging from mild non-bloody stools to those that are virtually blood.
- Hepatitis A which is caused by a virus that does not respond to antibiotics. Injections of gamma globulin may be given to those persons who have been in close and prolonged contact with a patient with hepatitis A.
- Giardiasis is an infection caused by protozoan Giardia lamblia and is associated with swallowing contaminated water. This disease causes a swelling of the abdomen, nausea, vomiting, burping, diarrhea, weakness and weight loss.
- Leptospirosis which is a zoonotic bacterial disease characterised by fever, chills, jaundice, severe myalgia, rash

and haemorrhage into the skin or mucous membranes. Treatment with antibiotics, such as penicillin, may be effective but only if administered in the early stages of the disease. Care should be taken when disposing of the patient's urine to prevent spread of bacteria.

- Shigellosis is acquired by swallowing contaminated pool water causing fever, diarrhea, nausea, vomiting and abdominal pain. Hospitalisation and isolation are required.

- Pseudomonas causes skin infections, pneumonia, endocarditis, or urinary infections. The bacteria thrive in hot spas as heat breaks down the disinfection ability of pool chemicals.

Proper and correctly designed swimming pool filtration systems together with optimally-sized disinfection equipment can prevent the above water-borne diseases. Designers can assist to provide a "healthy swimming" facility by incorporating in their designs the following:

- Installation of automatic chemical dosing systems to maintain and ensure correct chemical dosages (see Chapters 4, 5, 6 and 12).

- Installation of supplementary, optimally-designed, in-line disinfection such as ultraviolet sterilisers and ozonators (see Chapter 6).

- Avoid co-filtering pools (see Chapter 7).

- Installation of circulation pumps, piping and filters to reduce the turnover period of pools to less than the requirements of municipal codes of practice to cater to the bathing loads. A drop of black ink in a large volume of water will not be noticeable but will blacken a spoonful of water (see Chapters 2, 4, 7 and 13).

- Provide adequate and easily accessible toilet facilities.

- Provide proper ventilation for indoor facilities (see Chapter 8).
- Ensure facilities will not cause suction injuries (see Chapter 10)

M/s Maytronics Australia Pty Ltd has contributed an article on drowning prevention technologies (see Chapter 16) to the book. The manufacturer stresses that the drowning detection system is to assist the lifeguards in their duties not to replace them.

For the safety of non-swimmers, there must not be an abrupt change of depth in the swimming pool. Proper and correct designs of public swimming pool filtration systems are of paramount importance to minimise the spread of infectious diseases and to provide a safe and healthy environment for all pool users.

It is the sole responsibility of swimming pool operators to provide clean and sanitised pools. Pool operators are also responsible to ensure their facilities do not pose "suction" risks causing unnecessary drownings.

This book provides the guide and answers to ensure a safe, sanitised and healthy pool.

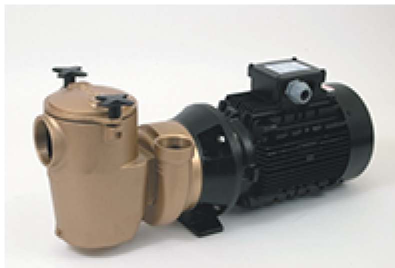
2: Principles of Swimming Pool Water Treatment

Treatment of swimming pool water is the most basic as the water has been treated and purified by the local water authorities to meet the World Health Organisation (WHO) standards for drinking water. Impurities in swimming pools are usually introduced by bathers, washed by rain from the atmosphere, or carried by wind into the water. Different treatments are required to remove or reduce these impurities to acceptable limits. The treatment of the water to higher purity will incur greater costs.

Impurities present in swimming pool water in descending finer states are suspended, colloidal or dissolved. Different methods of treatment are required for their removal or reduction to acceptable limits.

Suspended solids washed in by rain are usually dust or soot and are easily removed by filtering. The common suspended impurities in swimming pool water are floating debris, leaves, insects, dead skin, cosmetic oil, algae, hair and lint. These floating impurities in the water can be easily removed by screening or straining. For level-deck swimming pool systems, strainers, usually fabricated with stainless steel, are provided at the overflow drain inlets to the balancing tank to trap the suspended impurities in the water returning to the filtration system for treatment. For a pool installed with a skimmer or skimmers, a strainer is an integral part of the fitting. All purpose-built swimming pool pumps, mainly used in private and some condominium pools, have a hair and lint strainer as an integral part of the pumps. This is for the protection of the pump, as well as to trap suspended impurities that have escaped the first coarse screening. Figure 2-1 shows a purpose-built all-bronze swimming pool pump. For most commercial pools, purpose-built strainers commonly called bucket strainers or strainer boxes are provided at the suction pipe or pipes connecting to the inlets of circulation pumps for similar duties.

The naked eye cannot see the finer particles, colloids, suspended in the pool water. The colloids impart colour to the water. Even if the circulation pump is not in operation, the colloids remain in suspension. To remove them, these colloids can be coalesced by chemicals to form bigger particles so that they can be removed by the filters. Aluminium sulphate or alum is usually used as a coagulant with sand filters to give improved clarity to the water.



Pahlen All-Bronze Pump
Figure 2-1 *(courtesy of Pahlen)*

Dissolved impurities introduced to the swimming pool water by bathers include perspiration, urine, nasal secretions, body cream and ointments. These are easily removed, if not by straining, then with chemical treatment.

Filtration is the most important operation applied daily in the swimming pool treatment system for mechanical separation. In spite of its importance, very few swimming pool dealers have a good knowledge of the liquid-solid filtration. Swimming pool filtration is a daily operation to separate a given quantity of suspended particles in the pool water through the filters at the lowest possible cost. The goal is to eliminate the unwanted particles to a specified degree or as much as possible from the pool water.

The efficiency and effectiveness of filtration depends on the size of the filter or filters, with the assistance of the circulation pumps to remove a given quantity of suspended solids at a fixed flow, pressure drop and efficiency. The filter and circulation pump sizes determine the cost of the initial capital outlay.

Selection of the type of filters to be used is greatly dependent on the availability of space for the filtration plant room and other economic considerations. The maxim that “the lower the initial capital outlay the higher will be the operating or maintenance costs” holds true in the selection of filters to be installed.

As described in Chapter 1, in Singapore, a swimming pool will be considered as a public or commercial pool if used by more than one family. Otherwise, it is classified as a residential pool. The turnover period — the time in which all the pool water is deemed to pass through the filters, for the main and children pools must not exceed six and two hours respectively. For a residential pool, the turnover period can be eight hours or more.

The expected bathing load is the deciding factor in determining the turnover period. Pools with small volumes of water, but high bathing loads such as spa pools or Roman baths, are known to have a turnover period of fifteen minutes. Lower turnover periods will require having to provide bigger filters and circulating pipe sizes.

Due to the corrosive nature of chemicals used for the treatment of swimming pool water, it is imperative to install all pipes and fittings, including the filter and fittings in the pool, to be corrosion resistant to prevent repetitive replacement costs. Corrosion of circulating pipes or filters will also result in loss of swimming pool water. Rust will also impart unsightly stains on pool floors and walls.

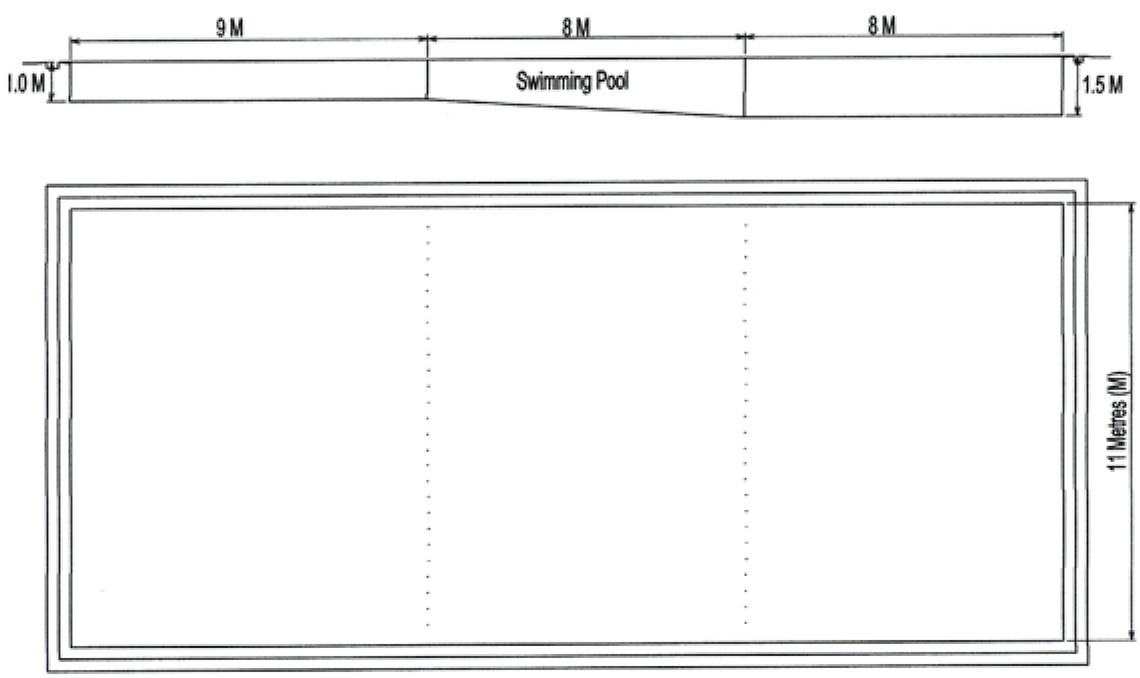
The removal of all suspended, colloidal and dissolved impurities and the extermination and elimination of all invisible contamination is the primary and ultimate aim of swimming pool water treatment.

3: Computation of Swimming Pool Volume

The volume of pool water is the fundamental information required to determine the size of the filtration system. This is similar to knowing the size of a room to determine the size of the air conditioner required to cool it. Should it require multiple room-size air conditioners or a central air-handling unit? Such analogous questions about the filtration system will be addressed in Chapter 4. The general equation for all volume calculations is:

$$\text{Volume} = \text{Surface Area} \times \text{Depth}$$

For a pool with varying depths, for accuracy of calculations, the depth should be the average depth of that section of the pool. For a regular-shaped pool, it is extremely easy to determine the volume of pool water. The drawing below shows a half-Olympic size pool measuring twenty-five metres (length) by eleven metres (width). The cross-sectional view shows the depth of the pool at different intervals.



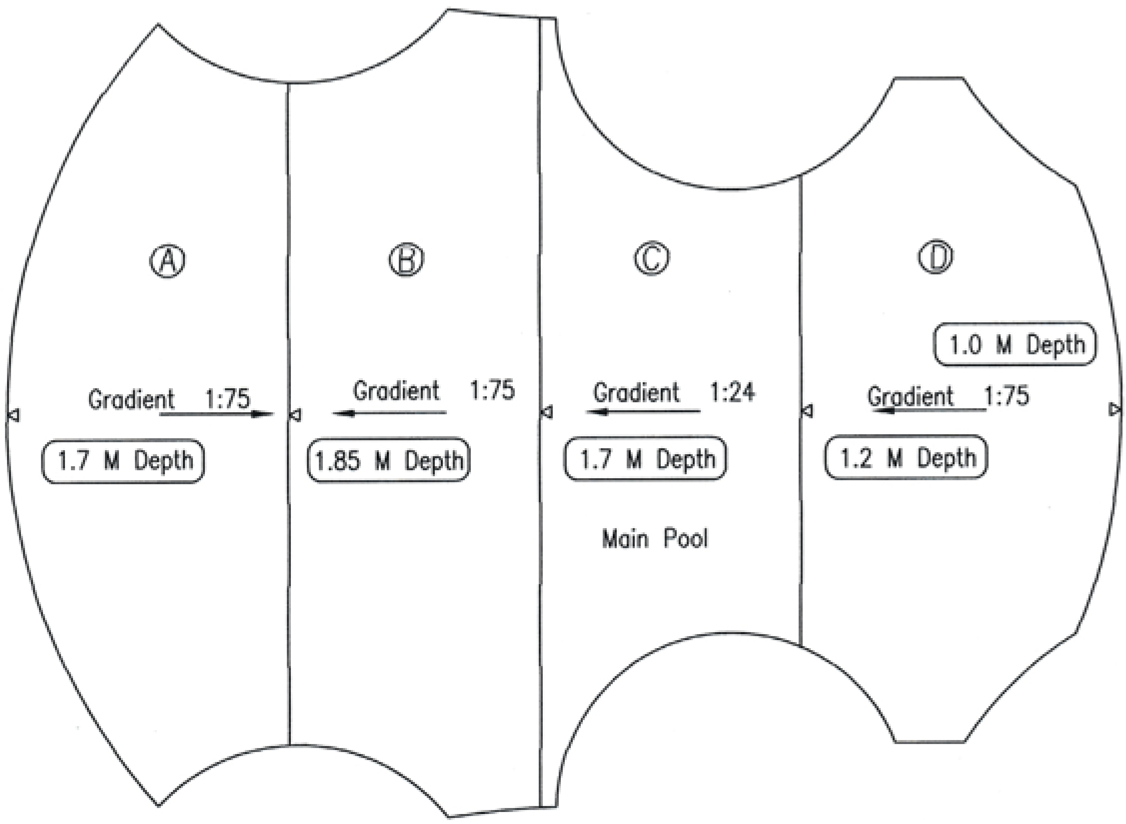
Drawing of Half-Olympic Size Pool

Figure 3-1

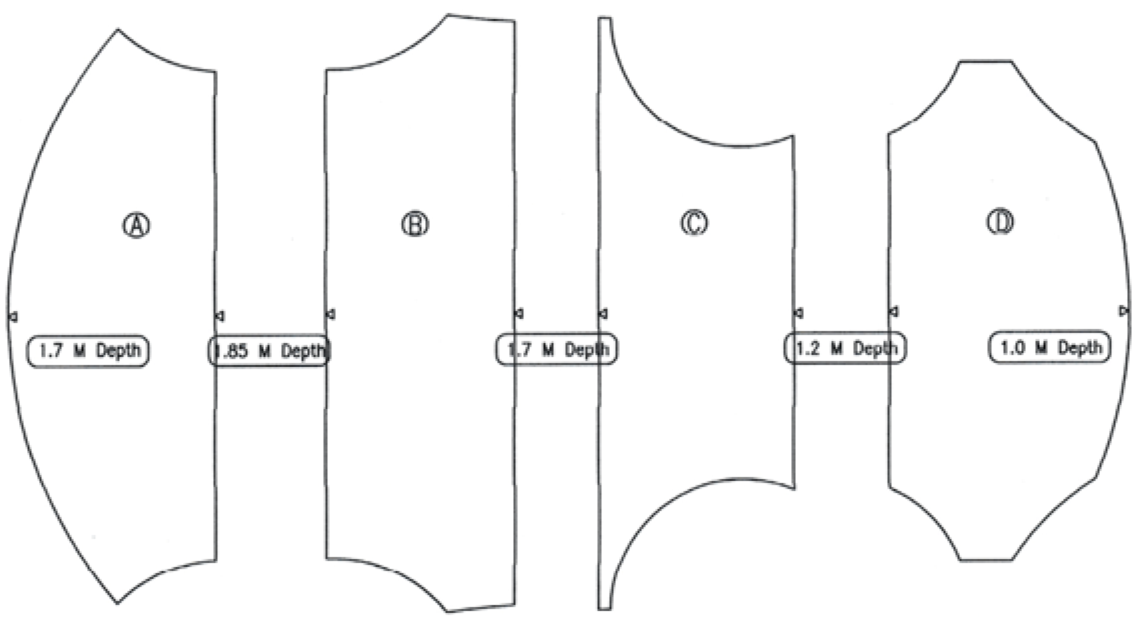
$$\text{Pool volume} = (9 \times 11 \times 1) + \left[8 \times 11 \times \frac{(1 + 1.5)}{2}\right] + (8 \times 11 \times 1.5) \text{ cubic metres}$$
$$= 99 + 110 + 132$$
$$= 341 \text{ cubic metres}$$

If the drawing of a free-form swimming pool is prepared by CAD (computer-aided design) software, the surface area of each section of the pool can be easily determined. For simplicity of discussion, we will use AutoCAD, one of the most powerful CAD software products available for personal computers, to explain the steps to determine the pool surface areas. Figure 3-2 shows the plan of a free-form swimming pool with varying depths at different sections of the pool produced with the AutoCAD software. As the swimming pool has varying depths, the four segments of the pool, each a different size and shape polygon, will have to be separated for ease of determining the surface area of each polygon.

For each polygon, you have to turn any first line to a polyline. Next, join the adjacent line to the first polyline, and subsequently join the rest of the adjacent lines to form a closed polygon of polylines. The intention is to create the polygon as one object, rather than a series of line segments. If an adjacent line cannot be joined to the first polyline, it will indicate that the two lines are not touching one another, that is, there is a gap or small distance between the two lines. In such a case, the lines can be caused to touch one another by using the “fillet” or “extend” command. The same is true for all other adjacent lines.



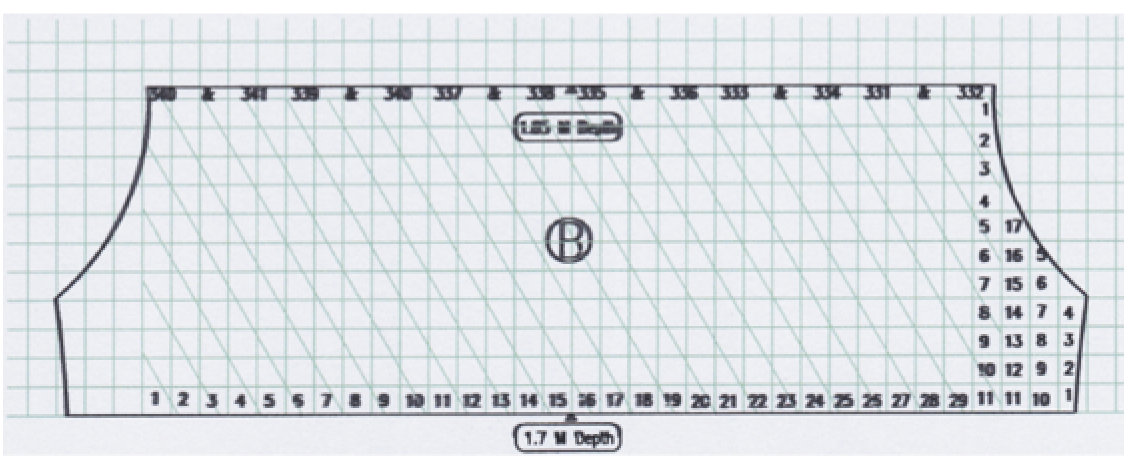
Free-Form Swimming Pool with Varying Depths
Figure 3-2



Segments of Free-Form Swimming Pool with Varying Depths
Figure 3-3

To check whether a polygon has been created as one object, you can attempt to erase the object by selecting it to be erased. If it is an object, the whole polygon will disappear from your screen. Just undo the previous “erase” command to bring the object back to your screen. Once a polygon has been created, the surface area can be known by pointing at the object with the “list” or “inquiry” command. The surface area will be displayed on your screen. The volume of each segment can be calculated by multiplying the surface area with the average depth of the segment. The volume of the pool will be the sum of the volumes of the four segments. It is that simple.

In the absence of a soft copy of a drawing for a free-form pool, we can use a primitive method to compute the surface areas of sections of the pool. If the scale of the hard copy of the pool is 1:100, just prepare a drawing, on an intermediate paper, with squares of ten millimetres by ten millimetres. Each square will represent one square-metre area. For other scales, you can similarly draw squares to suit the requirement, such as five-millimetre by five-millimetre squares for a drawing with a scale of 1:200. For this exercise, we are using section B of Figure 3-3 to assist in our discussion. Confirm with a scale rule on some of the dimensions indicated on the hard copy drawing to ensure it had been plotted to scale. An intermediate paper drawn with ten-millimetre by ten-millimetre squares is superimposed on Section B of the free-form pool, as the scale of the hard copy drawing is 1:100, as illustrated in Figure 3-4.



Intermediate Paper Drawn with Ten-millimetre by Ten-millimetre Squares Superimposed on Segment B of the Free-Form Swimming Pool with Varying Depths

Figure 3-4

The shaded area of the section of the pool is 330 square metres, as there are 330 squares covering it. From the hard-copy drawing, it is known that the distance across this section is 11.4 metres. So every five small rectangles will provide two square metres of surface area. As a result, that small strip on the top edge of Figure 3-4 will contribute twelve square metres of surface area. By counting only the right-hand side of the remaining polygon, we can obtain seventeen square metres of surface area. Since the pool is symmetrical, the left-hand side of the polygon will contribute the same surface area.

$$\text{Total surface area of this section of the pool} = 330 + 12 + (17 \times 2) = 376 \text{ square metres}$$

$$\text{Volume of this section} = 376 \times \frac{(1.85 + 1.7)}{2} \text{ cubic metres} = 667.4 \text{ cubic metres}$$

The same procedure is performed to the other three polygons to determine the volume. This primitive method can still provide a pretty accurate solution to solve the unknown.

Once the pool volume is known, the sizes of all the equipment required for the whole filtration system can be determined, i.e., the circulation pumps, pipe sizes, chemical dosing systems and the electrical power requirements.

4: Filtration

There are four main types of filters available for use in swimming pools. They are, namely, the cartridge filter, diatomaceous earth (DE) filter, high-rate sand filter and rapid-rate sand filter.

Of these, sand filters have the lowest maintenance costs and are easy to operate. You may need to open up a sand filter tank every five years or so to check the sand level and whether they are calcified. DE filters require removing the internal grid assembly at least annually to thoroughly clean them, and while cartridge filters do not get backwashed, the cartridge is removed almost fortnightly to be hosed clean.

In the not too distant past, cloth bag filters were used for filtration of swimming pool water. This is simply a bag fabricated with fine polythene filter cloth. The water to be treated enters the filter housing containing the filter bag from the top. The filtered water leaves the filter bag through the bottom of the filter housing. Dirt trapped in the filter bag can be cleaned by removing the filter bag from the filter housing. By turning the bag inside out, the trapped dirt can be removed by hosing with high-pressure water jets. Due to the messy and tedious cleaning procedure, most knowledgeable pool owners do not like its use, except for its relatively inexpensive costs and savings in space. Cloth bag filters are still available for industrial applications.

Cartridge filters are inexpensive and easy to install. Cartridge filters can be surface or depth-type filters. Depth-type filters capture particles and contaminants through the total thickness of the medium, while the particles are blocked on the surface of the surface filters. The cartridge filters employed for filtering swimming pool water are mostly surface type. Cartridge filter elements are either disposable or can be re-used by pressure washing inside and out with a garden hose to remove the dirt trapped in the pores of the elements. Cartridge filters are usually described by their nominal or absolute ratings. The nominal rating is the size of the smallest particles, ninety-eight percent of which can be retained by the element. Absolute rating is the size of the smallest particles that can be retained one hundred percent. Particle size ratings determine the cost of the cartridge filters. The smallest particle size ratings are the most expensive. A ten-micron cartridge will cost less than a 0.2-micron cartridge which is typically used in water treatment systems for kidney dialysis. The cartridges of different reputable makes are interchangeable as the dimensions of cartridges were standardised internationally in 1960.

The cartridge element is usually enclosed in a vertical cylindrical housing, made of plastic or stainless steel. A pressure relief valve is usually incorporated on either the body or lid of the housing to enable the housing to be depressurised for cartridge change-out. Water flows from the outside of the cartridge element to the inside. Treated water leaves the cartridge element through the bottom of the filter housing.

Specialised cartridges are made of materials with adsorbent properties such as activated carbon and ion exchange resins. These cartridges are intended mainly for adsorption of certain organic solutes in order to improve the odour, colour or taste of the filtrate, but they are limited to small flow applications.

Selection of cartridge filters for domestic pools is based on a filtration rate of fifty litres per minute per square metre of filter area. That is, for every square metre of filter area available in the cartridge filter, only fifty litres per minute of water is designed or allowed to pass through. For commercial pools, the filtration rate is limited to fifteen litres per minute per square metre of filter area. However, in Singapore, cartridge filters have not been used for commercial pools.

When costs and space availability are the main critical factors considered, cartridge filters would be selected. Unwary pool owners interested in obtaining the lowest prices for their projects will end up, more often than not, with cartridge filters being installed in their swimming pool projects.

Of course, most unscrupulous, profit-hungry property developers intent on maximising their profits will choose its use ignoring the tedious and cumbersome maintenance problems that will be faced by the new owners.

Cartridge filters are commonly installed for filtration of water fountains and water features as the water to be treated are of smaller volume. The frequency of cleaning the filter cartridges is dependent on the bathing loads and the cleanliness of the pool surround. It is usually replaced every year or two.

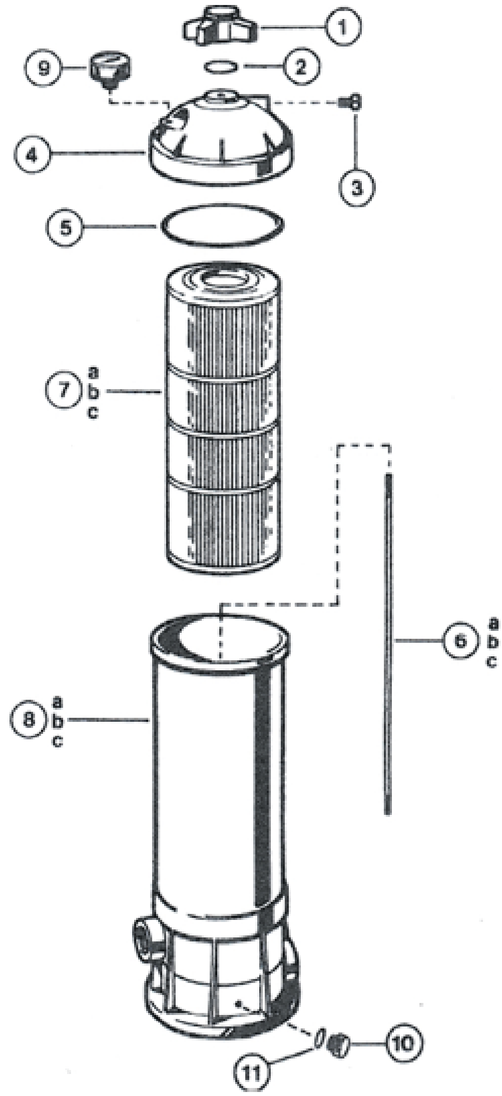
The standard cartridge filters available have filtration areas of twenty-five, fifty and seventy-five square feet. Should greater cartridge filtration areas be required, multiples of standard units will be employed. Standard cartridge filter elements are of twenty-five, fifty and seventy-five square feet. All filter manufacturers do not manufacture these cartridge filter elements. These are purchased from reputable OEM, Original Equipment Manufacturer, for supply with their products. All filter manufacturers make every attempt to hide the source of their supply of all components not of their manufacture, so as to enable them to supply the replacement parts. The marketing strategy is to always stress the use of original replacement parts.

For non-critical parts or components, we can always use “non-genuine replacement” parts.

For critical installations, it is always wiser to turn to the original equipment supplier for the higher-cost replacement parts, with profit margins slapped on by the equipment supplier, so that in the event of any defective manufacture, we will have recourse for protection.

PARTS
Models C-250, C-500, and C-750 Filters

REF. NO.	PART NO.	DESCRIPTION	NO. REQ'D.
1	CX250-G	Locking Knob	1
2	CX250-Z-7	O-Ring	1
3	ECX1321-A	Air Relief Valve w/O-Ring	1
4	CX250-C	Filter Cover (Dome)	1
5	CX250-F	Filter Cover Gasket	1
6-A 6-B 6-C	CX250-Z-2S CX500-Z-2S CX750-Z-2S	Tie Rod	1
7-A 7-B 7-C	CX250-RE CX500-RE CX750-RE	Cartridge Element	1
8-A 8-B 8-C	CX250-AA-1 CX500-AA-1 CX750-AA-1	Filter Tank Body w/Tie Rod Assembly	1
9	ECX2709-1	Pressure Gauge	1
10	CX250-Z-14	1/2" Drain Plug	1
11	SPX605-Z-2	Drain Plug O-Ring	1



Exploded View of Cartridge Filter
Figure 4-1 *(courtesy of Hayward Inc.)*

You can use two twenty-five-square-foot cartridge filter elements to replace a fifty-square- foot cartridge element if the latter is not available. Similarly, if there is a constraint in height, you can install two twenty-five-square-foot cartridge filters, instead of one taller fifty-square-foot cartridge filter. In Figure 4-1, you will note that most parts for the three different sizes of cartridge filters are identical, except for the lengths of the filter tank body, the cartridge filter elements and the fastening tie rods. This saves the manufacturer in tooling and moulding costs. In fact, the filter manufacturer can design the other components of the filter to accommodate standard manufactured heavy-duty PVC pipes without having to specially fabricate a mould to manufacture the filter tank body. They can then simply cut the pipe length to suit each model of the filter. This will further reduce the filter production costs. As the saying goes, you do not have to reinvent the wheel. All manufacturers strive to adopt value engineering to reduce manufacturing costs without sacrificing quality to maintain market leadership.

DE filters contain an arrangement of hollow elements or grids covered with nylon-type fabric inside the filter housing, which are made of either plastic or stainless steel. The filter cloth serves as a support for a coating of diatomaceous earth, which forms the filter medium that traps the dirt. These filter elements must be pre-coated with diatomaceous earth (diatomite) before they are put to service in order to protect their surfaces and provide the most efficient filtering action. Diatomite comprises fossilised remains of microscopic single-celled plants (diatoms) consisting mainly of silica (over eighty percent SiO_2) and small quantities of different metal oxides. The diatomite is processed by crushing, grinding, screening and drying. The large variety of diatomite species combined with different processing conditions yields a great number of diatomite grades that differ in particle size distribution, shape and density.

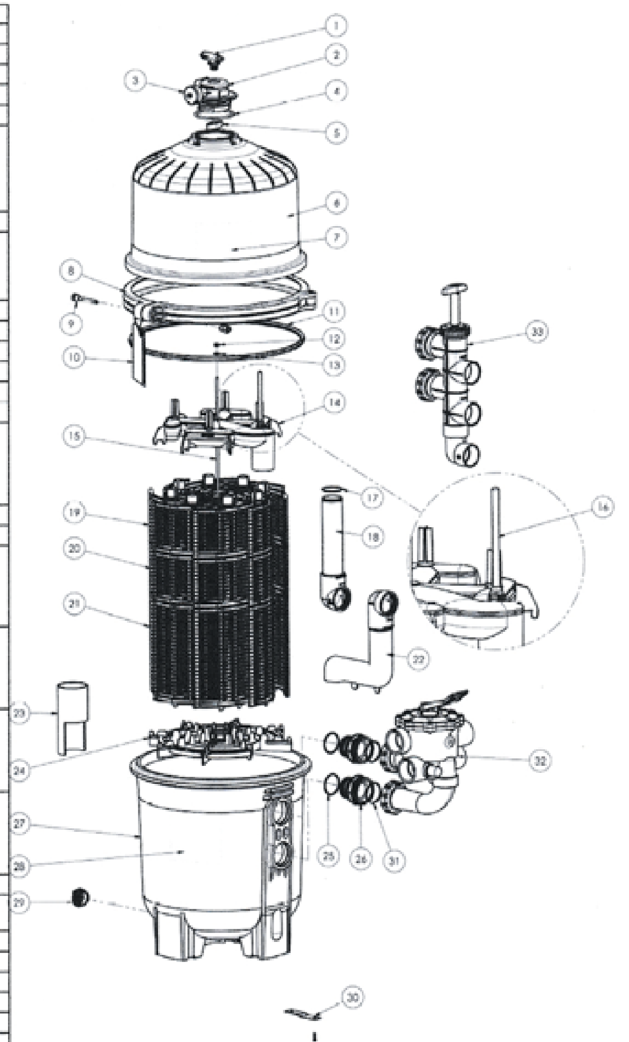
To pre-coat the DE filter, the required amount of diatomite is mixed with sufficient water to make a thin milky mixture. With the circulation pump in operation, this mixture is drawn into the suction pipe via the skimmer in the skimmer-type swimming pool. For the level-deck pool it is drawn through a pre-coat or mixing tank connected to the suction line of the circulation system via an on-off control valve into the filter. As a rule of thumb, one pound of diatomite will be required to pre-coat each ten square feet of the diatomaceous earth filter area. Once the DE filter is pre-coated, it can be put to useful service.

The filtration pump forces water in the filter housing through the elements from outside to a central manifold. When the flow passes a filter, a certain pressure drop occurs. This pressure drop is dependent on the filter media, the filter housing and the flow rate. An increasing pressure drop over the filter indicates that the filter is being clogged with dirt. In the DE filter, by reversing the flow of water, both dirt and diatomaceous earth are flushed to waste during backwashing, so that the coating procedure must be repeated before the filter is returned to service.

Common diatomaceous earth filters available have filtration areas of twenty-four, thirty-six, forty-eight, sixty or seventy-two square feet. These are in imperial units as most DE filters are of American make. From Figure 4-2, you will note that the lower filter body is identical for the five different sizes of filters. The upper filter body, filter elements, outlet pipe and retainer rods are lengthened for each subsequent size of filters above twenty-four-square- foot filter area. The outlet elbow, item no. 18, differs as the smaller filter sizes are provided with forty-millimetre-diameter pipes. The larger filters are provided with fifty-millimetre- diameter pipes.

Again, most DE filter manufacturers do not produce the DE filter elements and other smaller components of the filter due to economy of scale. This is similar to motor vehicle manufacturers purchasing various parts and components from other manufacturers to assemble to be sold as complete units.

ITEM	Part No.	Description
1	CCX1000V	Manual Air Relief w/O-ring
2	DEX2420MAR2	Manual Air Relief Assembly
3	ECX2712B1	Pressure Gauge
4	DEX2420Z8A	O-Ring Kit (Set of 2)
5	CCX1000N	Manual Air Relief Nut
6	DEX2420BT DEX3620BT DEX4820BT DEX6020BT DEX7220BT	Upper Filter Body DE2420 Upper Filter Body DE3620 Upper Filter Body DE4820 Upper Filter Body DE6020 Upper Filter Body DE7220
7	DEX2420LA6PAK	Label Pack*
8	DEX2421JKIT	Clamp System including: Clamp, Clamp nut and Bolt, Hang tag, Metal Reinforced Seal and Labels
9	DEX2421J2	Clamp Bolt and Nut
10	DEX2420LA6PAK	Label Pack*
11	DEX2422Z2	Metal Reinforced Seal
12	ECX176865	Retainer Nut 5/16"-18
13	ECX1109	Washer (2 Required)
14	DEX2400C	Top Collector Manifold
15	DEX2400R DEX3600R DEX4800R DEX6000R DEX7200R	Retainer Rod DE2420 Retainer Rod DE3620 Retainer Rod DE4820 Retainer Rod DE6020 Retainer Rod DE7220
16	DEX2400CR	Flex Air Relief Assembly
17	DEX2400Z5	Outlet Elbow O-ring
18	DEX2420EA DEX3620EA DEX4820EA DEX6020EA DEX7220EA	Outlet Elbow DE2420 Outlet Elbow DE3620 Outlet Elbow DE4820 Outlet Elbow DE6020 Outlet Elbow DE7220
19	DEX2420DC DEX3600DC DEX4800DC DEX6000DC DEX7200DC	Filter Element Cluster Assembly (Complete set of elements, collectors, Locators, Manifold, ect.
20	DEX2400DA DEX3600DA DEX4800DA DEX6000DA DEX7200DA	Filter Element (7 Required)
21	DEX2400DS DEX3600DS DEX4800DS DEX6000DS DEX7200DS	Filter Element Short (1 Required)
22	DEX2420GA	Inlet Diffuser
23	DEX2420T	Element Spacer (DE2420 Only)
24	DEX2400H	Filter Element Locator
25	SX220Z2	Bulkhead O-Ring (2 Req.)
26	DEX2420F	Bulkhead Fitting (2 Req.)
27	DEX2420AT	Lower Filter Body
28	DEX2420LA6PAK	Label Pack*
29	SP1022C	1 ½" Drain Plug w/ O-Ring
30	DEX2420DCKIT	Strap Kit (Optional) 2 straps, 2 Screws
31	SX200Z4	O-Ring (2 Req.)
32	SP0740DE SP0710XR50 SP0715XR50	Selecta-Flo™ Valve 2" SKT Vari-Flo™ Valve 1 ½" NPT Vari-Flo™ Valve 2" NPT (Optional)
33	SP0410X5025	Slide Valve 2" SKT (Optional)



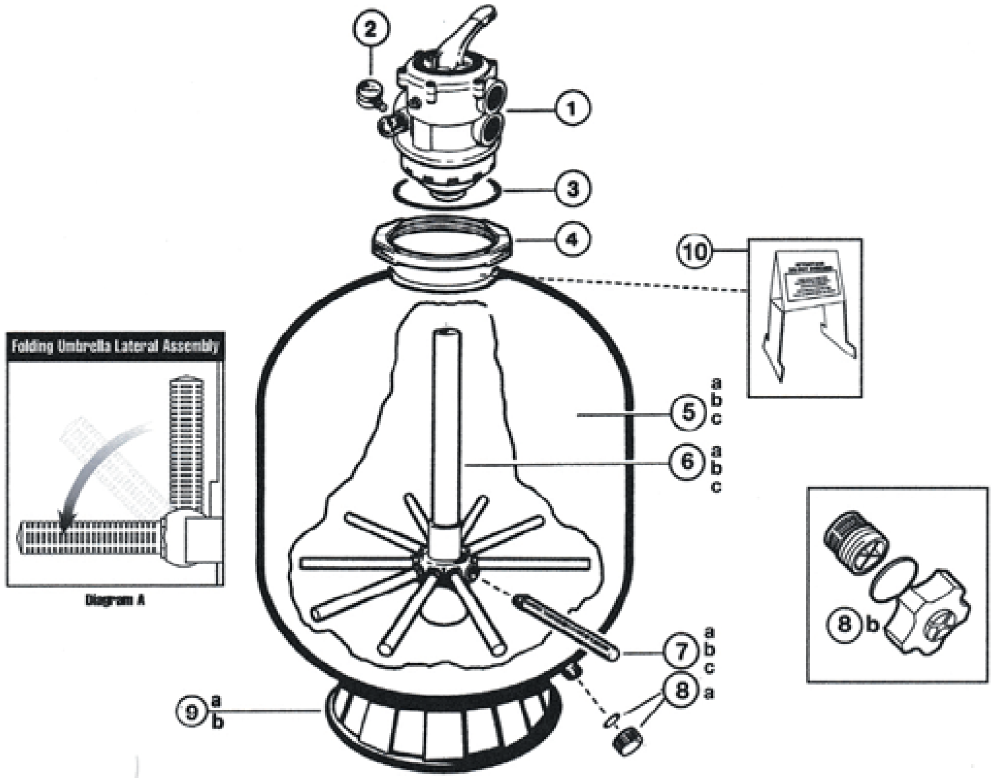
Exploded View of Diatomaceous Earth Filter
Figure 4-2 *(courtesy of Hayward Inc.)*

Figure 4-2 shows that the standard DE filter has eight elliptical filter elements; seven large and one slightly smaller element to accommodate the installation of the outlet pipe, indicated as item no. 18. Each section of the large hollow plastic element or grid has a surface area of 1.6 square feet. The smaller element has a surface area of 0.8 square feet. By connecting or adding one more section to a smaller filter, the filter size will be increased by twelve square feet.

Seven large elements with 1.6 sq ft filter area each + 0.8 sq ft filter area of a smaller filter element = 12. This will explain the incremental increase of filter size by twelve square feet. As the height of the filter element is increased, the affected components will have to be increased correspondingly. It is not possible to increase the filter size beyond seventy-two square feet, as a fifty-millimetre-diameter pipe has limited water carrying capacity. Multiple units will have to be installed to increase the filtration area required.

For simplicity of installation, DE filters are usually installed with side-mounted multi-port valves to direct the flow of water in and out of the filters. Under such circumstances, unfiltered water from the pool to be filtered is used to conduct backwashing. This explains the requirement to rinse the filter briefly to flush dirt trapped inside the DE elements, after completion of backwash. If an installation has two units of filters, the installer can provide their own control valves without the use of multi-port valves. The piping and control valve system can be arranged to direct the filtered water from one unit to backwash the other, hence eliminating the rinsing requirement. However, you have to note that the inlet to the DE filter is below that of the outlet, as opposed to the sand filter where the inlet to the filter is always above the outlet.

A sand filter is a device that uses sand as a natural filtration substance to clean water. Similar to water in underground aquifers that is filtered by passing through various layers of sand and porous rock, a sand filter seeks to simulate nature's design. Sand filters are available in both vertical and horizontal construction. The sand filter performance depends essentially on the adherence of impurities to the surfaces of the sand grains. The smaller the grain size of sand in any given filter, the greater is the total surface area of all the sand grains. It therefore follows that the depth of the sand bed and fineness of grains contribute as much to filter efficiency as filter area.



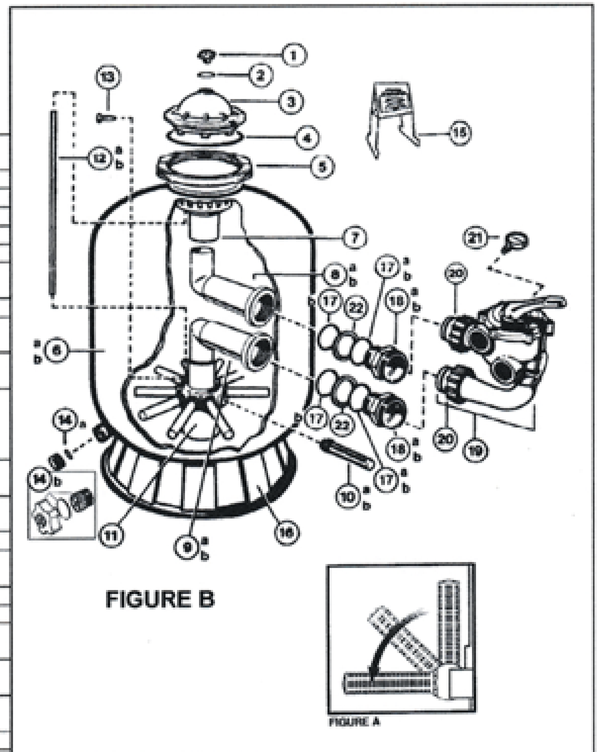
Ref. No.	Part No.	Description	Ctn. Qty.	No. Req'd
1	SP071620T	Vari-Flo Control Valve – 2" w/Clamp	1	1
2	ECX271261	Pressure Gauge Back Mount	10	1
3	GMX600F	Valve/Tank O-Ring	10	1
4	GMX600NM	Flange Clamp (Valve – Tank)	5	1
5a	SX270AA2	27" Filter Tank w/Skirt, Drain and Lateral Assembly	1	1
5b	SX310AA1	31" Filter Tank w/Skirt, Drain and Lateral Assembly	1	1
5c	SX360AA2	36" Filter Tank w/Skirt, Drain and Lateral Assembly	1	1
6a	SX244DA2X	27" Folding Lateral Assembly w/Center Pipe	1	1
6b	SX310DA2	31" Folding Lateral Assembly w/Center Pipe	1	1
6c	SX360DA	36" Folding Lateral Assembly w/Center Pipe	1	1
7a	SX240DN	27" Lateral (One Piece) w/Hub	10	10
7b	SX310HA	31" and 36" Lateral (2004 and prior)	10	10
7c	SX310HN	31" and 36" Lateral (One Piece) w/Hub	10	10
8a	SX180HG	Drain Cap (2005 and prior)	25	1
8b	SX180LA	Drain Cap Assembly, Gasket, Screen	25	1
—	SX200H	Bottom Drain Screen (2005 and prior)	10	1
9a	SX200J	27" Filter Support Stand	1	1
9b	SX310J	Filter Support Stand – Large	1	1
10	SX202S	Sand Shield	25	1

Exploded View of High-rate Sand Filter with Top-mounted Multi-port Valve
Figure 4-3 *(courtesy of Hayward Inc.)*

Usually the smaller sand filters are high-rate sand filters. The bodies are normally of plastic or stainless steel construction, whilst the bigger units can be fabricated of plastic, mild steel or stainless steel. When they are fabricated with mild steel, they will usually be coated thickly with corrosion-resistant materials to protect the metal surfaces. Figure 4-3 shows a plastic make high-rate sand filter with top-mounted multi-port valve.

PARTS
Models S210S, S244S

REF NO	PART NO.	DESCRIPTION	NO. REQ
1	SX200G	Manual Air Relief Cap	1
2	SX200Z5	O-RING, 13/16" O.D.	1
3	SX244K	Top Closure Dome	1
4	GMX600F	Valve/tank o-ring	1
5	GMX600NM	Flange Clamp	1
6a	SX210AA2FW	Filter Tank w/Base, S210S	1
6b	SX244AA2FW	Filter Tank w/Base, S244S	1
7	SX244G	Top Diffuser	1
8a	SX210CD1FW	Top Elbow Assembly (S210S)	1
8b	SX244CD1FW	Top Elbow Assembly (S244S)	1
9a	SX210CD2FW	Bottom Elbow Assembly (S210S)	1
9b	SX244CD2FW	Bottom Elbow Assembly (S244S)	1
10a	SX200Q	Lateral (Screw in) Prior 2005(20")	10
10b	SX200DN	Lateral (One piece) (20")	10
10c	SX240D	Lateral (Screw in) Prior to 2005	10
10d	SX240DN	Lateral (One piece)	10
11a	SX242MAX	Lateral Holder Assy w/S200DN	1
11b	SX242MA1X	Lateral Holder Assy w/S240DN	1
12a	CX3000Z2	Plastic Air Tube (S210S)	1
12b	CX1100Z4	Plastic Air Tube (S244S)	1
13	SX200Z2	Air Tube Lock Screw	1
14a	SX108HG	Drain Cap Kit (Round)	1
14b	SX180LA	Drain Cap Assy	1
15	SX202S	Sand shield, corrugated	1
16	SX200J	Filter Stand Support	1
17a	SX220Z3	O-Ring (Large) (S210S)	2
17b	SX360Z1	O-Ring (S244S)	4
18a	DEX360F	Bulkhead Fitting (S210S)	2
18b	SX244P	Bulkhead Fitting (S244S)	
19	SP710X62	1 ½" Vari-Flo Control Valve Assembly with Gauge	1
20	SX200Z4	O-Ring	2
21	ECX27061	Pressure Gauge	1
22	SX360E	O-Ring Spacer (S244S)	2

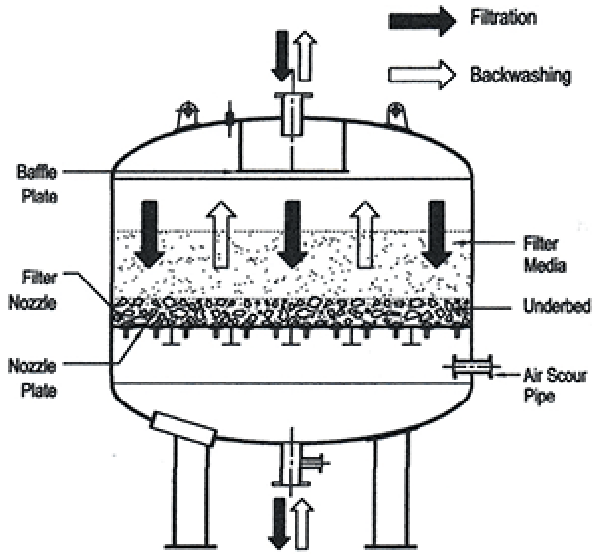


Exploded View of High-rate Sand Filter with Side-mounted Multi-port Valve
Figure 4-4 *(courtesy of Hayward Inc.)*

The larger sand filters can be high-rate sand filters or rapid-rate sand filters. The bodies of mass factory-manufactured filters are of plastic, mild steel or stainless steel constructions. Again, if they are of mild steel construction, the protection against corrosion is seriously taken into consideration. For large municipal pools where it is not cost effective to use multiple units of these standard factory-manufactured filters, the filters are tailor-made to suit the requirements. In Singapore, these filters are usually fabricated with SS316, a better grade than SS304, as every attempt is made to minimise corrosion. Usually, such tailor-made filters are of horizontal construction. Figure 4-4 shows a plastic-make high-rate sand filter with side-mounted multi-port valve.

Mass-produced sand filters vary slightly in sizes for the different filter manufacturers as different manufacturers use different processes and plastic materials for production.

The high-rate sand filter contains a deep bed of fine silica sand, about six hundred millimetres in depth, supported on a mechanical under drain. Water is forced down by the filtration pump through the filter bed at a high rate, at six hundred litres per minute per square metre ($l/min/m^2$) or twelve imperial gallons per minute per square foot ($igpm/ft^2$) of filter area, where the dirt penetrates the sand to a considerable depth. This gives the high-rate sand filter a great dirt-holding capacity. Backwashing is carried out at about the same rate as filtering which makes pump selection easy.

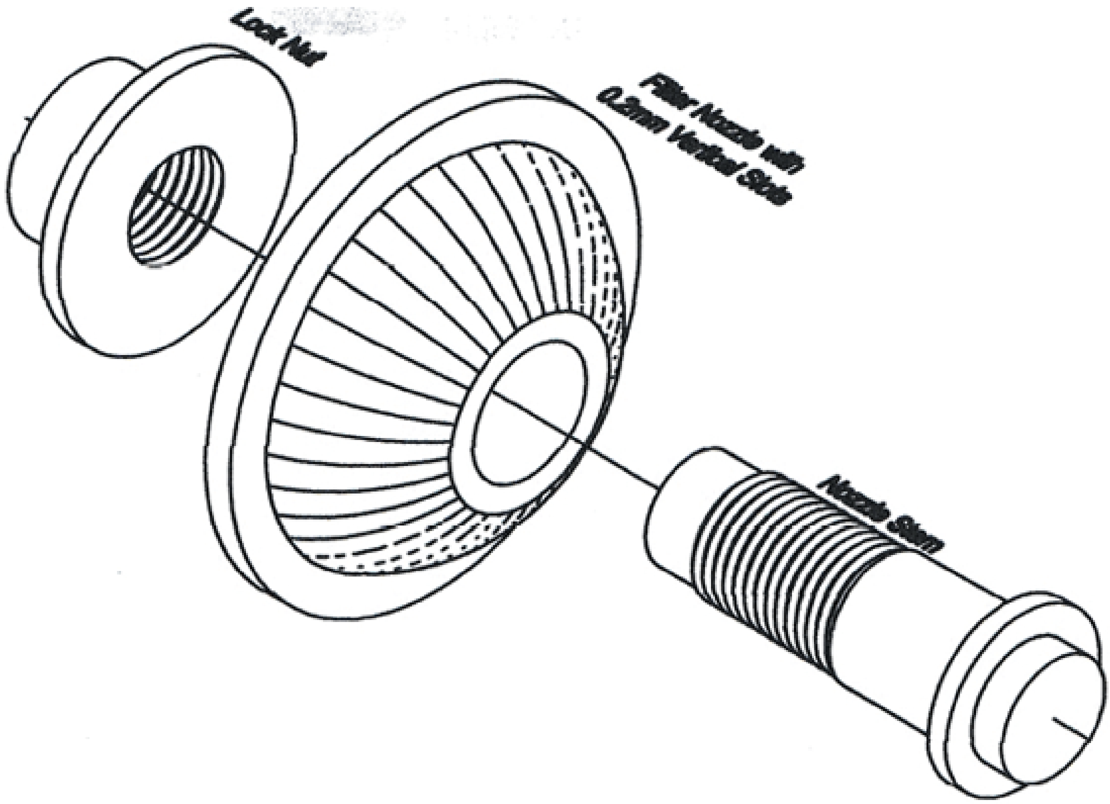


Cross-section of a Vertical Sand Filter
Figure 4-5

The rapid-rate sand filter contains a layer of fine silica sand supported on a graded bed of gravel. Water is forced down by the filtration pump through the filter bed at a slow rate of 200 $l/min/m^2$ or four $igpm/ft^2$ where the top layer of sand traps the dirt. By reversing the flow of water for backwashing at two or three times the filtering rate, the sand can be agitated to release the dirt which is flushed to waste. In commercial pools, air is usually used to scour the sand bed on commencement of the backwashing process to assist the fluidising of the sand bed to save on water consumption. Figure 4-5 provides a cross-sectional view of a vertical sand filter fitted with nozzles. A picture paints a thousand words.

Figure 4-6 shows the simplicity of a typical thermoplastic filter nozzle. In this drawing, the filter nozzle has 0.2-millimetre vertical slots. This will ensure sand of 0.3 to 0.5-millimetre mesh will remain at its rightful position, allowing only water to be returned to the pool. The filter nozzles can be supplied with different slot sizes to meet different requirements.

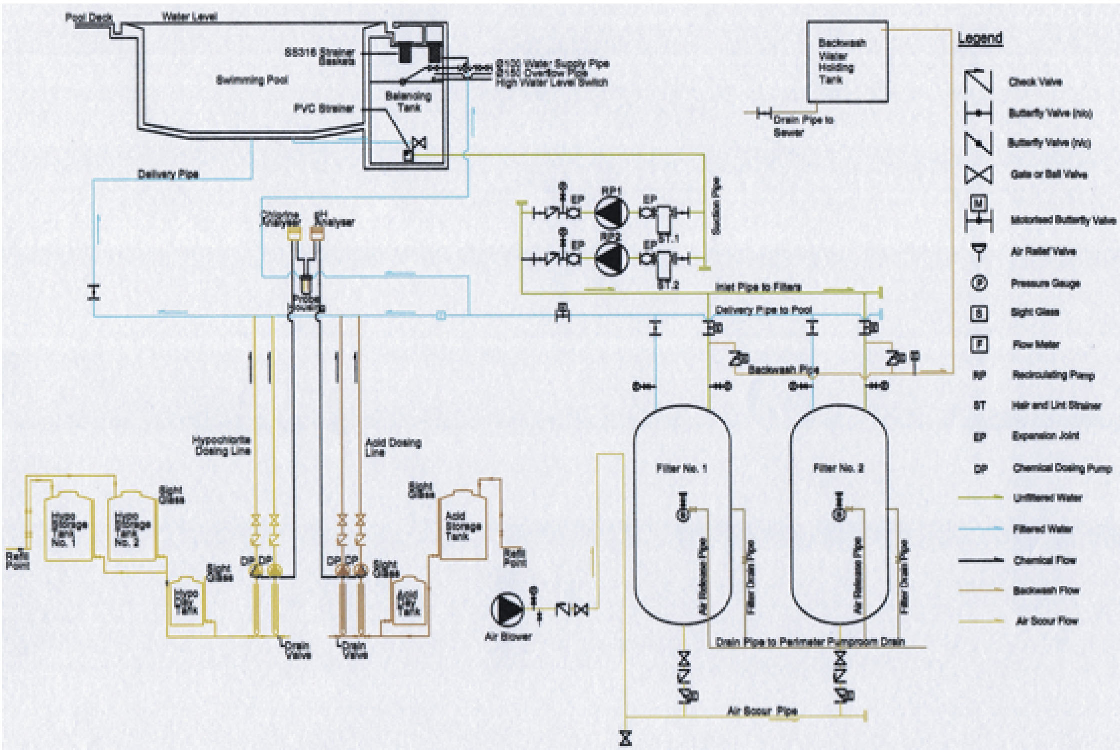
Figure 4-7 provides a simple example of the installation of control valves to enable one filter, on filter cycle, to supply filtered water to backwash the adjacent filter. The use of motorised valves controlled by PLC, programmable logic controller, is shown in the drawing. With the flip of a switch to backwash the pre-determined filter, the normally closed and opened motorised control valves of this filter will change their operating positions automatically. The positions of the motorised valves of the filter supplying the filtered water for backwashing remain unchanged. The motorised valve installed on the delivery line to the swimming pool will close during the backwash cycle. You can achieve the same intent with manual control valves by opening and closing the respective control valves.



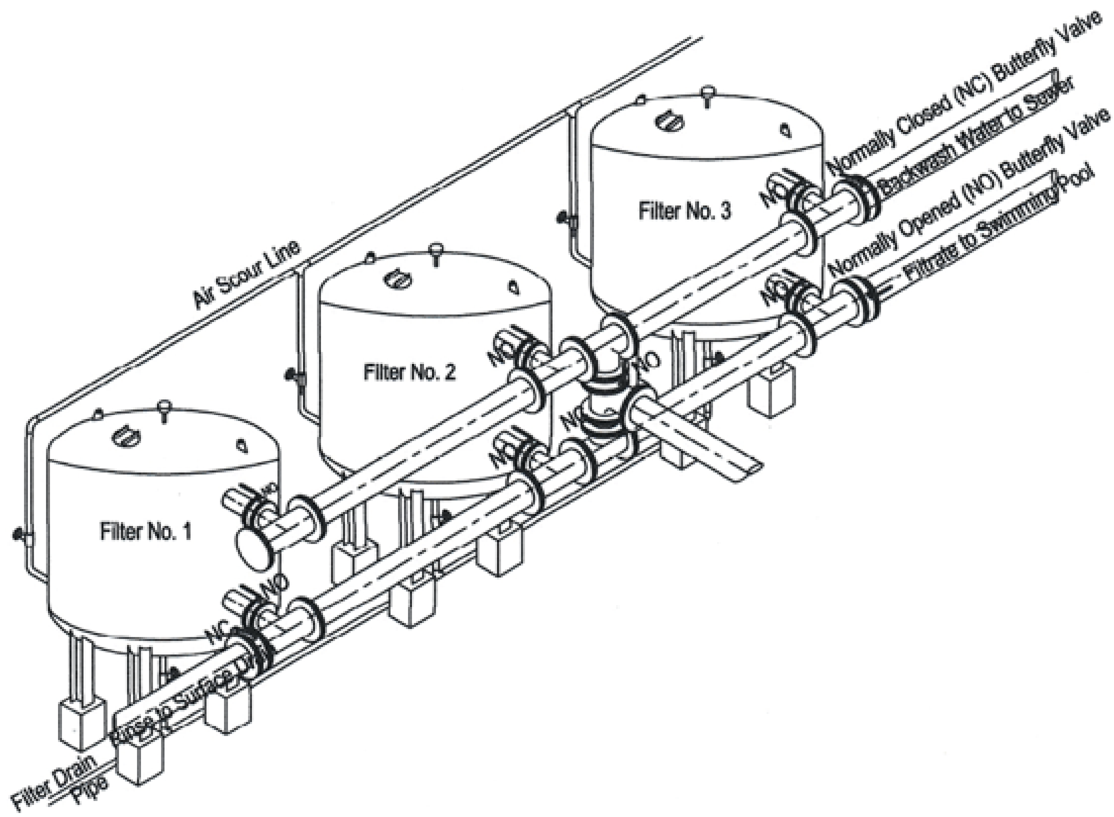
Exploded View of Filter Nozzle
Figure 4-6

An isometric drawing of a sand filter system with two-pipe manifold is shown in Figure 4-8. In this system, unfiltered water from the pool is used to conduct backwashing. On completion of backwashing, the filter that is backwashed has to be briefly rinsed to flush dirt trapped below the sand.

To increase sand filter areas, the diameters of vertical sand filters will have to be increased accordingly. For horizontal sand filters, you can increase either the diameter or length, and/or increase both, to increase the filter areas. However, there is a manufacturer in the northern hemisphere attempting to increase the filter areas of their sand filters by emulating the concept found in DE filters.



Schematic Drawing of Swimming Pool Filtration System
Figure 4-7



Isometric Drawing of Sand Filter System with Two-pipe Manifold
Figure 4-8

They utilised identical lower and top stainless steel filter bodies of 600-millimetre diameter for all different models and sizes of filters. Different lengths of intermediate tubular stainless steel sections are added between the lower and top filter bodies to suit the required height of the filters.

The smallest of these filters has two ribbed, for structural strength, polythene sand containers, each of 560-millimetre diameter by 300-millimetre height stacked one above the other at a clearance of fifty millimetres. Each container has a lateral holder assembly complete with radial laterals filled to 250-millimetre depth with filter sand, hence serving as an independent filter. Each will provide slightly less than 0.25 square metres of filter area. The fifty-millimetre diameter central core pipe connects the lower filter lateral holder assembly to the upper filter lateral holder assembly, thus forming the filter outlet pipe. The inlet and outlet pipes penetrate the filter through the base of the filter body.

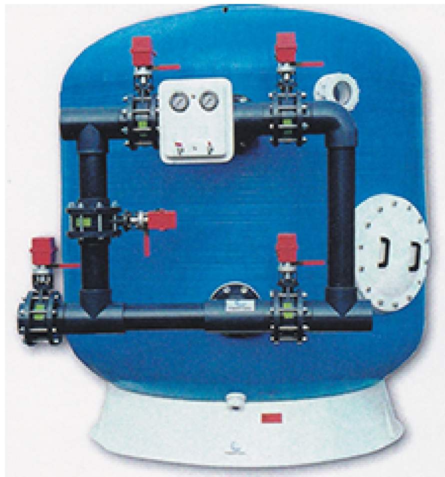
This filter manufacturer can supply double-, triple- or quadruple-tiered sand filters to provide filter areas of 0.5, 0.7 and 1.0 square metres of filter area. It will not be possible for the manufacturer to provide infinite tiers, as the fifty-millimetre diameter outlet pipe has finite water carrying capacity.

The top of the sand bed is only fifty millimetres below the top edge of the polythene sand container. During backwashing, when the sand bed is fluidised to release the dirt trapped in the sand bed, is it possible for some filter media to be ejected out of the polythene sand container? This will not happen if the backwashing is performed gently. In such an event, is the backwashing process conducted effectively?

The manufacturer’s claims that their products will result in savings in backwash water consumption does not hold water, as more frequent backwashing of the filters will be required to ensure that dirt will not be returned to the pool. To install such filters for commercial pools is similar to installing multiple room-unit air conditioners to cool large assembly halls.

In a few Scandinavian countries, the health authorities require all commercial pool filters to have a sand bed of one and 1.2-metre depth to ensure the pool water is meaningfully filtered. If a same quantity of water with the same amount of suspended impurities is forced at the same pressure through a 250-millimetre-depth sand bed and a thousand-millimetre-depth sand bed, or even a six-hundred-millimetre-depth sand bed, common sense will tell us which filtrate will be better. Figure 4-9 shows a typical sand filter with 1200-millimetre sand bed.

These filters were popularised in a neighbouring Muslim country with a population of slightly more than 400,000. We have to be aware that their bathing load is relatively low. Swimming is also not a popular activity in the country.



Sand Filter having 1200 mm
Sand Bed Depth
Figure 4-9 *(courtesy of Pahlen)*

Having spent a large sum of money to build recreation facilities for the citizens, is it wise not to install a proper filtration system as well? Those pools in Singapore installed with such filters would be dealt with major blows when the swim loads are heavy. The only solution to overcome the cloudy water problem is to conduct more frequent backwashing and increase the dosage of chemicals to overcome the poor performance of the filters.

Residents staying in the western part of Singapore could be aware of a swimming complex that has to be closed on every Monday for “maintenance” as the pool water is so cloudy and brownish due to the inability of the filtration systems to cope with the overwhelming weekend crowd despite of decent high-rate sand filters being installed in this complex.

5: Principles of Pumping

Two types of pumps are commonly used in swimming pool filtration systems. They are the centrifugal pumps drawing water for filtration or water display and the chemical metering pumps for injecting chemicals to the swimming pool circulation or filtration systems. Occasionally, submersible pumps will be used for dewatering purposes.

The major components of a centrifugal pump are the pump casing, the impeller, the shaft and the seal. The materials of construction of these components, type of seal and the desired rotating operating speed must always be specified by any buyer inviting quotations for fair comparison.

Most swimming pool pumps are driven by alternating current (AC) electric induction motors, as opposed to direct current motors. The major advantage of alternating current is that it can be transmitted easily and efficiently. Alternating current loses the least amount of energy when transmitted at a high voltage and can be easily decreased for safe use by the use of devices called transformers. Voltage cannot be changed easily and efficiently for direct current. The voltage of our local single-phase electrical supply is 230 volts (V), whereas the three-phase supply is 415 V. In the US, the voltage of their single-phase electrical supply is 110 V and 220 V for the three-phase supply. Of course pumps can be driven by diesel or petrol engines or any other rotating equipment, but they are not relevant for our discussion as they are not used in swimming pool filtration systems. As our electricity supply is available in fifty hertz (Hz), named after the German physicist Heinrich Hertz, the two most common operating speeds of the mass-produced electric motors in use are 1,500 revolutions per minute (rpm) and 3,000 rpm. The previous unit name for frequency was cycles per second (cps). The electricity supply in most US cities has a frequency of sixty Hz. The popular operating speeds of their pumps will be 1,750 and 3,500 rpm at such a frequency.

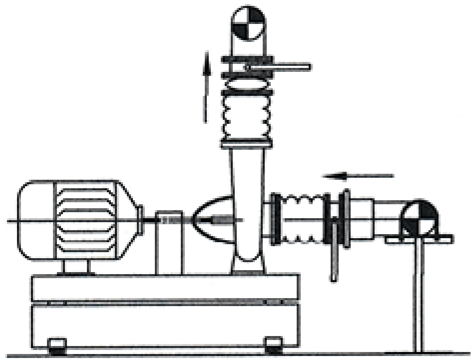
In a centrifugal pump, the impeller is mounted on a rotating shaft and contained in a solid cast casing. Water is drawn in from the suction pipe through the centre of the spinning impeller and centrifugally flung to the outside of the casing through the discharge. Centrifugal pump casings and impellers can be of cast iron, stainless steel, bronze or thermoplastic construction. The shafts are usually of stainless steel construction of different grades — a matter of economics. A slight gap is intentionally provided between the rotating shaft and the pump casing to prevent damage to the pump casing by the rotating shaft. This gap must be sealed to prevent water leakage. Mechanical seals or rope packing are employed to seal these openings.

A mechanical seal works through the use of two rings of very flat lapped surfaces to prevent water leakage along the shaft and through the gap between the shaft and pump casing. The stationary ring, usually made of ceramic, sitting on a hollow rubberised ring cup is tightly inserted into an engineered recess on the back of the pump casing where the shaft enters or exits the casing. The rubber seat will prevent water from leaking around the external surfaces of the stationary ring. The rotating ring, usually made of carbon or graphite, is attached with a rubber seal for mounting tightly around the rotating shaft to prevent water leakage along the rotating shaft. The two mating lapped surfaces, held in contact by a spring against the impeller, will prevent water leakage unless the sacrificial carbon-lapped surface is damaged. The lapped-carbon surface will be damaged only if the pump runs dry, i.e. the pump is operating without water in the casing. As the rotating carbon ring is not cooled, the flat lapped surface will be damaged due to the immense heat generated.

Pahlen Swimming Pool Pump
Figure 5-1

Graphite-coated square asbestos ropes are commonly used to seal the opening between the rotating shaft and pump casing. The cut-to-size packing pieces are eased down around the pump shaft in a gland box, just outside the back of the pump casing where the shaft enters or exits the casing. The cut ends are staggered to prevent leakages through them. On completion of sealing, the gland is adjusted to ensure slight leakage occurs. This is to allow the cooling water to remove the friction heat generated by the rotating shaft in the packing set. The soft sacrificial graphite serves as lubricant for the rotating shaft.

Centrifugal pumps can be self-priming or non-priming. Priming is the filling of water into a pump casing to displace the air inside. A self-priming pump is one capable of freeing itself of entrained air without having to fill the suction line completely with water. A check or one-way valve is usually installed at the end of the suction pipe of a non-priming pump. This will permit the suction line to be completely filled with water to displace all the trapped air before operating the pump. If the entrapped air in the suction pipe is not fully removed, the non-priming pump will not operate effectively. This could result in damaging the mechanical seal of the non-priming pump.



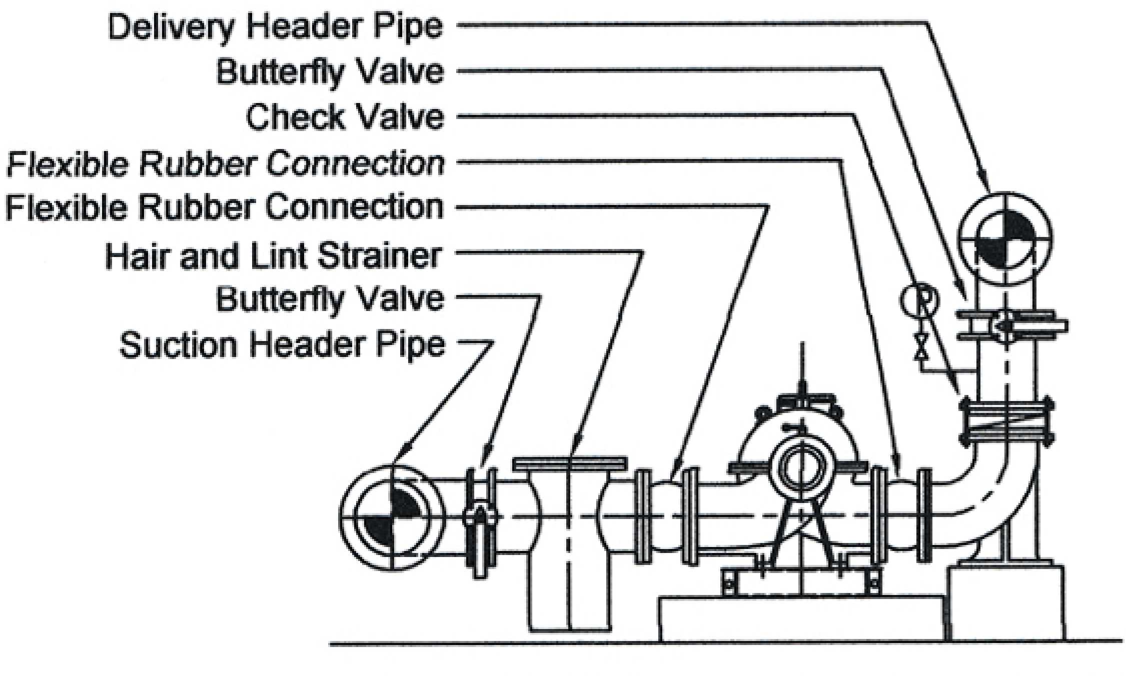
Typical End-Suction Pump Installation Details
Figure 5-2

The different types of centrifugal pumps used for swimming pools are: the end-suction (Figures 5-1 and 5-2), horizontal split-casing (Figure 5-3) or vertical split- casing (Figure 5-4) pumps. End-suction centrifugal pumps are mostly back-pull-out constructions. All end-suction centrifugal pumps can be close-coupled or direct-coupled sets. For close-coupled pumps, the impellers are mounted on the motor shafts. A high quality purpose-make all-bronze PAHLEN swimming pool close-coupled self-priming pump, complete with integral hair and lint strainer, is shown in Figure 5-1. You will note that the motor flange is bolted directly to the pump casing without the need of any coupling. Such pump is slightly lower in cost and quieter in operation. For direct-coupled pumps, the pump and motor have separate shafts connected by a flexible coupling. Usually a spacer coupling is used to allow the removal of the entire rotating element from the back of the pump casing without disturbing the motor and piping connections to facilitate repairs. Details of a typical end-suction direct-coupled back-pull-out centrifugal pump installation are shown in Figure 5-2.

To save cost, most companies will purchase a direct-coupled pump without the motor from a local pump stockist or distributor as they are aware that the pump supplier will also purchase the motor from others to couple to the pump. Such a unit is termed as bare-shaft pump.

Horizontal split-casing and vertical split-casing pumps are also manufactured with the same intention of not disturbing the motor and piping connections for the conduct of any repairs and maintenance inspections. These are non-priming pumps.

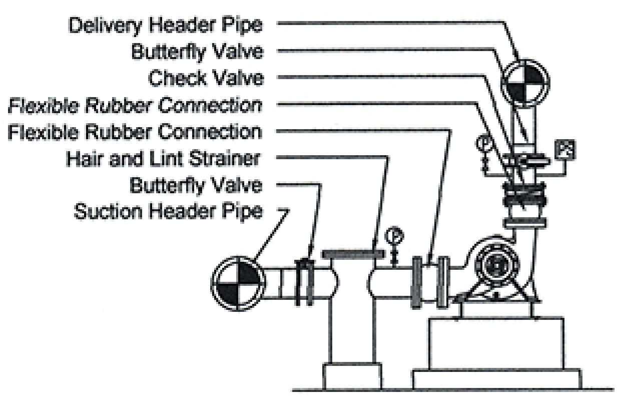
Horizontal split-casing (HSC) pump is a type of centrifugal pump in which the casing is horizontally split, parallel to the pump shaft, into two separate chambers. It is different from an end-suction back-pull-out pump in which the pump casing is split along a vertical plane in relation to the impeller. HSC pumps have the discharge and suction connections opposite to each other in the lower half of the casing. The impeller is mounted on a shaft that is supported by bearings on both sides. To remove the whole rotating element, the upper chamber is dismantled and moved away. After disconnecting the flexible coupling to the motor, the whole rotating assembly can be removed vertically for maintenance inspections and repairs without disturbing the motor and piping connections. Figure 5-3 depicts a typical HSC pump installation details. HSC pumps are usually employed for higher flow-rate applications than end-suction pumps.



Typical HSC Pump Installation Details
Figure 5-3

Figure 5-4 shows the proper installation details of a typical vertical split-casing (VSC) pump. The entire rotating assembly can be removed through the non-drive end of the pump, i.e., through the front of the pump, without disturbing the piping connections for repairs and maintenance inspections. There are not many comparative advantages of the use of VSC pumps over the end-suction back-pull-out pump. They are in fact higher in cost as they have too many bearing housings to be incorporated into its design with no advantages. Removal of the rotating assembly for repairs and maintenance is tedious and time consuming, failing to justify their costly prices against end-suction pumps.

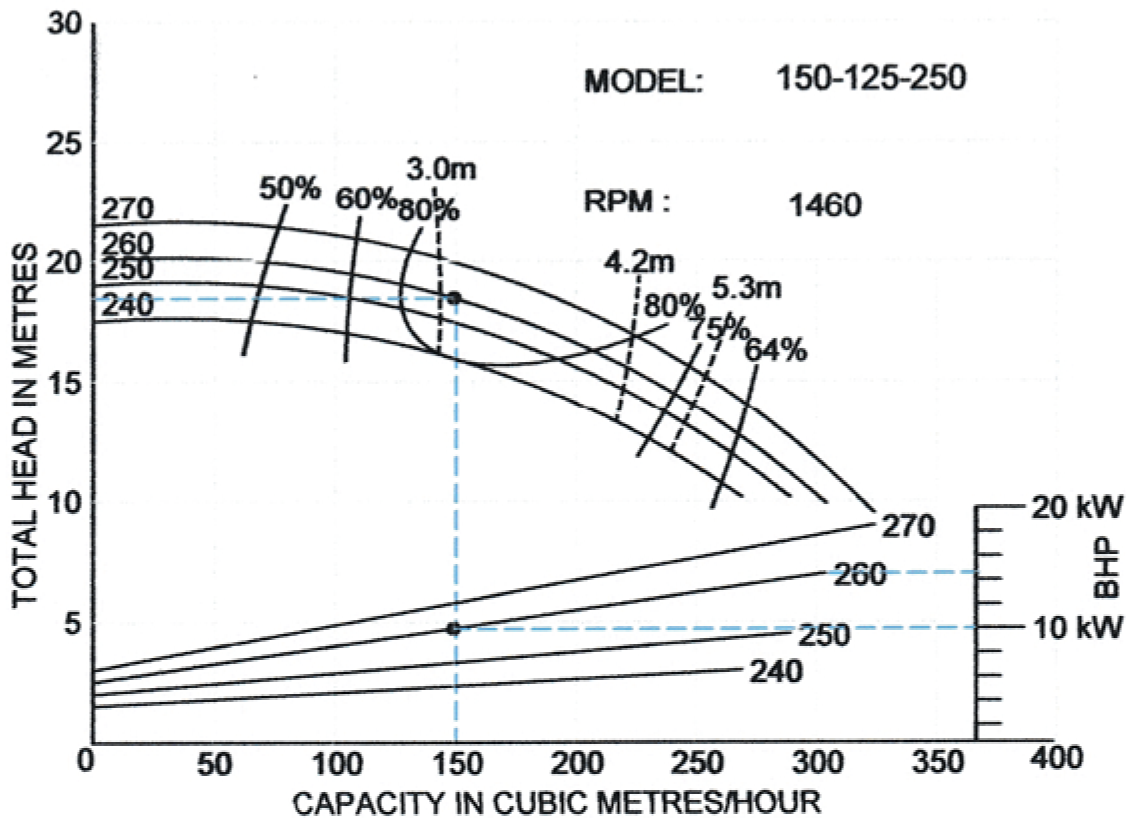
Similar to all equipment manufacturers, pump manufacturers subject their products to stringent and vigorous tests to ascertain and confirm their performances to enable the results to be published as pump curves. These performance curves provide engineers with information to guide pump selection. The performance curve is the easiest way to show graphically the relationship between parameters including head, capacity and horsepower of any pump. A typical pump curve is shown in Figure 5-5.



Typical VSC Pump Installation Details
Figure 5-4

The pump's flow capacity, in cubic metres per hour, is shown on the x-axis of the performance curve. The total head in metres is shown on the y-axis. In America, this head will be in feet and the capacity in US gallons per minute. Please note US gallons differ from British gallons. The amount of flow varies with the head generated. An increase of head causes a decrease in flow. The pump efficiency varies with the capacity and head of the pump. The line sloping downward from left to right is the varying capacity of this particular pump with variations in head or pressure. The number on this curve represents the diameter of the impeller. In this case 270-millimetre is the maximum impeller diameter of this pump. All pump distributors usually stock their inventory with pumps having maximum impeller diameters. You will notice that there are four curved parallel lines shown in this performance curve. These curves show the actual pump performance with various impeller diameters. Impellers can be trimmed in a machine shop to match the impeller to the head and capacity in the application. The intersection of these lines with the zero capacity line shows the “shut-off head” or pressure developed by the pump when the discharge valve is fully closed.

Knowledge of the shut-off head or pressure is critical in swimming pool filtration systems. Most mass-produced swimming pool filters are designed to withstand a maximum operating pressure of fifty psi and are tested to seventy-five psi. Of course, purpose-built filters can be designed to withstand higher operating pressures but at higher costs with thicker materials. If the delivery valve is fully closed, the filter will be subjected to the shut-off head or pressure. This must be within the safe operating pressures of the filters.



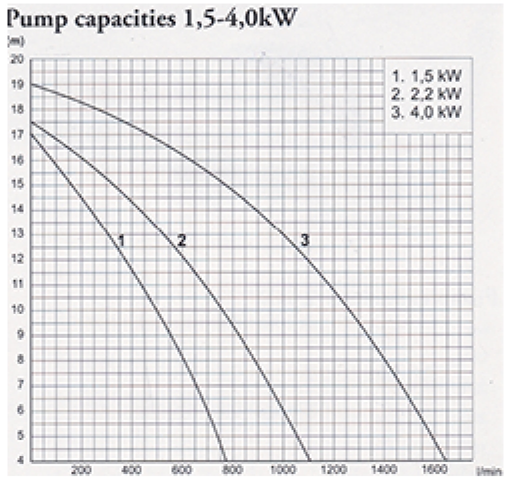
1460 RPM Pump Curves
Figure 5-5

The line indicating the horsepower required to drive the pump slopes upward from left to right. For all impeller diameters the lowest horsepower required to drive the pump is at the shut-off head of the pump. These lines indicate the required amount of driver horsepower at different points of the performance curve. You will notice from the performance curve that for all the different impeller diameters, the horsepower required to drive the pump increases with the flow and decreases with the increase of head.

The point on the curve where the capacity and head match the application's requirement is known as the duty point. The pump's flow is dependent on the amount of resistance or head it encounters in the pipeline. To attain the desired flow, it is necessary to restrict the discharge from the pipeline with the installation of a control valve on the delivery line. The valve on the suction line should never be used to restrict the pump's flow, as this could lead to serious damages to the pump. In swimming pool filtration systems, the strainers on the suction lines of the circulation pumps must be regularly cleaned as clogged strainers restrict water flow. This is similar to air-conditioner systems, where dirty air filters restrict efficient air flow.

If we require a flow of 150 cubic metres per hour of water at eighteen metres head, it can be seen from the performance curve shown in Figure 5-5 that the pump fitted with a 260-millimetre diameter impeller will be capable of performing this duty. This duty point is represented by the dot planted on the curve. At this duty point, the corresponding required brake horsepower (BHP) is ten kW. When selecting a motor to drive the pump, it is important to consider whether the pump will ever be required to operate at a higher flow than at the calculated duty point, as this will result in an increase in the required brake horsepower. If someone unknowingly opens the control valve fully in the delivery line, the duty point could be shifted to the end of the curve. As a good practice, it would be wiser to select a motor to drive the pump to meet the brake horsepower at the end of the curve. This is termed as the non-overloading horsepower to fully meet any drastic changes in the pump performance. In our example it should be a fifteen kW motor.

Swimming pool circulation pumps are sized and selected to deliver the required treatment rate when the filters are dirty. When the filters are clean, the head is lower than the calculated head and the flow of water through the filters is greater than the required treatment rate. Under such circumstances, the brake horsepower required to operate the pump is greater than necessary. To save on power consumption, for the newer filtration systems, an electro-magnetic flow meter together with a motorised butterfly control valve is installed on the main delivery line to the pool. The electro-magnetic flow meter will throttle the motorised butterfly valve and decrease the speed of the motors when the flow rate exceeds the designed flow rate. By such actions, the electrical power consumption is minimised.



Pahlen Swimming Pool Pump Curves
Figure 5-6

Swimming pool pump manufacturers do not provide pump performance curves with such details as indicated above. Their performance curve for each pump model will be a single line sloping downward from left to right indicating the varying capacities with variations in head. The size of impeller and the pump efficiencies at different operating points will not be provided. These pumps are tested with the largest impeller and coupled with non-overloading-horsepower motors. All purpose-built swimming pumps are provided with motors operating at 3,000 rpm. The performance curves of some of PAHLEN swimming pool pumps are shown in Figure 5-6. The y-axis indicates the head in metres and the x-axis provides the capacity of the pumps in litres per minute.

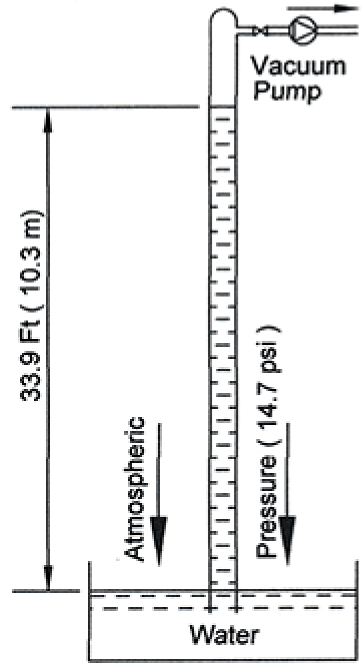
When we need extra water pressure to clean our filter elements, this extra pressure is called demand pressure. This pressure is usually expressed in pounds per square inch, or psi. One psi is equaled to 2.3 feet head of water, that is, if you weigh a column of water of one inch square by 2.3 feet high, it would weigh exactly one pound. Or if you have 2.3 feet height of water in a tank, the water pressure in the pipe taken at the base of it will be one psi. So if the water height is 23 feet, the pressure will be ten psi. The horizontal cross-sectional area of the tank is immaterial, only the height of the water to the take-off point is of paramount importance.

This salient property of water is put to good use for its supply by gravity to residents staying in high-rise apartments, with immense savings in electrical power. Water to the first three lower levels of the high-rise apartments is usually supplied directly from the water authorities' mains. Water required by the residents in the higher levels is supplied from roof-top water storage tanks. This water is delivered by pumps from the water-storage tank located on the ground level. Water-level control switches in the roof-top water-storage tank will trigger the ground-level pump or pumps to deliver water when the water level in the roof-top storage tank falls to a certain unacceptable low level. Residents staying at the lower levels, above the third level, of the high-rise apartments will have greater water pressure than those staying in the higher levels due to the greater water height of fall. During non-peak usage hours, residents in the upper most level will not sense the depressed water pressure, as the water level in the roof-top storage tank is sufficiently high to provide sufficient pressure. However, during peak usage hours, residents staying at the highest level will sense a loss of water pressure. Due to the high water consumption, the water level in the roof-top storage tank falls very rapidly, faster than the water supply rate from the ground level pump or pumps. As a result, those residents using instant water heaters will not have hot water as most instant water heaters will not work with lesser water pressure. This is a safety feature incorporated in the heater design to protect the device to ensure the heater elements will not be energised when there is insufficient water flow. Most instant heater manufacturers employ pressure switches as the safety-sensing device. To appease residents staying at the higher levels, the public housing authorities in Singapore have progressively installed water-pressure booster systems in these high-rise apartments to be operational only during the peak usage hours with the aim of conserving power consumption.

A few years ago, I was consulted to solve an installation problem for a hotel in a secluded area in the eastern part of Singapore. The swimming pool was located on the 15th level and the DE filtration plant was situated two levels below ground level. Each level of the hotel was about three metres high. The water pressure at the filtration pump suction was approximately twenty-five psi without the pumps in operation. The installer of the filtration system did not seriously take the height of fall of water into consideration.

When the filters are clean, the pressure gauges will usually register pressure readings of about ten psi. As the filters become clogged with dirt, the pressure readings will creep upwards. In this unfortunate situation, the head of the filtration pump was unduly oversized by the original installer. After a few days of operation of the filtration system, the upper halves of the DE filters were dislodged in the wee hours of the hotel's operation. All the water in the rooftop swimming pool and balancing tank were emptied into the basement plant room.

Fortunately, submersible pumps were installed for dewatering in the basements, as otherwise the basement would have been converted into a swimming pool. The PVC piping connected to the swimming pool circulation pumps were completely distorted indicating that they must have been continuously running despite the depletion of water in the balancing tank. It was a nightmarish experience for the facilities manager of the hotel. The installer, lacking technical knowledge, could not provide any sensible response to the hotel management's requirement for proper and logical explanations. Surprisingly, the consultant employed to oversee the hotel project overlooked the simple possibility of this happening.



The Might of Atmospheric Pressure
Figure 5-7

As fate had it, when I commenced business, I was entrusted to supply and install the complete piping systems including supply and installation of a potable water treatment system for a tetra-pak milk plant by a Swedish Company in Jogjakarta, Indonesia. The plant's piping system consisted of steam, steam condensate, compressed air, icy water, cooling water and potable water.

The pipes for the steam, steam condensate and icy water systems required external insulations. Provisions had to be made for the elongations and contractions of the pipes for the varying temperatures. The pressure of the steam from the steam boiler required reductions to different pressures at various points of use. Many good and useful lessons were learnt in the execution of the hectic project.

There were two ways to solve this hotel's simple problem. A pressure-reducing valve could be installed on the suction line or the circulation-pump impellers could be trimmed to ensure the pressure attained in the system would never reach the safe maximum operating pressure of the filters. The cost of a corrosion-resistant spring-loaded pressure-reduction valve is relatively higher than trimming the impellers. The hotel management selected the second option.

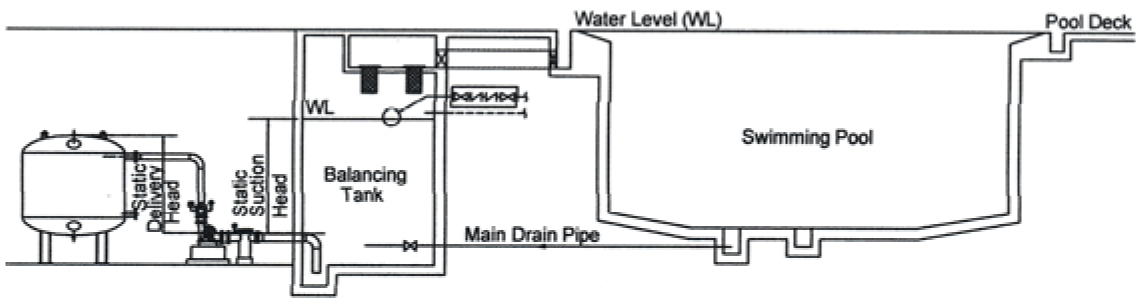
All over the world, dams are built to raise water from the level of the original riverbeds to higher levels. By the natural flow of gravity, the water power is used to drive hydraulic turbines. The turbines change the kinetic energy of the moving water into rotational energy which turns generators to generate electricity for homes and industries, harnessing massive benefits from water. High capital outlay, but low in maintenance and operating costs.

Daily, at sea level we are subjected to an atmospheric pressure of 14.7 psi. Such pressure is also constantly acting on all water surfaces. We do not feel any discomfort as we have been subjected to this pressure since birth. As we move higher above sea level, this pressure will decrease causing unpleasant health problems. As we dive deeper into the sea, we will be subjected to greater pressure with greater life risks. It is the presence of this atmospheric pressure that pump manufacturers use to conceptualise their designs.

If all the air in the sealed pipette in Figure 5-7, with one end immersed in a container of water, is expelled completely by the vacuum pump, that is elimination of atmospheric pressure in the tube, the atmospheric pressure will be capable of forcing water into the pipette to a height of 10.3 metres. The centrifugal pump is employing this basic principle for the pumping operation.

The spinning impeller in the pump throws out water in the pump casing, reducing the atmospheric pressure not only in the casing, but also in the suction pipe between pump and water supply. Most pumps are capable of reducing the pressure in the suction pipe to about eleven psi below atmospheric pressure. This will translate into the external atmospheric pressure capability of pushing the water to a height of twenty-five feet into the suction pipe, that is, a suction lift of twenty-five feet. Practically, most pumps operate efficiently with a suction lift of fifteen to twenty feet range.

In the above hotel incidence cited, the filtration system is termed as flooded suction in the physics of pumping. When the water level of the water source is above the centerline of the pump suction, a suction head exists.



Static Suction Head
Figure 5-8

Figure 5-8 depicting a filtration system installed adjacent to the balancing tank will provide a clearer and better understanding of the term “static suction head”. Static suction head is the vertical distance in metres from the top of the operating water level in the balancing tank to the pump centre. There are two water levels in the balancing tank — the operating and non-operating water levels. When the circulation pump is in operation, the water level in the balancing tank will fall slightly as water is delivered via the filters to the swimming pool. A thin film of water will be suspended above the overflow edge of the pool, causing this slight drop in water level in the balancing tank. This will be discussed in greater details in Chapter 9 of the book. The calculation of the total dynamic head (TDH) for a filtration system with flooded suction is indicated by the formula below:

TDH = **Total Discharge Head – Total Suction Head**, where

Total Discharge Head = Static Delivery Head + Total Frictional Loss in the Delivery Pipe
Total Suction Head = Static Suction Head – Total Frictional Loss in the Suction Pipe

The static delivery head is the vertical distance in metres from the centre of the pump to the highest point of the filter or filters. It requires power to drive a car on the road to overcome friction so similarly it takes power to push or suck water through a pipe. The faster the car moves, the greater is the power required to propel it forward.

This phenomenon is the same in pipes. If we double the quantity of water flowing through a pipe, it must obviously flow at twice the speed. This will result in increasing the friction greatly. The doubling of flow does not mean the friction is also doubled. The increase of friction can be greater than four-fold. The larger the diameter of the pipe, the lesser will be the frictional losses for the same quantity of water flow.

Frictional loss must be calculated separately for the suction and delivery pipes. Tables or charts of friction head loss of water can be obtained from the various pipe suppliers. Different pipe materials have different frictional loss for same flow rate. The smoother the internal surface of the pipe, the lesser will be the frictional head loss. A friction head loss table usually indicates the frictional head loss in metres per 100 metres for the different flow rates for the various pipe diameters. So the length of the suction or delivery pipe must be established. Frictional loss in fittings is greater than in straight pipes. For purposes of calculation, frictional losses in fittings can be expressed in equivalent length of straight pipe.

If the coefficients of friction of the fitting is known, you can use the following formula to determine the head loss through the fitting:

$$\mathbf{h} = \frac{\mathbf{k \times v^2}}{\mathbf{2g}}$$

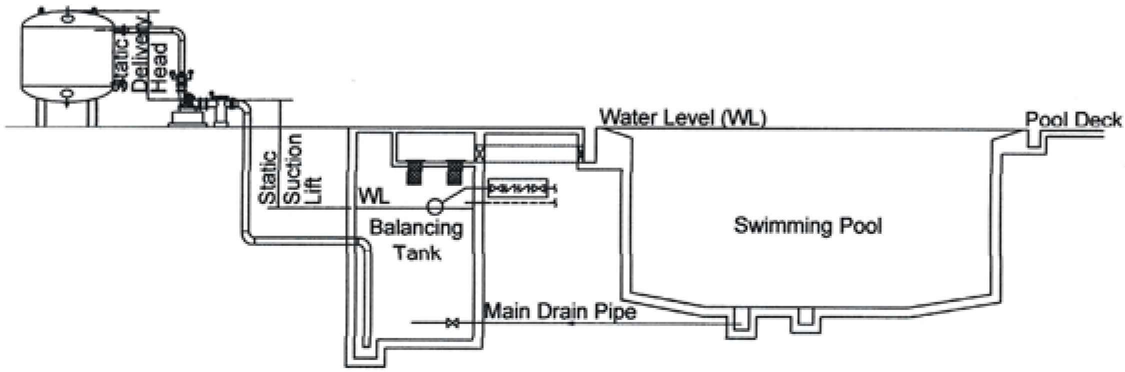
where, h = Head loss in metres
k = Coefficients of friction of the fitting
v = Velocity of flow of water in the pipe in metres per second
g = Acceleration of gravity, 9.81 m/s

$$\text{As } \mathbf{Q} = \mathbf{A \times V}$$

where, Q = Rate of flow in the pipe in cubic metres per second
A = Cross sectional area of the pipe in square metres
V = Velocity of flow of water in the pipe in metres per second

$$\mathbf{V} = \frac{\mathbf{Q}}{\mathbf{A}}$$

The total frictional head loss in the suction and delivery pipes will be the sum of the head losses through all the straight pipes, bends and all the fittings.



Static Suction Lift
Figure 5-9

If the swimming pool filtration system is located above the balancing tank, a suction lift condition is created. The calculation of the total dynamic head (TDH) will be:

TDH = **Total Suction Lift** + **Total Discharge Head**, where

Total Suction Lift = Static Suction Lift + Total Frictional Loss in Suction Pipe
Total Discharge Head = Static Delivery Head + Total Frictional Loss in Delivery Pipe

Figure 5-9 will ease the understanding of this concept. The calculation for the total dynamic head is similar to the earlier discussed example.

As a rule of thumb, if the velocity of flow in the suction and delivery pipes does not exceed two and four metres per second respectively, a circulation pump capable of delivering the required quantity of flow at eighteen metres head will suffice to meet the head requirement of the filtration system. The suitable diameter of the pipes, d, can be determined by using the following formulae:

$$A = \frac{Q}{V}$$

$$d = \sqrt[2]{\frac{(A \times 4)}{\pi}}$$

Ideally, for commercial pools, to minimise noise in the plant room, the operating speed of the circulation pumps should not exceed 1,500 rpm. On entering any swimming pool filtration plant room, if you are unable to converse with those around you in your normal tone, it will instantly indicate that it is a bad and poor installation. To determine whether there is a mechanical problem with the pump, stop the operation of the circulation pump and drain it. Close both the suction and discharge valves and operate the pump briefly. If the noise persists, then it is a mechanical problem with the pump. The noise can be due to the impeller rubbing against the casing, faulty bearings, misalignment or worn coupling or damaged pump shaft. Simply dismantle the pump for inspection to rectify the fault or faults accordingly.

If the noise disappears in the above investigation, more often than not the noise is caused by the under-sized suction piping, that is, the diameter of the suction piping and other fittings must be larger than installed. Check the vacuum reading of the pump with a vacuum gauge. If the reading is high, it will confirm a suction cavitation. Under-sized suction pipe, high suction lift, high friction loss in the suction line, partially closed suction line valve or clogged line all contribute to suction cavitation. Many circulation pumps in several of our public pools had been repaired and replaced and found to have pitted pump shafts and impellers as thin as a piece of paper. On all instances, all in very noisy plant rooms. These are results of improperly and incorrectly sized suction pipes resulting in damages to the pumps.

Cavitation occurs when the water vapourises as it enters the pump and then quickly turns back into water. The continuous collapse of the vapour bubbles creates destructive water microjets strong enough to pit the impeller and shaft. Cavitation can be easily solved by reducing the frictional losses in the suction line.

Suction cavitation occurs when the net positive suction head available (NPSHA) is lesser or smaller than the net positive suction head required (NPSHR).

In a flooded suction system, NPSHA = Atmospheric Pressure – Vapour Pressure + Height of Water above Pump Centre – Frictional Loss in Suction Pipe.

In a suction lift system, NPSHA = Atmospheric Pressure – Vapour Pressure - Height of Water below Pump Centre – Frictional Loss in Suction Pipe.

The vapour pressure is the pressure pushing against atmospheric pressure on liquids at elevated temperature. For water, at 212 degrees Fahrenheit or 100 degrees Celsius, the vapour pressure is 14.7 psi. NPSHR is a function of pump design, capacity and operating speed. It is measured at the pump suction at the test bench of the pump manufacturer. Some pump manufacturers incorporate the NPSHR curves in their pump performance curves. In Figure 5-5, the pump manufacturer incorporated the NPSHR curve in their pump performance curves. The dashed elliptical lines indicate the NPSHR at various points of the pump’s application. The NPSHR can be interpolated on this curve at the required duty point. For our duty point, the NPSHR is about three metres. Some pump manufacturers provide these NPSHR curves to slope gently from left to the right below the head to capacity curve. It is imperative for all pump installations to ensure that NPSHA does not exceed NPSHR to avoid suction cavitation.

Most commercial or municipal pools employ chemical metering pumps to inject chemicals into their swimming pool filtration or circulation systems to disinfect or correct the pH of the water or for adding coagulants to improve filtration. All metering pumps are positive displacement pumps.

Most diaphragm metering pumps used for swimming pool filtration systems are of thermoplastic construction to withstand the corrosive chemicals. These are either driven by electric motors or actuated by solenoids. They can run dry without damaging the pump.

The inlet and outlet of metering pumps are usually fitted with thermoplastic ball check valves, one-way valves, to the pump head.

The inlet valve permits a solution to enter only via the suction line into the diaphragm chamber, not the reverse direction. The outlet valve permits the solution to be delivered from the chamber, not the reverse. The motor or solenoid causes the diaphragm to pulsate causing the volume of the chamber to become smaller or larger repeatedly. When the diaphragm moves back from the chamber, a vacuum is created, as a result the atmospheric pressure will force the solution into the chamber through the inlet check valve. When the diaphragm moves forward, it will pressurise the solution in the chamber causing the inlet valve to close. The higher pressure will cause the outlet valve to open resulting in the solution to be discharged. This metering rate can be easily adjusted by varying the stroke length with which the diaphragm moves back and forth or the speed of the diaphragm motion. The metering pump must be capable of delivering the desired quantity of solution into the system by overcoming the pressure in the filtration pipe that it is delivering into, that is overcoming the back pressure.

On automatic control mode, the metering pumps in the swimming pool filtration system will operate only when the filtration or circulation pumps are in operation: that is, they are electrically interlocked. From the schematic drawing shown in Figure 4-7, the operation of the metering pumps, in addition to being electrically interlocked, can also be controlled by programmable logic controller (PLC).

With so much advancement in electronics technology, the PLC can automatically vary the stroke and speed of electronic solenoid metering pumps. The stroke and speed of the metering pump are manually set at maximum capabilities. When the sensor detects that the water quality is far from the desired setting, the metering pump will automatically operate at maximum stroke and speed. As the quality of the water approaches the desired setting, the stroke and speed of the metering pump will decrease and stop once the desired setting is attained.

Submersible pumps are of cast iron and stainless steel construction. The smaller submersible pump can be of thermoplastic construction. The basic duty of a submersible pump is for dewatering. Its operation is usually controlled by water level switches.

Filtration pumps are provided either with threaded inlet and outlet or flanges for connections to other components of the circulation piping systems. Small purpose-built American swimming pool pumps are provided with their national pipe threads (NPT) which are different from the British standards pipe threads (BSP) and metric threads. For residential pools, usually PVC pipes and fittings are employed for the filtration system installations. If the installation is using Schedule 80 PVC pipes and fittings, the connections do not pose a problem as such pipes and fittings are manufactured to American piping standards. However, if PVC pipes and fittings manufactured to Japanese industrial standards (JIS) are used for the installation, such an installation would meet with slight problems. Some fittings will have to be specially machined to connect to the pump inlet and outlet, as JIS fittings pipe threads are quite similar to the British standards, but the diameters of the PVC pipes are different to the British. PVC materials are quite versatile. They can be heated to be enlarged or forced to reduce slightly in diameter. So before any installation can be effected, it is important to note the type of pipe threads that are provided on the pumps and all other equipment.

American-made pumps and fittings are equipped with American standards flanges. From the Flange Tables provided in Appendix IV of this book, you will realise that the dimensions of flanges vary with the different flange standards. If the pumps are especially purchased for a project, the standard of the flanges to be provided can be specified to suit and ease the piping installation. The same is true for all other fittings to be used in the project. Knowledge of these minor details will facilitate project execution.

6: Disinfection

While filtration makes the water clear and inviting by removing suspended matter, chemical treatment of invisible contamination is vital to the safe operation and proper maintenance of the pool. The purpose of chemical treatment is to disinfect the pool water by killing algae, bacteria and microorganisms.

Chlorination is especially suitable for disinfecting swimming pool water as it has the property of maintaining a disinfectant residue to combat any pollutant that will be introduced into the water. The use of ultraviolet sterilisers and ozone to treat pool water cannot fully replace chlorination as they have no disinfectant residue in the pool water.

Chlorine product is available in different forms. As a gas, chlorine is supplied as a liquefied gas in pressurised cylinders or drums; as a liquid, commercial sodium hypochlorite solutions are available with concentrations of two to fifteen percent, on-site generated sodium hypochlorite has a concentration of less than one percent; or as a solid. Calcium hypochlorite is available in powder or tablet form that releases sixty-five percent of its weight in free chlorine when dissolved in water. Trichloroisocyanuric Acid (TCCA) tablet releases ninety percent of its weight in free chlorine when dissolved in water. Iodine and bromine are also used, but less often due to costs.

If chlorine in any form is added before the water passes into the filtration system, it is termed as pre-chlorination. If chlorine is dosed into the water after passing through the filtration system, it is called post-chlorination.

Three decades ago, the most cost-effective gaseous chlorine was used to sanitise water in public and commercial pools in Singapore. For most private and condominium pools, powder chlorine was and still is the preferred choice due to the ease of handling. Chlorine is a yellowish-green poisonous gas with strong unpleasant odour. Chlorine causes irritation to the nose, throat and lungs. Germany employed the use of chlorine during World War I. Gas warfare proved so destructive that most nations agreed to avoid its use during wars. Once wet, chlorine is highly corrosive and all materials used in connection with its supply must be suitably resistant.

During those cost-saving days, manufacturers usually supplied chlorine gas in cylinders to small commercial consumers. For municipal potable and sewage water treatment plants, they were supplied in ton containers. As chlorine is very corrosive, the cylinders were housed in rooms separate from the filtration equipment.

Direct cylinder-mounted chlorinators were widely used to dispense the gas to the application points. The yoke of the chlorinator is designed to fit easily over the chlorine cylinder valve and the adaptor mates exactly with the cylinder valve outlet. A malleable lead gasket is positioned between the chlorinator inlet and the cylinder outlet to make a tight seal when the yoke screw is tightened. On completion of tightening of the yoke screw, the gas cylinder outlet valve must be opened to check for leakages. An open bottle of ammonia held below the connection will give off a white vapour if chlorine is escaping. In the event of a leak, the outlet valve of the cylinder must be closed immediately and the tightening process rectified. The ejector comprising a nozzle and diaphragm-operated check valve is installed at the point of chlorine application. A pressure-booster water pump is installed to create a vacuum in the ejector. This vacuum causes the spring-opposed diaphragm check valve to open in the ejector. When the spring-opposed check valve opens, a vacuum signal is sent to the vacuum regulator mounted on the gas cylinder via the connected tubing. This vacuum causes the diaphragm to open the chlorine-inlet safety valve, permitting gas to flow through the tubing. Chlorine gas passes through the flow meter and rate-control valve to the ejector where the gas is thoroughly mixed with and dissolved in the water and carried as a solution to the point of desired chlorination through the ejector outlet.

For the safety of plant room operators, chlorine leak sensors are usually installed above floor level near the cylinders as chlorine is denser than air and will sink to the floor level if there is a leak. The chlorine sensor will trigger the exhaust fan, also installed slightly above floor level, on sensing chlorine in the air. Due to a few nasty accidents caused by untrained and or poorly trained maintenance personnel resulting in plants being destroyed and personnel being hospitalised, the local Environmental Health Department (EHD) discouraged the use of gaseous chlorine in swimming pools, hence promoting the use of sodium hypochlorite (NaOCl) in public pools.

The amount of chlorine dosage is dependent upon the dirt and germs in the water as well as the sun and wind. The chlorine residual should be maintained between 1.0 and 3.0 ppm (parts per million parts of water).

The addition of chlorine gas to water results in the formation of hypochlorous and hydrochloric acids as shown in the following chemical reaction:

$$\mathbf{Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^-}$$

The hypochlorous acid represents the “free available chlorine” which is an extremely powerful bactericide.

Hypochlorous acid is very unstable and breaks down readily to release free chlorine for disinfection purposes. Hydrochloric acid contributes nothing to the treatment process, but is stable and increases the acidity of the water. This change in acidity is a typical side effect of any process of disinfection and requires additional chemicals to counteract it. Excessive counteraction in this case would result in too much alkalinity.

Sodium hypochlorite is a by-product of chlorine manufacturers. Sodium hypochlorite is more expensive than chlorine gas when compared on a free available chlorine content basis. By adding chlorine gas (Cl_2) to caustic soda (NaOH), sodium hypochlorite (NaOCl), salt (NaCl) and water (H_2O) is produced as shown by the following chemical reaction:

$$\mathbf{Cl_2 + 2NaOH \rightarrow NaOCl + NaCl + H_2O}$$

Commercial sodium hypochlorite is a clear, pale yellowish green solution and smells distinctly of chlorine. Sodium hypochlorite is generally manufactured as aqueous solutions containing twelve to fifteen percent sodium hypochlorite. As it is unstable, it is sold as having only ten percent sodium hypochlorite, as it will lose one to two percent concentration when transported to the buyers. For solutions of less than one percent concentration, the degradation is slower so that changes in concentration will be negligible. Due to the presence of caustic soda in sodium hypochlorite, the pH of the water will increase when dosed. Hydrochloric acid (HCl) is used to lower the pH. Due to the presence of salt, the salinity of the swimming pool water will rise. However, this is counteracted by routine replacement of water lost from evaporation and backwashing of filters. When sodium hypochlorite is added to water, hypochlorous acid is formed:

$$\mathbf{NaOCl + H_2O \rightarrow HOCl + NaOH}$$

The hypochlorous acid (HOCl) liberates the oxygen (O) to oxidise the impurities in the water and hydrochloric acid (HCl) is produced. Sodium hypochlorite disinfects the same way as chlorine does.

As shown in Figure 4-7 and Figure 7-2, public or commercial pools will have big storage tanks to contain sufficient solution to last ten to fourteen days of use. Similar to chlorine cylinders, these tanks should be housed in a separate well-ventilated room away from the other filtration equipment. These solutions are piped to a day-tank for daily use. Depending on the bathing load and weather, sometimes the storage solution could last only seven days as the metering pump dosing rate is controlled by PLC.

Bathing loads in Singapore public swimming pools are particularly high as on schooling days, the primary school students are ferried in busloads to the swimming complexes for their swimming lessons as part of their study curriculum. All military personnel must be able to swim at least one length of an Olympic-size pool, as otherwise they will be retained for night or weekend swimming lessons. The strategy is to maximise the use of public facilities. However, the entrance fees to swimming complexes are relatively low by any standards. The monthly entrance fees collected are insufficient to cover the utilities and chemical costs, let alone the administrative and maintenance costs including other labour costs such as hiring life guards. Operations of public pools are heavily subsidised by public funds.

In Hong Kong, On-Site-Sodium-Hypochlorite-Generating-Systems (OSSHGS) are widely used in their public swimming pools. This on-site generation process begins with filling the salt (NaCl) dissolving tank with water that has been softened through a water softener to remove calcium and magnesium from the feed water. Salt is then poured into the salt dissolver tank. Salt has a property in that it will automatically dissolve to form a thirty percent brine solution. One part of this brine is then diluted with twelve parts of softened water to attain a 2.6% salt solution that is pumped through the electrolyser cell. The cell applies a low voltage DC current to this brine and 0.8% sodium hypochlorite is produced on-site. The cell electrolyses this brine solution into sodium hypochlorite as per the following equation:

$$\mathbf{NaCl + H_2O + 2e \rightarrow NaOCl + H_2}$$

Salt + Water + Energy → Sodium Hypochlorite + Hydrogen

The sodium hypochlorite solution produced by the electrolyser is forced by the water pressure to flow to the storage tank. The dosing pumps will extract the sodium hypochlorite from the storage tank to dose into the circulation system.

Hydrogen is the only by-product of the on-site sodium hypochlorite-generating system. To prevent the gas from increasing to potentially dangerous concentrations, an air blower blowing air into the storage tank is employed to dilute it well below flammable level.

Titanium electrodes are employed in the electrolyser cell to minimise corrosion of the electrodes. If the incoming water to the OSSHGS is not softened, the calcium and magnesium salts will be deposited on the cathodes. These deposits will close the electrode gap causing reduced electrolysis and electrode degradation, thus requiring frequent maintenance cleaning to protect the electrodes. Cell cleaning is a routine part of the maintenance program.

Huge initial capital outlay is required to install an OSSHGS as titanium, used for the anodes and cathodes, is an expensive material. I was fortunate to be able to discuss this matter with a few relevant officers in Hong Kong. I was told the OSSHGS had a lower operating cost than commercial hypochlorite and, in fact, paid for itself within four years of installation. The maxim that high initial capital outlay for equipment will result in lower operating and maintenance costs holds true again. Salt is the only item to be stored thus enhancing public safety.

Many years ago, an OSSHGS was installed by a vendor in a public swimming pool in Singapore for evaluation. On learning of this exercise, the supplier of sodium hypochlorite immediately voluntarily slashed the selling price drastically in the midst of the supply contract to kill competition. This evaluation exercise was never revisited.

In Australia, salt chlorinators are very popular with home pool owners. These are in-line salt chlorinators. In such systems, the in-line salt cells are installed on the return lines to the pools. Salt is poured directly into the swimming pool. On start-up, about fifty kilograms of salt is poured into the swimming pool for every cubic metre of pool capacity, that is, 5,000 parts per million (ppm) salt concentration is created. This salinity requirement varies marginally for different makes of salt chlorinators. Salt makes the water conductive so that electricity can pass between the plates in the cell. The electric controller sends power to the salt cell to convert the salt to chlorine to disinfect the water. The quantity of chlorine produced is regulated by the duration of power applied to the cell. The electric controller is also equipped to sense the level of salt in the pool water and indicate the need to add more salt. If the system indicates a low salt level, the water should be tested with a salt test kit before adding salt. If a salt cell is scaled or failing, it may give a false indication. The scales in the salt cell can be removed with dilute hydrochloric acid. Self-cleaning units have a feature to reverse the polarity of the voltage through the cell to clean any scale on the cell plates.

Salt chlorinators are popular in places where it is difficult to purchase chlorine products to disinfect the swimming pool water. Surprisingly, it fails to gain popularity in Singapore. Most of the home pool owners felt that the fewer the moving parts or equipment that are installed in their filtration systems the fewer will be their maintenance headaches. This is probably reinforced by the absurdly ridiculous meagre price offered by private pool-servicing organisations to service home pools inclusive of supply of all chemicals.

Worldwide, there are many manufacturers of powder chlorine that is a dry, white compound available in granular and tablet forms. It must always be stored in a cool dry place. When dissolved in water, it releases a certain percentage of its weight in free chlorine, but with a different effect on the pH than chlorine gas. As a result of the alkalinity, usually due to the calcium by-product, the pool water will become alkaline thus requiring the addition of acid to restore the balance.

I have a brilliant and shrewd Middle-Eastern friend who builds about 2,500 swimming pools a year, a contrast to the smallness of our domestic market. After declining his many invitations, I visited him in the early 1990s. He employed at least four hundred foreign workers. Due to the huge market size, he imported chlorine powder by container loads from any reputable manufacturer who offered him the best price but with his own brand name printed on the thermoplastic containers, providing him with massive passive income. The original manufacturer's details were never indicated on the containers. Any reputable manufacturer capable of offering him a better price would receive his subsequent orders with the same conditions attached. At that juncture, I was puzzled that no such marketing strategies were adopted by our largest home-grown supermarket to promote their own house brands.

Powder chlorine or calcium hypochlorite, $Ca(ClO)_2$, is manufactured using the calcium or sodium process. In the sodium process, it is produced by adding chlorine gas over slaked lime as shown in the following chemical reaction:

$$2Cl_2 + 2NaOH + Ca(OH)_2 \rightarrow Ca(ClO)_2 + 2NaCl + 2H_2O$$

If it is produced by calcium process, it is shown in the following chemical reaction:

$$2Cl_2 + 2Ca(OH)_2 \rightarrow Ca(ClO)_2 + CaCl_2 + 2H_2O$$

Usually it is dissolved in water for use. When calcium hypochlorite is dissolved in water hypochlorous acid is formed as shown in the following equation:

$$Ca(ClO)_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HOCl$$

For home pools, the powder is usually dissolved in a plastic bucket. The lime content is insoluble and the solution should be allowed to settle before use. Only the clear liquid should be poured into the water around the pools. The importance of using only the clear liquid is that the residue of calcium carbonate would form lime scale on the walls and floor of the pool.

For condominium pools, the solution is usually prepared in a thermoplastic tank. The tank is filled with water and the required quantity of powder is added to form a known concentration. With the aid of a motorised agitator, the chemical solution is prepared. At the end of the suction line of the dosing pump, a strainer and foot valve is provided to minimise drawing of the sediments that has sunk to the bottom of the tank. The suction line is placed way above the bottom of the tank. Periodically, the collected sediments have to be cleared as good maintenance practice.

Calcium hypochlorite and TCCA tablets can be placed in the baskets of the automatic skimmers by home pool owners to allow them to be dissolved slowly. Use of floating chlorinators is discouraged as they will pose danger to children. For condominium pools, they are sometimes placed in the overflow drains to allow them to be dissolved slowly.

Erosion-type chlorine feeders can also be installed to dispense the chlorine from the calcium hypochlorite and TCCA tablets to the pool. The off-line feeder is preferred than the in-line feeder. The off-line chlorinator is free-standing and has tubing that connects to the circulation system. The vertical thermoplastic tubular chamber with a top screwed-on cap is slightly bigger in diameter than the standard seventy-five-millimetre-diameter chlorine tablets. With the removal of the cap, the chlorine tablets can be stacked vertically in the chamber. A narrow diameter tubing fitted with a control valve to divert water from the pump delivery before the filter is connected to the bottom of the chamber. This water is used to dissolve the tablets. The water exits the chamber at the top via the tubing fitted with a control valve connected to the delivery line to the pool. This is to allow the purging of air in the chamber and sending the dissolved chemical solution to the pool. As there is a pressure drop across the filter, the chemical solution will be able to overcome the back pressure on the delivery line. The intended chlorine dosage rate to the pool can be easily controlled by the quantity of chlorine tablets stacked in the chamber and the flow rate of fluid flowing in and out of the chamber determined by the control valves.

As TCCA slowly dissolves in the water, the concentration of cyanuric acid in the pool will build up. At high cyanuric acid concentrations, normal chlorine levels will be rendered ineffective. It is a good practice to supplement the use of TCCA tablets with calcium hypochlorite to ensure the cyanuric acid concentration is kept within an acceptable level. TCCA tablets are seldom used in public pools.

Ultraviolet (UV) sterilisation is an electronic disinfection method that uses mercury-vapour UV lamps, housed in quartz glass sleeves so that the lamps are not in direct contact with the water to kill the microorganisms. The UV lamps emitting 2537-Angstrom wavelength are usually mounted in tubular flow chambers to ensure optimum exposure of the water to the deadly ultraviolet light. UV disinfection is only effective for clear water. Microorganisms buried within suspended particles are shielded from the UV light and will escape disinfection.

The three types of UV energy are grouped according to their wavelength — “long”, “medium” and “short”. The short-wave UV energy with a range from 2000 to 2900 Angstroms possesses the greatest germicidal effectiveness of all UV wavelengths. 2537 Angstroms is considered the peak intensity of the germicidal spectrum of the short-wave UV.

UV sterilisers have no moving parts. Installation consists of piping the water to be treated to the equipment and provision of electrical supply for operation. The lamps are replaced at intervals recommended by the manufacturer for its effectiveness.

As mentioned in Chapter 5, I was given the golden opportunity to install a potable water treatment plant in Jogjakarta for a tetra-pak milk plant. In this factory, their main production line was for the production of S26, a well-known brand of infants' milk powder. The tetra-pak milk products were the by-products of the manufacturer.

The manufacturer had specified that UV sterilisers must be employed for the disinfection of the potable water as they were afraid chlorine would impart an undesirable adverse flavour and taste to their products. They had also indicated they did not have and did not wish to engage nor specially train any personnel to operate chlorine treatment systems.

UV disinfects water without adding chemicals and does not create new chemical complexes or remove any beneficial minerals from the water, nor does it change the taste or odour of water. On completion of installation, a water sample was collected in a sterilised container to confirm the effectiveness of the UV sterilisers.

The chemists in the manufacturer's laboratory were surprised and alarmed that the initial water sample contained a substantial amount of bacteria commonly found in their milk plant. On reviewing the water sample collection process, it was found that the technician collecting the water sample had placed the sterilised bottle at 150 millimetres away from the sampling tap. This was an incorrect method for collection as there should not be any air gap between the sterilised bottle and the sampling tap. By having this air gap, the water was washing the bacteria in the air gap into the collecting bottle. To properly collect a water sample for bacteriological analysis, the sampling tap should be run and then to sterilise it, a piece of cotton wool should be impregnated with methylated spirit, ignited and held underneath the tap on a piece of wire. Great care must be taken to ensure the fingers do not touch the part of the stopper in contact with the sample. Subsequent tests using stringent precautions confirmed the effectiveness of UV disinfections. This incidence also showed that UV sterilisation has no residual disinfectant effect.

As a matter of interest, swimming pool water samples required for coliform and Escherichia coli count tests must also be collected in sterilised bottles. These sterilised bottles can be obtained from the EHD's accredited laboratory to which the sample will be sent for tests. The caps of these bottles are usually tightly capped and sealed. To collect a water sample for this test, the sterilised bottle must be lowered to at least two hundred millimetres below the surface of swimming pool water level without removing the cap and seal. The maintenance personnel collecting the sample must have clean hands. On reaching the required depth into the pool, the cap and seal can then be removed horizontally. The bottle is subsequently tilted slightly to dispel the air to allow the water to flow in. Once the bottle is completely filled, the bottle is capped and sealed underwater. The water bottle is then placed in an ice-packed container and sent to the EHD's accredited laboratory for tests. Usually, the laboratory will store this sample for 24 hours before commencing the tests.

Bottles required for collecting swimming pool water samples for pH and chlorine tests can be any clean bottles. Compact kits for performing these two tests are readily available. It is very important that the indicators and reagents are stored in a cool place away from direct sunlight. Reagents will deteriorate with age and should be replaced yearly. When samples are to be collected for testing, the sample must be as representative as possible of the entire pool water. Water samples collected at or near the return inlets will not be representative as they will indicate the characteristics of the water returning to the pool. All containers used for the tests should be rinsed thoroughly with the water to be tested.

Phenol red is the most widely used pH indicator for swimming pool water testing. A few drops of the testing solution are introduced into the sample collected in a small container. The colour which develops is compared with standard slides normally provided adjacent to the small container in compact test kits.

The test of residual chlorine in swimming pool water is extremely important. Orthotolidine arsenite solution is commonly used for testing in home pools. A few drops of the reagent introduced into the test sample will produce a yellow colour which is compared with the standard slides normally provided adjacent to the small container in compact test kits, but the reading indicates the total available chlorine content in the pool water, not the residual chlorine. This reagent is falling out of favour as orthotolidine is believed to be carcinogenic. As such the tested water sample should not be discarded into the pool.

DPD tablets (NN-diethyl-p-phenylene diamine sulphate) have largely replaced the use of orthotolidine solution testing — colouring the water sample in various shades of red. The darker the red colour, the higher the concentration of chlorine. DPD tablet No. 1 is used to measure the free or “available” chlorine in the pool water. DPD tablet No. 3 is used after DPD1 to measure the total chlorine. The difference between the two measurements is the combined chlorine value. Combined chlorine in excess of 0.3ppm should be treated to bring the level down. Chlorine molecules combine with ammonia and other nitrogen compounds, introduced by bathers into the pool water to form chloramines, which is called combined chlorine. These ammonia and nitrogen compounds are introduced in the form of perspiration, urine, nasal secretions and saliva. These compounds are also introduced into the pool water by rain. Chloramine is the undesirable form of chlorine that does not sanitise but causes irritation and contributes excessively to chlorine odour in the pool water. The excessive chlorine smell in pool water is not free available chlorine, but chloramines.

To eliminate chlorine odours in the pool water, it is necessary to raise the free chlorine residual to 5.0 ppm. The free chlorine then starts to oxidise the chloramines and other chlorine compounds. As these reactions absorb much of the excess free chlorine, the residual falls suddenly to a lower value and the chlorine compounds disappear together with their tastes and odour. This is called the break point, at which most of the chlorine in the water is in the free-state.

Ultraviolet light too has the ability to decompose chloramines to harmless compounds while also providing disinfection power without chemicals.

Ozone is also a strong agent to remove chloramines. By introducing ozone into the pool water it will oxidise the ammonia and nitrogen compounds.

Oxygen molecules have two oxygen atoms and the chemical symbol O_2. Ozone molecules have three with the chemical symbol O_3. Once ozone has done its oxidative work it reverts primarily to oxygen. In the stratosphere, nature produces ozone either by UV radiation or lightning. UV radiation from the sun will break the oxygen molecules into individual oxygen atoms. These atoms quickly attach themselves to the first molecule they encounter. When they join with an oxygen molecule, the tri-atomic oxygen (ozone) is born. When lightning, which is a corona discharge occurring in the stratosphere, strikes the air, the electrical power breaks the oxygen molecules and rejoins them in the same manner as UV radiation.

Mankind replicates nature to generate ozone for the treatment of water by these two methods. In the UV method, air is passed over a UV lamp, from which a small portion of the oxygen is converted into ozone by high radiation energy. This process is far simpler and less expensive from the viewpoint of capital equipment investment than corona discharge ozonators. The main disadvantage of UV-generated ozone is that only a very low concentration of ozone is generated. The low ozone concentration produced by UV generation severely limits its practical use to only residential pools. In commercial pools and spas with heavy bathing loads, UV ozone generators cannot produce sufficient ozone concentrations to carry out effective oxidation of organic contaminants and achieve proper disinfection.

Most UV lamps operate in the 2537-Angstrom range and are primarily used for disinfection purposes. For ozone generation, a wave-length of 1850 Angstroms is normally used. Under ideal conditions, a maximum ozone concentration of 0.1% is produced. A UV lamp operating at 2537 Angstroms produces only trace quantities of 0.001% ozone.

Air preparation is crucial for efficient and reliable operation of corona discharge (CD) ozone-generators. Moist air will cause nitric acid, due to the presence of 78% nitrogen, to form in the ozone generator decreasing ozone production and corroding the generator cell components.

Air preparation is far less important to UV ozone generator than the CD method. Although humidity affects the UV system by loss of ozone production, nitric acid is not formed as in CD systems. Desiccant dryers are employed to dry the air before sending them to the high-voltage ozone-generating cells. This oxygen-containing air is passed between the high-voltage electrodes and glass dielectric tubes. Cooling water surrounding the outside of the dielectric tubes serves as the grounded high-voltage connection. When the high-voltage AC power is applied across the air gap, a corona discharge occurs resulting in ozone generation. The dielectric simply spreads the arcing voltage over the entire surfaces of the high-voltage electrodes eliminating individual heavy arcing. This enables a high current density and an efficient corona to be formed. Typical voltages used in CD generators vary between 7kV and 20kV. The amount of ozone generated is directly proportional to the energy applied to the generation cell. CD is the most widely used method for commercial ozone production.

Ozone is an effective disinfectant but is unstable and cannot be stored for future use. Ozone is only partially soluble in water and has an unpleasant acrid smell above 0.1ppm concentrations. Similar to gas chlorination, an ejector comprising a nozzle and diaphragm-operated check valve is installed at the point of ozone application. A pressure-booster water pump is installed to create a vacuum in the ejector to draw the ozone produced. This water and ozone mixture is sent to a contact tank to enable the ozone to maintain a contact period of two minutes. Ozone is an oxidative and reactive gas that is harmful to humans above certain concentrations and therefore excess ozone must be completely removed by contact with granular activated carbon for ninety seconds before returning the water to the pool. Ozone gas is heavier than air and any ozone not removed could collect at the water surface and be inhaled by swimmers. Carbon is a strong reducing agent. Upon contact with ozone gas, the carbon is oxidised to carbon monoxide and carbon dioxide resulting in the destruction of ozone. Carbon monoxide is slightly less dense than air and will disappear into the atmosphere. This oxidation degrades or powderises the granular activated carbon hence it has a finite life. Due to this consumption, the carbon filter must be backwashed regularly and the media replaced occasionally. Unfortunately, the carbon also removes free chlorine that must then be re-established in the water entering the swimming pool.

To size the contact tank for a system having a treatment rate of say, 180 cubic metres per hour, the treatment rate is converted to cubic metres per minute as follows:

180 cubic metres per hour ÷ 60	=	3 cubic metres per minute
Therefore, the size of the contact tank	=	3 x 2
	=	6 cubic metres

Similar to gas chlorination, ozone gas leak detectors must be installed at floor level to provide a warning at 0.1 ppm and an alarm at 0.3 ppm. On alarm, the ozone generation equipment must be switched off.

Similar to chlorination, the ozone can be dosed either before or after filtration. If it is dosed before filtration, it is termed as single-stage ozonation. Dual-stage ozonation will mean it is dosed after filtration. For either system, the basic design criterion remains the same: requiring two minutes contact with ozone then ninety seconds contact for deozonation.

With single-stage ozonation, ozone contact, deozonation and filtration are carried out in a single vessel. The obvious advantages are the lower capital outlay due to the requirement for only one vessel, lower piping and installation costs, and the ease of retrofitting to existing pool.

The main disadvantage of the single-stage ozonation is that the granular activated carbon (GAC) is employed as a pre-filter, exhausting the carbon faster than the dual-stage ozonation.

In the dual-stage ozonation, ozone contact and deozonation are carried out in separate vessels after filtration. Figure 6-1 shows a typical dual-stage ozonation, where the ozonation process can be by-passed, if required. The obvious disadvantage will be the higher capital and installation costs.

Most of the filterable organic and particulate materials will have been removed by sand filtration in the dual-stage ozonation. As such the GAC will serve as a polishing filter. Due to its lighter duty, the GAC filter will require lesser backwashing.

There are two systems to introduce ozone into commercial pools — the full stream and the slip-stream system. In the full-stream ozonation system, one gram per hour of ozone is introduced into the water for every cubic metre per hour of water to be treated. Figure 6-1 depicts the flow of water to be treated for a full-stream system. The ozonated water is sent to a contact tank to enable the ozone to maintain a contact period of two minutes. Excess ozone is removed with a GAC filter with a contact time of ninety seconds. Should the ozonation system be off-line for any reason, the carbon filter can be easily by-passed so that normal chlorine residual can be economically maintained.

In the slip-stream system, approximately twenty percent of the filtered water is diverted to a separate stream which is then ozonated with one gram per hour of ozone for one cubic metre per hour of this quantity of filtered water. After two minutes of contact, this twenty percent of water is returned to the main return line to the pool. As the quantity of ozone introduced into the pool water is only one-fifth of the total quantity of treated water, a GAC filter can be omitted.

Pools treated with ozone in conjunction with chlorine provide a quality of water not achievable with single-treatment disinfectants. Ozone will easily oxidise chloramines to remove chlorine smell in pool water and eliminate bather irritation. However, due to its high capital costs and lack of knowledgeable staff, there are few ozonated pools in Singapore, but is a requirement in Germany and other European countries.

Chlorine dose is dependent on two considerations — the chlorine demand and the desired chlorine residual:

Chlorine Dose = Chlorine Demand + Chlorine Residual

The chlorine demand is the amount of chlorine required to react with the various components of the water such as harmful organisms and other organic and inorganic substances. When the chlorine demand is satisfied, these reactions stop. It is desirable to have excess chlorine residual in the pool water to combat contaminants that will be introduced subsequently into the pool water.

When commercial pools were treated with chlorine gas, there was one hundred percent available chlorine. So if a dosage of five kilograms per day were required, the setting on the chlorinator would be five kilograms per day. As calcium and sodium hypochlorite are not one hundred percent pure chlorine, the setting of the chemical feed rate will have to be increased as we are dosing chemicals having less than full strength to ensure the same amount of chlorine for disinfection is dosed.

In chemical dosing, a measured quantity of chemical is added to the water. The amount of chemical is dependent on such factors as the type of chemical, the reason for dosing and the flow rate of water to be treated. The expression used for the amount of chlorine to be dosed is parts per million (ppm) or milligrams per litre (mg/L). The strength of a chemical solution is a measure of the chemical (solute) dissolved in the solution. Percent is calculated as "part over whole". Percent strength is calculated as part chemical in kilograms divided by the whole solution in kilograms, as expressed in the following formula:

$$\% \text{ Strength} = \frac{\text{Chemical (kg)}}{\text{Water (kg)} + \text{Chemical (kg)}} \times 100$$

One litre of water weighs 1000 grams. As the density of sodium hypochlorite is slightly higher than water, for a safe margin of error, we can state that one litre of ten percent strength sodium hypochlorite solution contains one hundred grams of chlorine, i.e., there is only one gram of chlorine in every ten litres of the solution. For the preparation of all chemical solutions to treat the pool water, the above formula should be adopted.

In Singapore, the Environmental Health Department requires all public pools to maintain residual chlorine of one to three ppm. To attain this result, it is required to dose the water with five ppm of chlorine to satisfy the chlorine demand and attain the chlorine residual, i.e., for every cubic metre of pool water, five grams of chlorine must be added. One cubic metre of water weighs 1,000,000 grams.

From Chapter 7, for the residential pool having a water volume of 96 cubic metres, the quantity of chlorine to be added daily to the pool water will be:

$$96 \times 5 = 480 \text{ grams}$$

If calcium hypochlorite is used, more than 480 grams of calcium hypochlorite must be fed into the pool water to obtain the same amount of chlorine for disinfection as calcium hypochlorite is not

100% pure chlorine. To calculate the quantity of calcium hypochlorite required, the following formula must be used:

$$\textbf{Dosage quantity (grams)} = \frac{\textbf{Quantity to be dosed (grams)}}{\textbf{Percent available chlorine}}$$

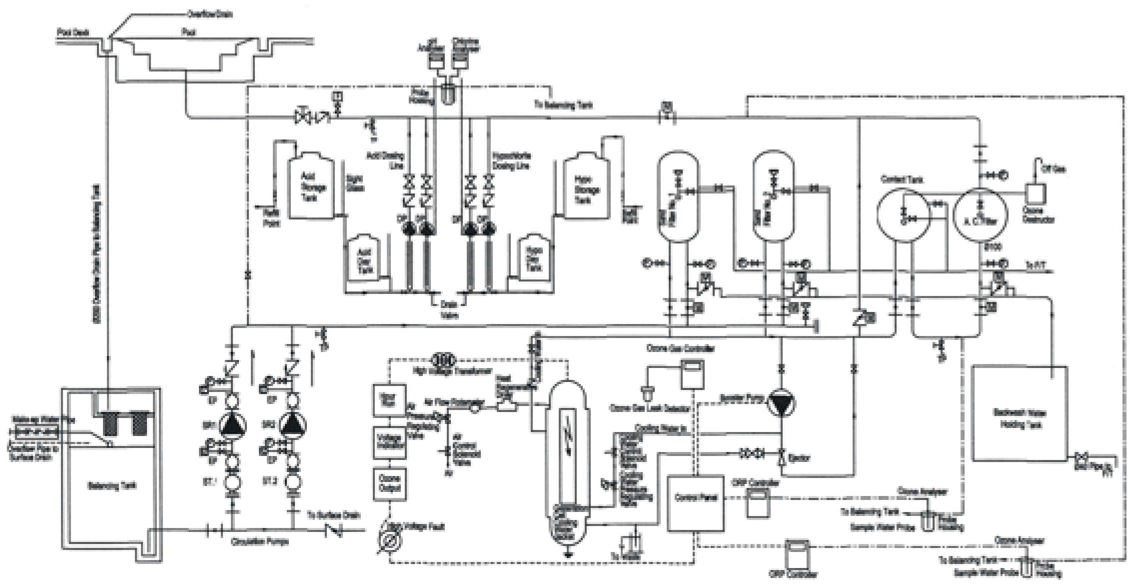
If a 65% calcium hypochlorite is used, then:

$$\text{Dosage quantity (grams)} = \frac{480 \text{ (grams)}}{0.65}$$

The dosage of chlorine for the competition pool in Chapter 7 should be:

$$\begin{aligned} \textbf{Chlorine dosage rate} &= \textbf{Chlorine dosage quantity x Pool treatment rate} \\ \text{g/h} &= \text{g/L x L/h} \\ \text{g/h} &= \frac{5 \text{ (g/L)}}{1{,}000{,}000} \times 425{,}000 \text{ L/h} \\ &= 2.215 \text{ g/h} \end{aligned}$$

Hence, the chemical pump should be capable of delivering not less than 22.15 litres of the 10% sodium hypochlorite solution per hour to contain 2.215 grams of chlorine. The back pressure it has to overcome has to be taken into serious consideration. The selected chemical dosing pump to be installed must be capable of dosing at least twice this amount of this solution for super-chlorination requirement. Similar calculations can be conducted to determine the sizes of the metering pumps for the teaching and wading pools. From experience, it was found that the capacity of the metering pump for dosing of acid for the correction of pH is half that of the sodium hypochlorite pump.



Schematic Drawing of an Ozonated Pool
Figure 6-1

7: Sizing of Filters

High-rate sand filters are the choice of knowledgeable home-owners — preferred over DE filters for their residential pools. When DE filters are backwashed, both trapped dirt and the DE coatings are sent to the sewer lines, ultimately leading them to be choked after a period of time unless a separation tank is installed in the backwash line. A separation tank is simply a cloth bag filter designed to trap the DE to enable only water to be sent to the sewer. Yearly, the DE filter tank must be opened for thorough cleaning of the DE elements. DE elements require replacement almost every three years. However, the quality of water filtered by the DE filter is better than the high-rate sand filter. Any cloudiness in DE-filter pool can be clear in one turnover cycle, unless the DE elements are damaged.

The popular capacity of most residential pools is between eighty and one hundred cubic metres.

For a residential pool having a capacity of, say, 96 cubic metres, we can compute the size of a high-rate sand filter required as follows:

$$\text{Turnover period for a residential pool} = 8 \text{ hours}$$

$$\text{Treatment rate}\left(\frac{m^3}{h}\right) = \frac{\text{Pool Volume } (m^3)}{\text{Turnover Period (h)}}$$

$$\text{Treatment rate} = \frac{96}{8}$$

$$= 12 \text{ cubic metres per hour}$$

$$\text{Required filter area } (m^2) = \frac{\text{Treatment Rate } (m^3/h)}{\text{Filtration Rate } (m^3/h/m^2)}$$

$$\text{Filtration rate for high-rate sand filter} \leq 600 \text{ l/min/m}^2$$
$$\text{or} \leq 36 \text{ m}^3/\text{h/m}^2$$

$$\text{Therefore, minimum filter area required} = \frac{12}{36}$$

$$= 0.33 \text{ m}^2$$

The diameter of the filter that can provide this cross-sectional area can be calculated as follows:

$$\frac{\pi d^2}{4} = 0.33 \text{ m}^2$$

$$d = \sqrt[2]{\frac{(0.33 \times 4)}{\pi}}$$

$$= 0.648 \text{ m}$$

Therefore, the high-rate sand filter must have a diameter not smaller than 650mm.

Should you prefer to install a DE filter instead of a high-rate sand filter, then we can determine the filter area required as follows:

$$\text{Filtration rate for DE filter} \leq 100 \text{ l/min/m}^2$$
$$\text{or} \leq 6 \text{ m}^3\text{/h/m}^2$$

$$\text{Therefore, minimum filter area required} = \frac{12}{6}$$
$$= 2 \text{ m}^2$$
$$= 21.5 \text{ square feet}$$

The metric calculation of the DE filter has to be converted to imperial measures as DE filters are only available in imperial measures. Hence, the suitable size DE filter will be the 24 square feet.

For public pools, due to the heavy bathing loads on weekends, the turnover periods are shortened for all the pools. Instead of the 6-hour turnover period for the competition and teaching pools, the turnover period is shortened to four and three hours respectively. Even the turnover period for the children's pool is shortened to one hour. With the reduction in turnover period, the filters will have to be increased in size and the circulation pipes increased accordingly to convey the greater flow. We will perform a filter sizing for this swimming complex shown in Figure 7-1.

1.0 Swimming Pool Data

Capacity	:	Competition Pool	:	1,700 m^3
		Teaching Pool	:	1,050 m^3
		Wading Pool	:	123 m^3
Turnover Period	:	Competition Pool	:	4 h
		Teaching Pool	:	3 h
		Wading Pool	:	1 h
Treatment Rate	:	Competition Pool	:	425 m^3/h
		Teaching Pool	:	350 m^3/h
		Wading Pool	:	123 m^3/h

2.0 Calculation

$$\text{Required filter area } (m^2) = \frac{\text{Treatment Rate } (m^3/h)}{\text{Filtration Rate } (m^3/h/m^2)}$$

$$\text{Filtration rate for high-rate sand filter} \leq 600 \text{ l/min/m}^2$$
$$\text{or} \leq 36 \text{ m}^3/\text{h/m}^2$$

$$\text{Therefore, minimum filter area required for competition pool} = \frac{425}{36}$$
$$= 11.80 \text{ m}^2$$

$$\text{minimum filter area required for teaching pool} = \frac{350}{36}$$
$$= 9.72 \text{ m}^2$$

$$\text{minimum filter area required for wading pool} = \frac{123}{36}$$
$$= 3.41 \text{ m}^2$$

If two filters are to be installed for each pool, then each filter must have an effective filter area of:

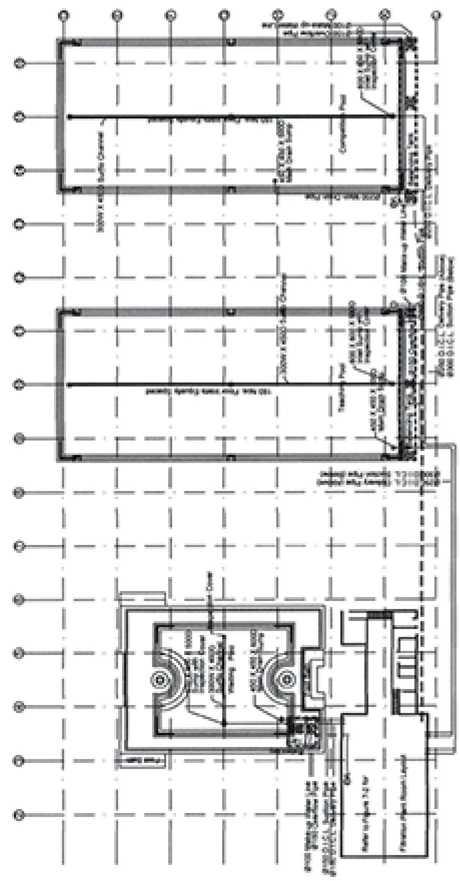
For Competition Pool = 5.90 m^2

For Teaching Pool = 4.86 m^2

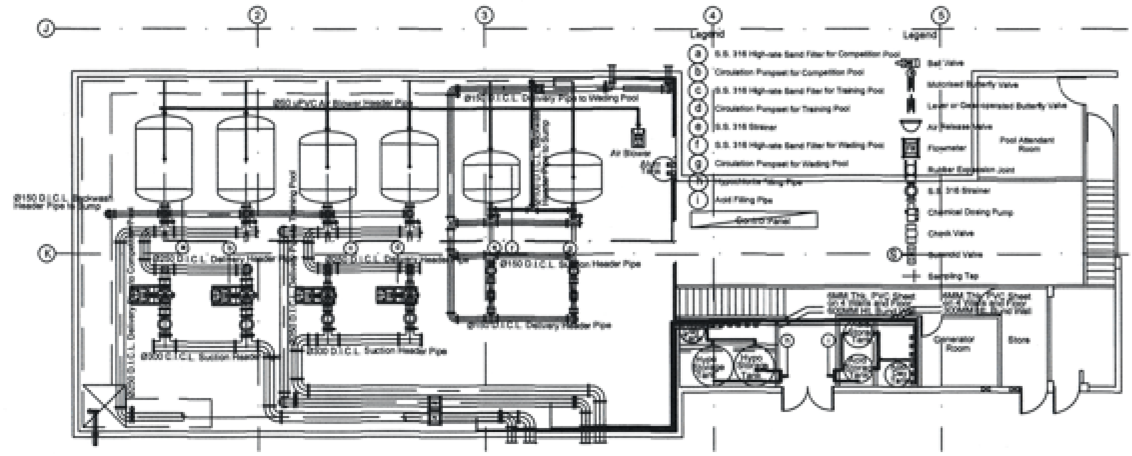
For Wading Pool = 1.70 m^2

As these are custom-designed filters, a diameter of two metres was adopted and the body of the filters elongated accordingly to obtain the required cross-sectional filter areas. Figure 7–1 provides the layout of the pools in this complex, while Figure 7–2 shows the overly-sized filtration plant room and its equipment layout.

The sizes of the filters have to be known in order to determine the space required to house them. As the treatment rate of each pool is known, based on limiting the velocity of flow in the suction and delivery pipes to two metres per second and four metres per second respectively, the sizes of the suction and delivery pipes can be computed to enable the sizing of the other fittings to determine the optimal plant room size.



Plan of Swimming Pools in a Swimming Complex
Figure 7-1

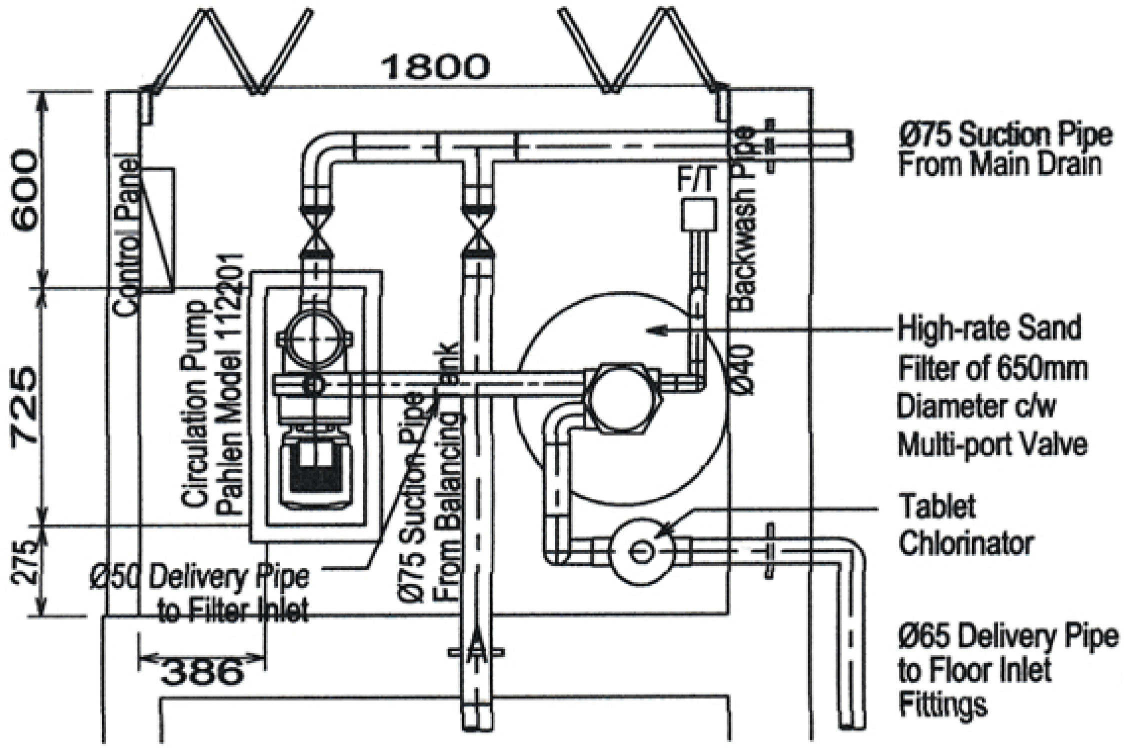


Layout of Filtration Plant Room
Figure 7-2

8: Optimal Sizing of Plant Room

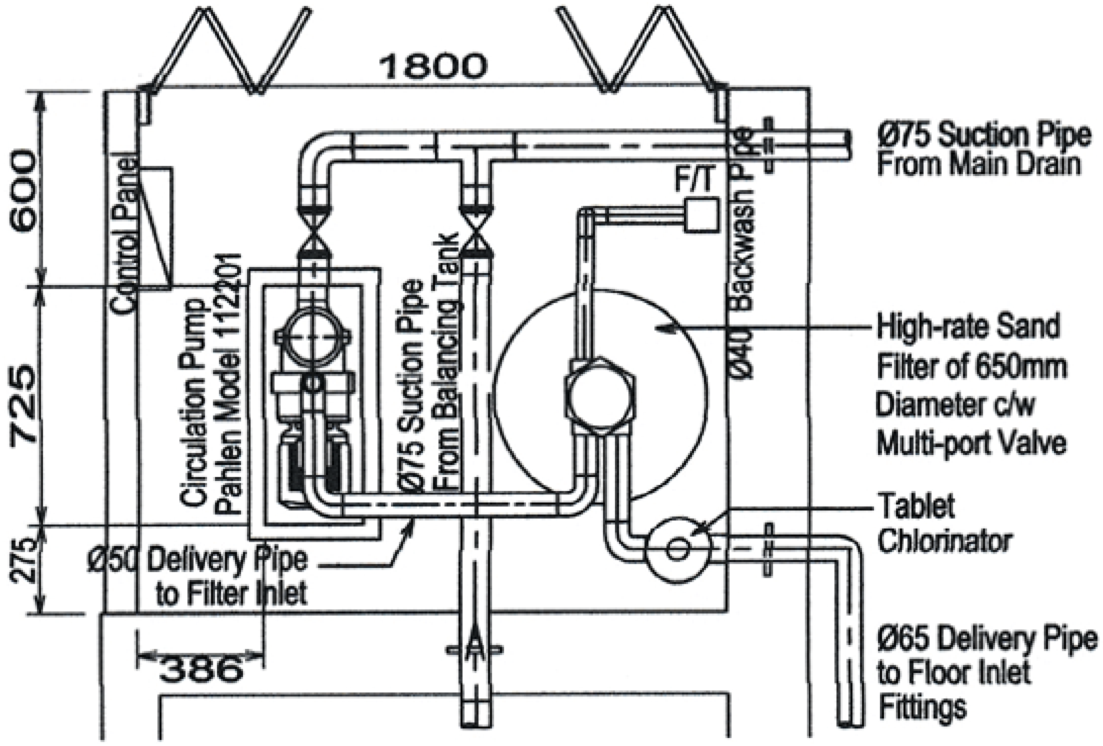
Dimensions of all equipment to be installed in the filtration room must be known in order to be able to size the plant room correctly. Such information can usually be found in the suppliers' catalogues of equipment and fittings, except for custom-made equipment.

From our calculations in Chapter 7, we have determined that a 650-millimetre diameter high-rate sand filter will be required for filtration of a residential pool with a capacity of 96 cubic metres. From the catalogue of PAHLEN swimming pool products in Figure 8-4, we can safely deduce that the Pahlen model 112201 1.5 kW pump capable of delivering 200 litres per minute or 12 cubic metres per hour, at 15 metres head will be capable of meeting this duty. Based on the velocity of flow in the suction and delivery pipes not exceeding two metres per second and four metres per second respectively, we can compute the diameters of the suction and delivery pipes to be fifty and forty millimetres respectively. However, the Pahlen pump has provided 75-millimetre and 65-millimetre diameter suction and delivery connections respectively as shown in the catalogue. With the increases in pipe sizes, the frictional head losses will be reduced drastically. If the diameters of the suction and delivery pipes are reduced by one size, we will probably have to select the next bigger size pump, that is, Pahlen model 112211 2.2 kW pump. With the slight savings from the cost of the pump, this price advantage can be employed to defray the costs of the piping and fittings.



Pump Room Layout A
Figure 8-1

PVC pipes and fittings are relatively inexpensive. These relatively small extra costs incurred can be recovered easily from savings in power consumption in the operation of the 1.5 kW pump for eight hours a day for 365 days as opposed to a 2.2 kW pump. From the catalogue, we note that the size of the pump is 620 mm (length) x 275 mm (width).



Pump Room Layout B
Figure 8-2

If we install a thermoplastic high-rate sand filter, the filter can be positioned close to the plant room wall as shown in Figure 8–1, as there is no maintenance required on the exterior of the filter body. It will require only periodic cleaning to remove the collected dust. For such an installation, only the cover of the hair and lint strainer requires frequent opening and closing to remove any trapped debris. By providing a 400-millimetre working space beside the pump motor, it will suffice future working space should the motor require attention.

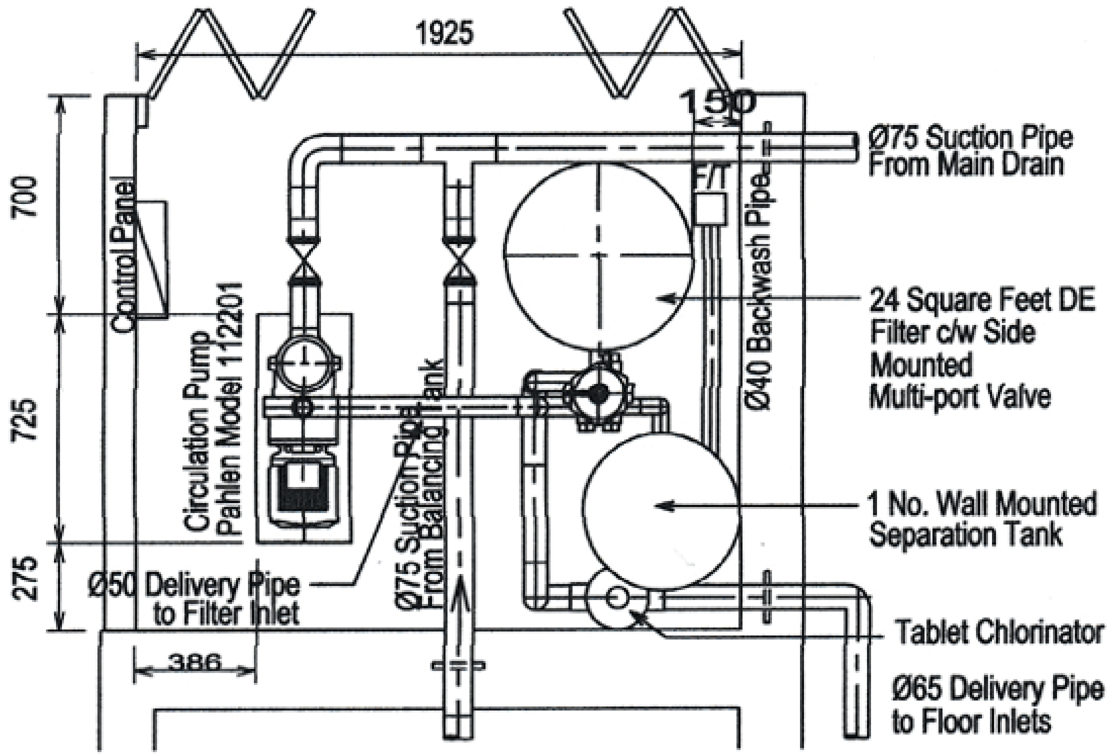
With the installation of two tri-fold-louvred doors to the pump room, the pump room is naturally ventilated without the requirement for mechanical ventilation. This also provides tremendous ease to access the equipment in the pump room. From Figure 8–1, a pump room size of 1800 mm (L) x 1600 mm (W) x normal room height is adequate to house the filtration equipment.

For all installations, the main consideration will be to connect the circulation pump to the filter without impeding access to the other equipment in the system. In this respect the installation shown in

Figure 8–2 is a poor installation as the pump delivery pipe to the filter obstructs the easy access to the motor. The technician dismantling the motor, if the need arises, may hit his head on the pipe. By rotating the filter ninety degrees clockwise in Figure 8–2, the better installation shown in Figure 8–1 can be attained.

As most drawings are prepared by CAD software, all equipment drawn to scale can be easily moved or re-positioned to determine the best layout, bearing fully in mind the maintenance requirements. The best layout will be an operational system utilising the least fittings besides being neat and professional in appearance. Many mistakes can afford to be made on the computer screen in the preparation of the drawings with no major cost implications. However, once the intended layout is implemented on site, any shortcomings that had gone unnoticed during the design phase will be a costly affair.

From Chapter 7, we note that a 24-square-foot DE-filter will be required to provide filtration to the same residential pool, if we so preferred. Figure 8–3 illustrates the ideal pump room layout with similar constraints. The DE filter must be positioned at least 100 to 150 millimetres away from the wall, as the upper half of the filter body has to be dismantled yearly to clean the elements thoroughly. This small distance is to provide a clearance for the maintenance personnel to adjust and ensure the proper tightening of the clamps of the two halves of the filter body. The separation tank can be wall mounted well above the tablet chlorinator without impeding the stacking of the chlorine tablets in the chlorinator. The backwash pipe does not hinder the removal of the upper filter body as it is on floor level. From Figure 8–3, the optimal room size of 1925 mm (L) x 1700 mm (W) will be able to accommodate all the filtration equipment.

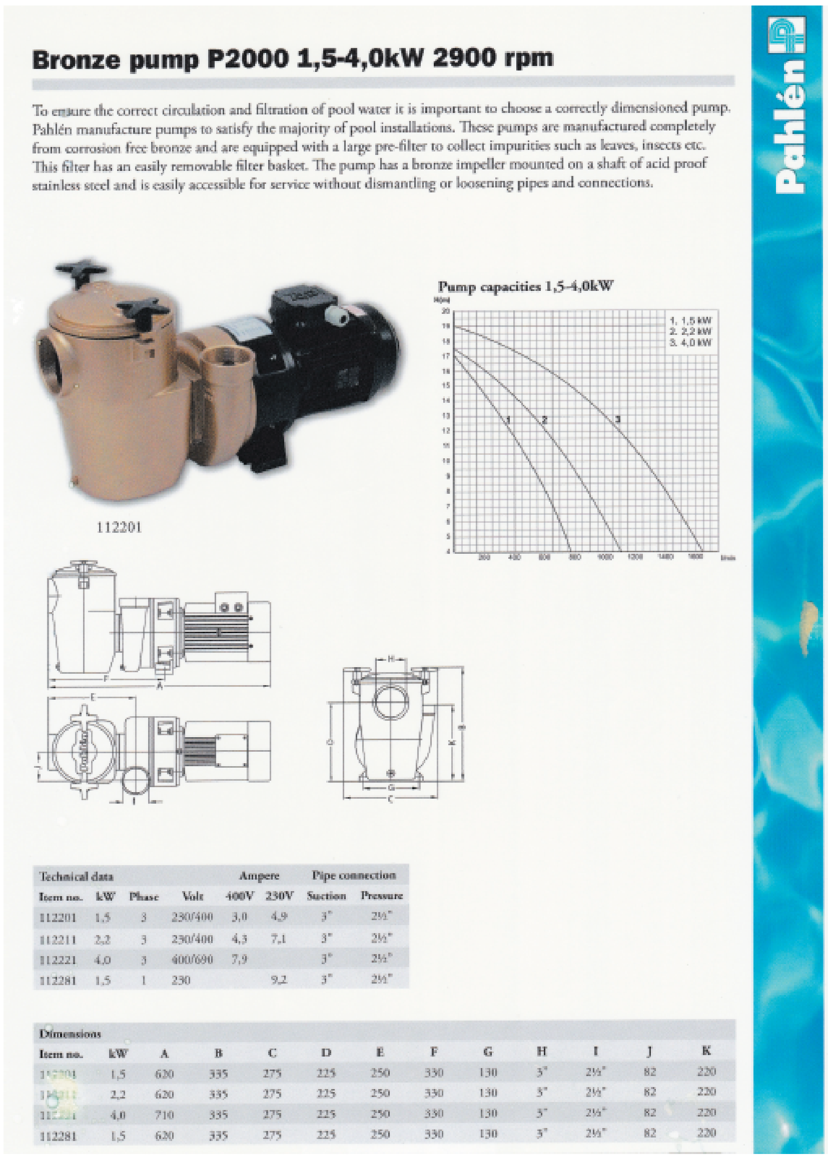


Pump Room Layout C
Figure 8-3

To maximise the use of space it is alright to utilise the height of the room to install some of the equipment that does not require much maintenance. Such space-saving efforts should not be exploited to the extremes as it could create maintenance problems. I had witnessed an installation where an inverted "U" concrete plinth was constructed over the circulation pumps for the installation of DE filters. This installation created maintenance problems for the circulation pumps as well as for the backwashing of the DE filters and the yearly cleaning of the DE elements.

Ideally, residential pool owners should not locate their pump rooms underground with the wrong belief of freeing useful space above ground. An underground pump room has to be larger than an aboveground plant room considering the required provision of ample working space between equipment to conduct maintenance and a sump complete with submersible pump to keep the room dry. Cat ladders are also required to provide access and mechanical ventilations will need to be considered. Lighting is required for equipment inspections even during the day. Underground pump rooms make it difficult for residential pool owners to service and attend to problems encountered themselves, as access covers can be too heavy for them to handle. It will be nightmarish to attempt to resolve problems encountered in the evening or on a rainy day.

heavy for them to handle. It will be nightmarish to attempt to resolve problems encountered in the evening or on a rainy day.



Bronze pump P2000 1,5-4,0kW 2900 rpm

To ensure the correct circulation and filtration of pool water it is important to choose a correctly dimensioned pump. Pahlén manufacture pumps to satisfy the majority of pool installations. These pumps are manufactured completely from corrosion free bronze and are equipped with a large pre-filter to collect impurities such as leaves, insects etc. This filter has an easily removable filter basket. The pump has a bronze impeller mounted on a shaft of acid proof stainless steel and is easily accessible for service without dismantling or loosening pipes and connections.

Technical data				Ampere		Pipe connection	
Item no.	kW	Phase	Volt	400V	230V	Suction	Pressure
112201	1,5	3	230/400	3,0	4,9	3"	2½"
112211	2,2	3	230/400	4,3	7,1	3"	2½"
112221	4,0	3	400/690	7,9		3"	2½"
112281	1,5	1	230		9,2	3"	2½"

Dimensions												
Item no.	kW	A	B	C	D	E	F	G	H	I	J	K
[illegible]	1,5	620	335	275	225	250	330	130	3"	2½"	82	220
[illegible]	2,2	620	335	275	225	250	330	130	3"	2½"	82	220
[illegible]	4,0	710	335	275	225	250	330	130	3"	2½"	82	220
112281	1,5	620	335	275	225	250	330	130	3"	2½"	82	220

Pahlen Swimming Pool Pump Curves
Figure 8-4

From Chapter 7, we are aware that to install the filter in an underground pump room, the access opening size must be at least

700 mm x 700 mm or 650 mm x 650 mm respectively to enable the 650-mm-diameter high-rate sand filter or the 600-mm-diameter DE-filter to be lowered into the filtration room. To cover these opening sizes, a few pieces of smaller pre-cast concrete slabs can be provided. However, the main consideration will be to minimise the ingress of water into the underground pump room when it rains.

Humidity in an underground pump room is unfavourably high — not a conducive environment to electrical and electronic equipment and components, causing frequent short-circuiting and component replacements. The life cycles of all equipment will be shortened due to the higher temperature and humidity. The myth of space savings will be busted when all the foreseeable problems are known.

For public pools, where sand filters are commonly installed, most major equipment including the filters should be spaced at 400 to 450 millimetres apart to facilitate maintenance requirements. When multiple units of DE filters are installed, they can be spaced at 100 to 150 millimetres apart as the body of the filter tanks are either of thermoplastic or stainless steel construction not requiring maintenance on the exterior of the filter tanks.

Equipment that require maintenance should be provided with adequate working space. Attempts should be made to ensure all pipes and fittings before the pump suction are kept lower than the centre line of the pump to minimise frictional head loss. The height of the plant room can be exploited for installation of the delivery pipe to the filters. However, ease of maintenance should be the main consideration. The opening and closing of all valves should be reachable from plant room level without the need of any ladders. Easy access to the hair and lint strainer should be the primary concern as periodic cleaning will ensure an efficient filtration system. Chemical storage and its related dosing systems should be installed in locations separate from the circulation system. Good ventilation of the room will ensure the well-being of the maintenance personnel and will not discourage them from entering the room.

Figure 7-2 shows an overly-sized pump room for public pools. Such generosity never occurs in private developments. In private developments, the filtration equipment is often cramped into rooms due to poor knowledge of the basis to size the room. The gravest mistake is the preparation and use of single line drawings to determine the size of the plant rooms required. Single-line drawings of pipes and fittings do not represent the true and correct dimensions of the fittings thus causing the plant rooms to be inadequately sized.

9: Sizing of Balancing and Backwash Water Holding Tank

For a "level-deck" or "surflo" swimming pool circulation system, a balancing tank is required between the scum drain and the circulating pump or pumps. The tank is required to hold sufficient water to ensure the circulation pump or pumps will not run dry and provide water for conducting backwashing besides holding water displaced by swimmers. Usually, the tank is constructed adjacent to the deep end of the pool, sharing a common wall with the swimming pool. If space permits, it is better to provide an over-sized balancing tank as it can be used to store rain water for backwashing the filters thus conserving water consumption.

An under-sized balancing tank will result in water overflowing every time the circulation pumps stop operation. When the circulation pumps commence again, city water supply will be required to replenish the water loss.

When the filtration system is in operation, a thin layer of water, about three millimetres, will be suspended above the overflow edge of the pool. Using the competition pool shown in Figure 9-1, this volume of water can be determined as follows:

Volume of thin film of suspended water above the overflow edge	=	21.6 x 50.6 x 0.003
	=	3.28 cubic metres

Approximately, 150 millimetres of water will be flowing in the 250-millimetre wide overflow drains of the pool. The volume of this water can be determined as follows:

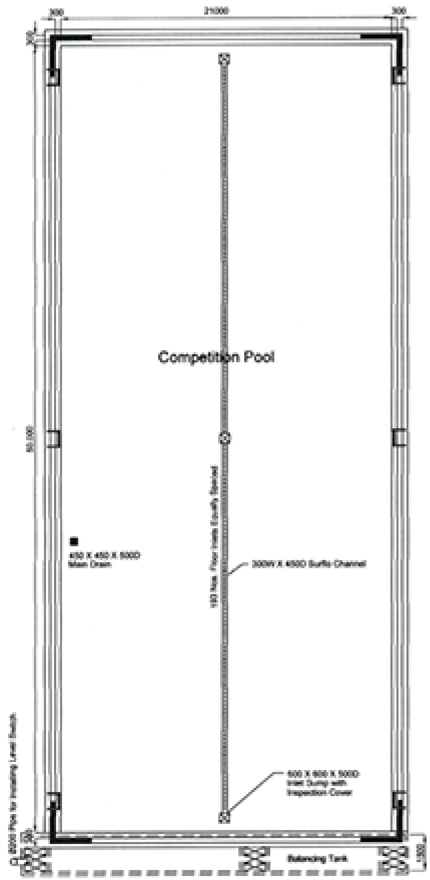
Volume of water flowing in the overflow drains	=	(50.6 + 21.6) x 2 x 0.150 x 0.250
	=	5.42 cubic metres
Total amount of water drawn from the balancing tank	=	3.28 + 5.42
	=	8.7 cubic metres

When 8.7 cubic metres of water is drawn from the balancing tank with an internal depth of 2.25 metres by 1.5 metres wide by 21 metres length, the water level will fall.

$$\text{Depth of fall of water level in the balancing tank} = \frac{8.7}{1.5 \times 21} = 0.276 \text{ m}$$

From the above calculations, the operating water level in the balancing tank will be 0.276 metre lower than the non-operating level. From Chapter 1, we are aware that if a swimmer is swimming, he will displace ninety percent of his weight of water. If the average weight of a swimmer is eighty kilograms, he will displace seventy-two kilograms of water or 0.072 cubic metres of water. The 8.7 cubic metres of water drawn from the balancing tank will be able to accommodate the water displacement by 8.7 ÷ 0.072 = 120 swimmers.

Water wears down mountains and erodes the soil and rocks. The water in Singapore is very soft, i.e., it contains very little minerals or calcium and magnesium compounds. Hard water does not dissolve soap easily. For pools not maintained at a correct chemical balance, the daily constant flow of water over the overflow edges of the pools will easily etch the cement screed between the tiles as shown in Figure 9-2. In many older public pools, when the circulation pumps stop operation in the evening, more than three millimetres of water that is suspended above the overflow edge of the pool will spill into the balancing tank. This is dependent on the slope of the overflow edge of the tiles and the degree the cement screed has been worn down. The height of water that will overflow into the balancing tank can be as much as ten to fifteen millimetres.

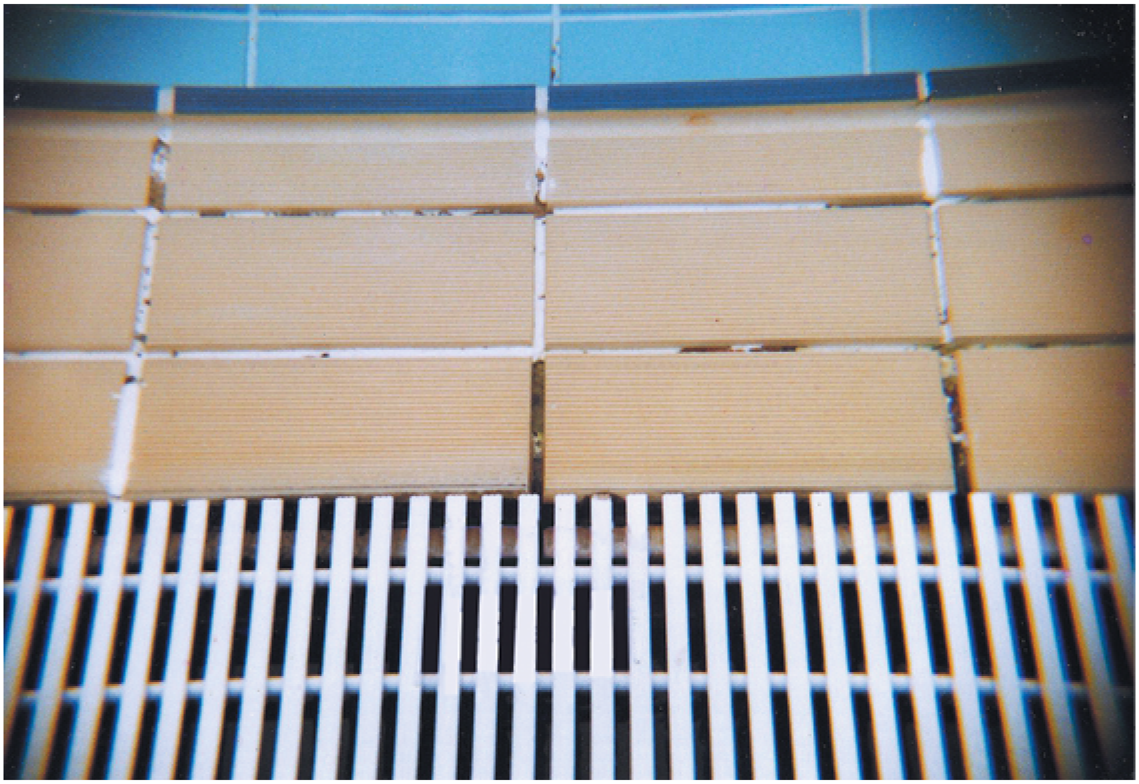


Plan of Competition Pool
Figure 9-1

Assuming the worst-case scenario, this volume of water can be as much as 16.4 cubic metres. This is derived as follows:

Volume of 15 mm of water suspended above the overflow edge of the pool	=	21.6 x 50.6 x 0.015
	=	16.4 cubic metres
Increase in height of water level in the balancing tank when the circulation pump stops	=	$\frac{16.4 + 5.42}{1.5 \times 21}$
	=	0.693 metres
Difference in height of water level in the balancing tank from earlier calculations	=	0.693 – 0.276
	=	0.417 metres

If space permits, it will be better to size the balancing tank for the worst-case scenario. Otherwise, the balancing tank will always overflow when the circulation pumps stop operation and replenishment of water will be required when the circulation pumps commence again.



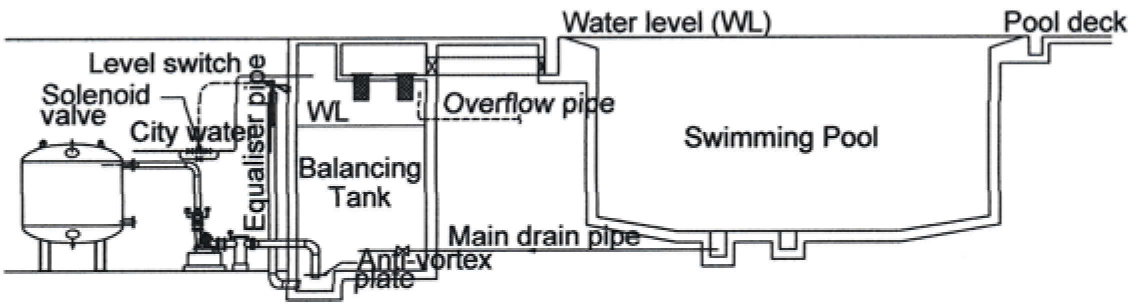
Photograph of Cement Screed of Tiles Etched at the Overflow Edges of a Pool
Figure 9-2

The balancing tank must also be sized to contain water required for backwashing the filters. It is not necessary to design the balancing tank to contain sufficient water to backwash all the filters in one operation. As long as it is made known that the design intent is to allow one filter to be backwashed per operation, nobody will fault you on its design.

From Chapter 7, the treatment rate for the competition pool is 425 cubic metres per hour. This flow of water will be used to backwash the filter. As shown in Figure 4-7, water filtered by one filter can be used to backwash the other filter. The duration for backwashing each sand filter is usually not more than five minutes. Therefore, volume of water required for backwashing is determined as follows:

$$\text{Volume of water required for backwashing the competition pool filter} = \frac{425}{60} \times 5$$
$$= 35 \text{ m}^3$$

$$\text{Equivalent height of water level in the balancing tank} = \frac{35}{1.5 \times 21}$$
$$= 1.111 \text{ metres}$$



Anti-vortex Plate
Figure 9-3

Sufficient water must also be maintained in the balancing tank to ensure the circulation pumps do not run dry. If an anti-vortex plate of at least three times the diameter of the suction pipe is provided near the end of the suction pipe as shown in Figure 9-3, then a three hundred-millimetre depth of water will suffice to ensure the circulation pump will not run dry. The anti-vortex plate is to enable the water to be drawn radially through the sides of the suction pipe, thus preventing a vortex formation. The anti-vortex plate must have a clearance of at least one suction-pipe diameter distance away from the walls of the sump.

From the above calculations, we can deduce the non-operating water level in the balancing tank of a pool without etched screed between the tiles as follows:

$$\text{Non-operating level of water in the balancing tank} = 0.3 + 1.111 + 0.276$$
$$= 1.687 \text{ metres}$$

The non-operating water level in the balancing tank of a pool with etched screed between the tiles will be calculated as follows:

Non-operating level of water in the balancing tank	=	0.3 + 1.111 + 0.693
	=	2.104 metres
Operating water level in the balancing tank if the filter is not backwashed	=	0.3 + 1.111
	=	1.411 metres
Operating level of water in the balancing tank after the filter is backwashed	=	0.3 metres

The figures indicated above are based on the assumption that there are no swimmers in the pool, as otherwise some water will be displaced by the swimmers into the balancing tank. From the above, we can safely conclude that the balancing tank of 2.25 metres depth by 1.5 metres wide by 21 metres length is capable of meeting all eventualities.

The use of ball floats as employed in water cisterns to control the level of water in the balancing tanks is a big and grave mistake. Yet this practice is widely used in Singapore. The buoyancy of the ball stops the city water from flowing into the tank. When a ball float is used to set the non-operating water level in the balancing tank, this poor ball will always be submerged in the water.

When the circulation pumps operate, the water level in the balancing tank will fall to the operating level resulting in the inflow of city water into the tank. It will fill the tank to the non-operating level as set earlier. When the circulation pumps stop, all the water suspended above the overflow edge of the pool and the water flowing in the overflow drains will return to the balancing tank to submerge the ball.

If it rains, even if the circulation pumps are in operation, the ball will be submerged. Failures of ball floats are fairly common, as they are not designed to be submerged. The better solution is to utilise electrodes to control the level of water in the balancing tank. The electrodes will trigger the solenoid valve to deliver water into the balancing tank. The make-up water system should be electrically interlocked with the circulation pumps so that no make-up water is required when the circulation pumps are in operation. If the level of water in the balancing tank falls dangerously low due to leakages, the make-up water system should trigger an alarm or stop the operation of the circulation pumps. As shown in Figure 9-1, a pipe connected to the balancing tank should be used for the installation of the level switches. This is to locate the electrical components away from the highly humid environment in the balancing tank. Similarly, the solenoid valve can be located away from the balancing tank with only the water supply line entering the tank. If the plant room is adjacent to the balancing tank, as shown in Figure 9-3, it will make the installation even easier.

The intention of a backwash water-holding tank is to contain the backwash water and have it discharged slowly into the sewer line without flooding it. If all the filters of a swimming complex are housed in a common plant room, then the largest flow rate should be used to size the holding tank. As shown in the above calculations, the backwash water-holding tank should be able to contain at least thirty-five cubic metres of backwash water for the competition pool in Chapter 7 so as not to cause flooding of the sewer line.

10: Pool Fittings

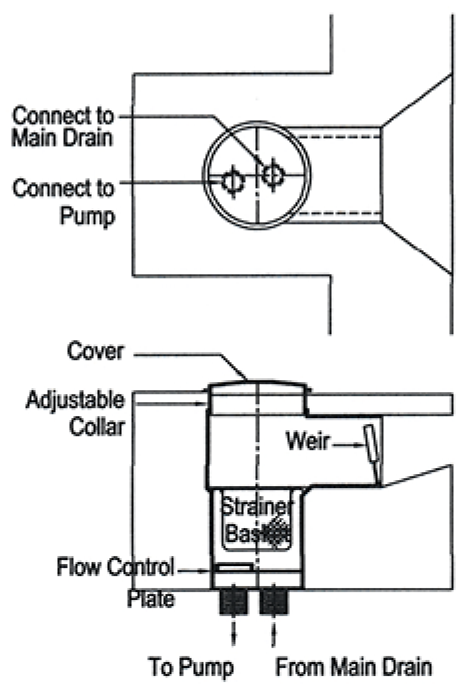
Most pool fittings are manufactured with plastic as they can be mass produced with ease and speed besides being corrosion resistant. Injection moulding makes production of such fittings relatively inexpensive. However, in Sweden a sizeable number of pool fittings are manufactured with stainless steel not of AISI 304 quality, but of AISI 316 quality. The Swedes are well known internationally for their high quality stainless steel for all industries including tool steel. Of course other swimming pool equipment manufacturers do produce fittings with stainless steel, but they are normally of AISI 304. Plastic material deteriorates with time when exposed to sunlight.

Automatic Skimmer
Figure 10-1

(***courtesy of Hayward Inc.***)

We have to bear in mind that plastic materials deteriorate after long exposure to the sun. As a safety measure, the main drain cover should preferably be of stainless steel, especially if water is drawn from it for water display or for hydrotherapy jets. In the later part of this chapter, I will narrate an unfortunate incidence that happened in Singapore to reinforce my suggestion.

When dust and leaves are blown into a swimming pool, they will float on the water surface before sinking to the pool bottom. The purpose of a skimmer, as shown in Figure 10-1, is to promote surface flow across the pool. Besides drawing in the top layer of water requiring the most treatment because of exposure to wind and rain, it also removes floating dust, debris, leaves and oil films before they can accumulate on pool floors and walls. It is connected to the main drain and the filter pump. A trimmer valve is incorporated in the skimmer to divide the total flow through the filter between the flow across the surface of the pool and through the bottom main drain. It also serves as the connection for the vacuum hose for vacuuming the pool. As a rule of thumb, one skimmer is required for every forty-five square metres or part thereof of pool surface area.



Skimmer Installation Details
Figure 10-2

Figure 10-2 illustrates a “wide mouth” skimmer installation. The skimmer should be installed on the downward side of the prevailing winds and across the wall inlet fittings to promote surface flow. The pivoted floating weir at the entrance of the skimmer causes a differential water level resulting in a positive skimming action. Without the floating weir, there will be no skimming effect. For efficient operation, the strainer basket must be regularly inspected and cleaned as necessary.

Wall inlet fittings, as shown in Figure 10-3, are installed in conjunction with skimmers. They are available with various orifices and the flow can be deflected in any direction, up to 30^0 from centre.

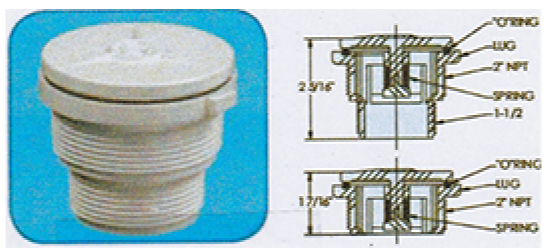
The flow from each wall inlet can be controlled by varying the sizes of the orifices only. They are usually installed on the pool walls between 150 and 500 millimetres below pool water level.

Wall Inlet
Figure 10-3 *(courtesy of Hayward Inc.)*

The return water is usually directed towards the skimmers to further promote surface flow. The sum of the cross-sectional areas of the orifices of all wall fittings in each pool must not be greater than the cross-sectional area of the delivery pipe as otherwise water will not be delivered through some of the fittings.

In certain parts of Singapore, the water table is extremely high, especially areas near the sea, lakes, ponds, swampy areas and reservoirs. The water table is the level below the surface of the ground where there is water. Lowering the table by excavation for construction causes special problems in coastal areas, because salt water from the ocean enters reservoirs of ground water.

More than four decades ago, I was employed by an Italian semi-conductor manufacturing company in Toa Payoh. The company was manufacturing integrated circuits (ICs). An IC costs far less than circuits produced with discrete components. A photographic process reduced a large design for the circuit to microscopic size. These microscopic designs were made into hundreds of integrated circuit chips on one wafer. After the wafer was made, it was divided into individual chips and gold wire connections were made to each and encapsulated with plastic on completion. The gold plates on the surfaces of the leads had to be removed before they could be tin-plated. Potassium cyanide, an extremely toxic chemical, was employed for the removal of the gold. Great precautions were exercised to ensure the rinsing water during the gold removal process, must contain a very low level of potassium cyanide before being discharged into the sewer. An underground polyethylene neutralising tank was installed for that purpose.

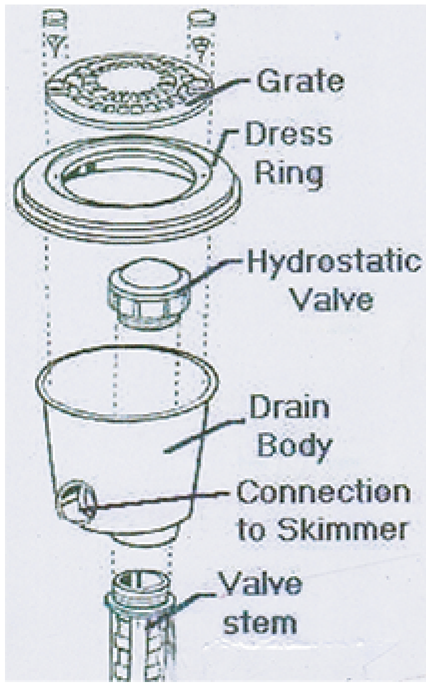


Hydrostatic Relief Valve
Figure 10-4 *(courtesy of Hayward Inc.*)

When the tank was first installed, a huge hole was dug to bury the tank. As there was presence of ground water, a submersible pump was employed for dewatering. In the evening on completion of installation, the hole was backfilled. In the morning, to our surprise, the tank was found to have floated above soil level, severing all the connected pipes. The installation was repeated with steel ropes instead of fibre ropes, tied to the collars of the tank to anchor it to the ground. To our dismay, we were defeated by the forces of nature. The tank was again lifted off the ground in the evening.

We realised, at that juncture, of the need to provide a counter weight to balance the forces of ground water. On completion of the remedial works on the third attempt, the tank was immediately half filled with water, before backfilling the hole. It assisted in resolving the problem partially as we were unable to drain the tank completely. To resolve the problem, another tank was added to the installation so that each tank can be drained by half.

At that point of time, even the Italian engineers were ignorant that a simple humble fitting such as the hydrostatic pressure relief valve, as shown in Figure 10-4, could have helped to resolve the problem. Toa Payoh was formerly a swampy area thus explaining the high water table.



Exploded View of Hydrostatic Relief Valve Installation
Figure 10-5 *(courtesy of Hayward Inc.)*

The hydrostatic pressure relief valve is designed to relieve the hydro-static pressure created by ground water to prevent pool floating. It is a spring-loaded design to ensure positive tight sealing yet opens easily to relieve the ground water pressure and prevent a pool from floating. No tools are required to remove the valve for cleaning and maintenance.

The hydrostatic pressure relief valve is installed at the deepest end of the pool. Figure 10-5 illustrates the typical installation details of such a fitting for residential pools. Fine slots, similar to those provided on filter nozzles are provided on the valve stem to prevent the ingress of sand allowing only ground water to flow through.

Usually gravels are packed around the valve stem to further protect the slots.

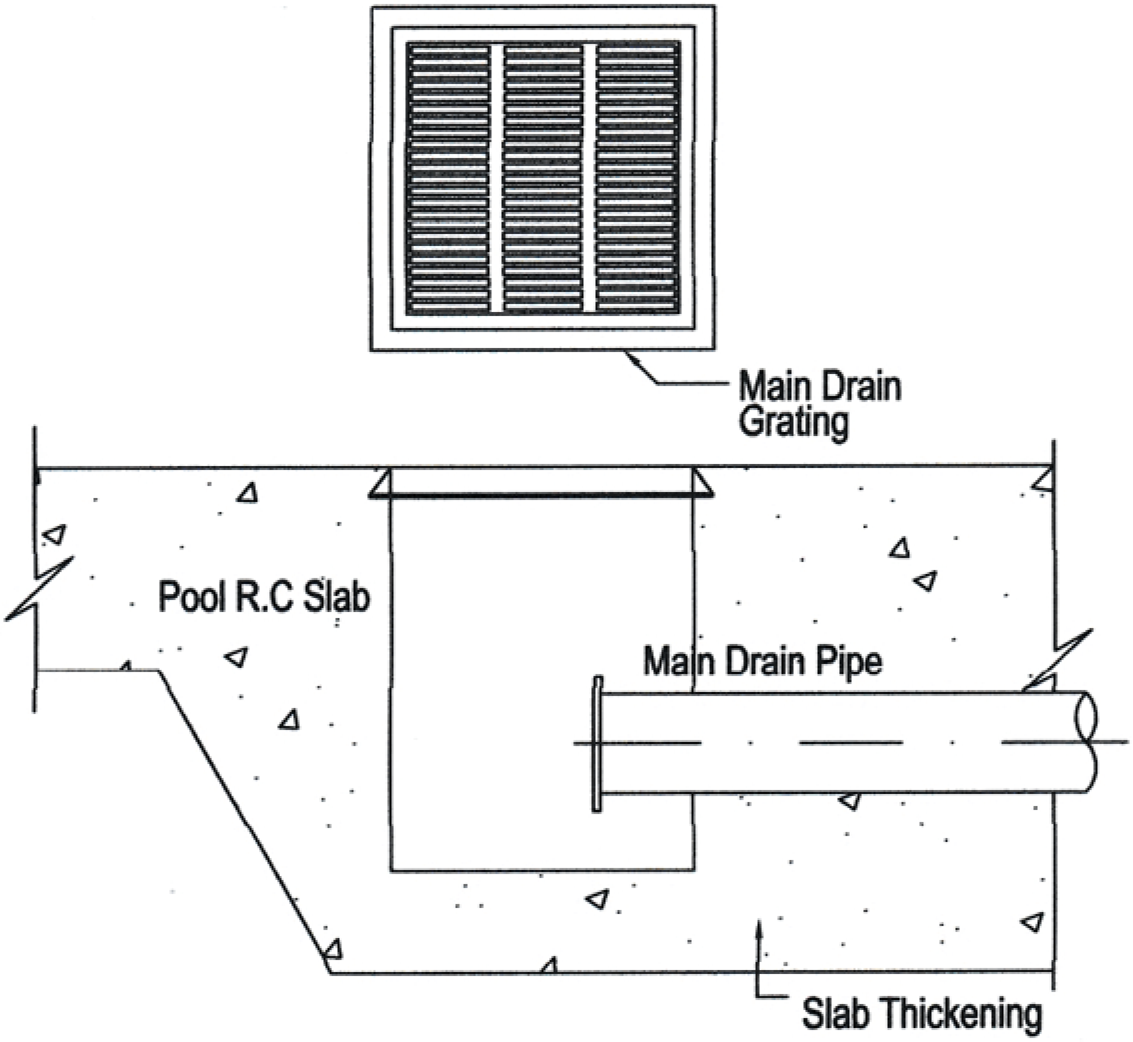
Commercial pools are usually constructed with square main drain sumps at the deepest end of the pool. A typical main drain grate, as shown in Figure 10-6, is usually provided as the drain cover. For commercial pools to be built in high water table locations, fifty-millimetre diameter PVC Schedule 80 female adaptors would have to be casted on the base of the main drains to enable the installation of the hydrostatic valves. Considering the advances of technology, this simple hydrostatic relief valve is still relatively unknown to many.

Main Drain Grate
Figure 10-6 *(courtesy of Hayward Inc.)*

In the late 1970s while commissioning an installation in Singapore's first water park at East Coast, similar floatation experiences were encountered. In those days before the sea was pushed far out to the current position, the water park was just adjacent to the sea. On that fateful commissioning day, it was a night with full moon. When the pools were cleaned and dewatered to be filled with clean water, the pools floated. The sea tide was at its highest peak. Naturally, all pipes connected to the aluminium pools were severed. Due to its close proximity to the sea, the water table swelled with the rise of the tide.

The Japanese pool fabricator was also unaware of the availability of the hydrostatic pressure relief valve. When the tide receded, the pools returned almost to its original level with slight unevenness. All the pipe openings in the pools were plugged and the pools were quickly filled with water. The last sections of pipes to the pools were connected with flexible hoses. The poor adherence of paint to aluminium surfaces makes these relatively cost-effective pools unpopular as every two years the pools had to be drained for re-painting. The water park management would refer to the tide tables produced by the local authorities to monitor the rise and fall of sea water to determine their painting schedules.

The floatation of the aluminium pools was not due to the weight of the materials. It was due to the massive ground water pressure. A few kilometres down the road, also along the same coastal area, an Olympic-size concrete pool of a social swimming club also met with the same calamity. The whole pool was lifted and tilted, resulting in a poor circulation system. Fortunately, the underground pipes were not damaged due to the flexible connections of the pipes. Water was just overflowing over certain sections of the scum channels of the pool to return to the balancing tank for treatment. As a result, the condition and recirculation of the water were adversely affected.



Main Drain Installation Details
Figure 10-7

We participated in the up-grading works to renovate the pool to convert it to a “surflo” system including replacement of the complete filtration system. The New Zealander consultant did attempt to maintain the water table to a certain safe level to ensure the pool would not be lifted while the remedial and re-tiling works were in progress. However, that level of water table did not meet our piping requirements. To lay the main-drain pipe, we had to excavate a certain area of the ground to slightly deeper than the pool and employed submersible pumps to continuously dewater the ground water so as to be able to lay the pipes. To safe-guard our works, we provided a couple of flexible joints to the pipes, although it was not called for in the contract documents. The renovation works were successfully completed.

A few years ago, on one of my visits to their restaurant, I noticed that the pool had again tilted slightly with water only overflowing at certain lower sections of the pool. Unfortunately, hydrostatic relief valves were not installed in the pool by the building contractor. Our tasks during the renovation were mainly the mechanical and electrical parts of the renovation works. Unfortunately, our working relationship with the project consultant was not cordial, as otherwise we would have given them some decent sound advice.

Through the years, we had witnessed massive underground beams being designed and constructed to anchor pools to the ground along the coastal areas. Before draining a pool in a high water table location, it would be wise to install a submersible pump at a level deeper than the pool to continuously dewater the ground water before any further works. For new projects, it is possible to employ well-point pumps to lower ground water levels to provide stable ground condition for excavations.

Well points consist of a series of closely spaced small diameter wells created by the use of high-pressure water jets at the end of a boring pipe. Small-diameter (about fifty millimetres) tubes with slots provided near the bottom are inserted into the ground from which water is drawn by a vacuum-generated dewatering pump. Well points are typically installed at which water can be drawn to about six metres. For deeper under-ground construction works in a high water table area, several bore-hole submersible pumps controlled by water level switches are usually employed to provide a dry working area.

Hydrotherapy Fitting
Figure 10-8

(***courtesy of Hayward Inc.***)

For in-ground pools, the drainpipe normally penetrates the main drain sump through the side wall with slab thickening around the sump as shown in Figure 10-7. It is not uncommon for condominiums and hotels to build swimming pools above underground car parks. In such constructions, the drainpipe can still penetrate the main drain sump through the side wall as the sump floor will be deepened at their location.

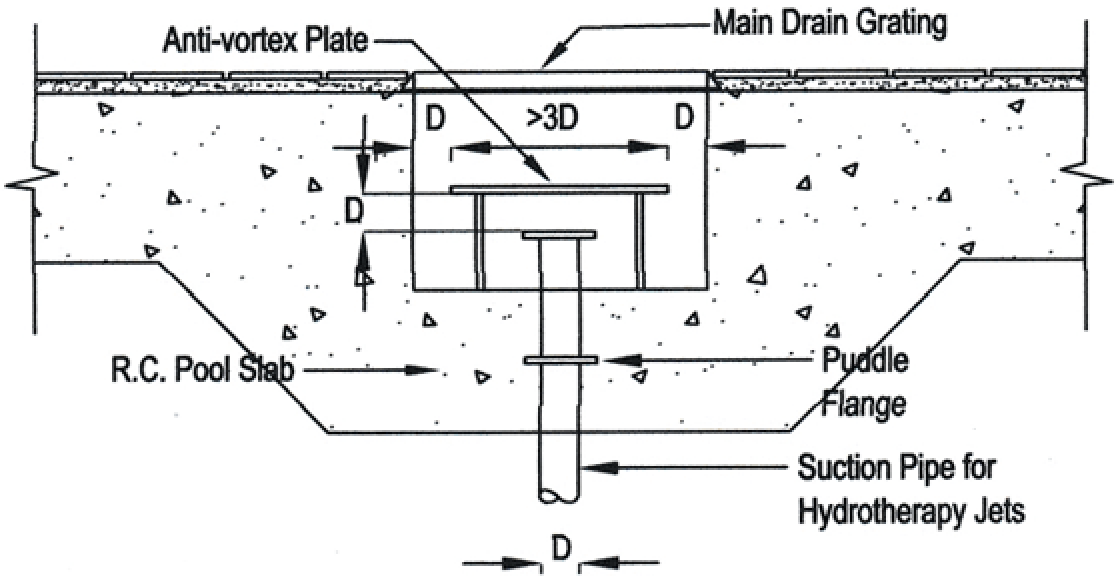
Hydrotherapy jets are quite often installed as an added new dimension to the pool to provide hydro-massage. Water required to operate these fittings are usually drawn from the main drain in the pool. These fittings can be installed on the walls or floors of the pools. These fittings create a turbulent stream of bubbling aerated water.

Two pipe connections are to be made to the hydrotherapy fittings as shown in Figure 10-8. Care must be exercised to ensure that the air supply and water supply pipes are correctly interconnected when multiple fittings are installed.

Hydro-massage Feature at a Public Pool
Figure 10-9

A separate pump is installed to operate the hydro-fittings. Usually, an air switch is provided in the vicinity of the jets to activate the hydro-pump as and when required. This timer is usually set to automatically operate for fifteen and thirty minutes on activation so as to ensure savings in power consumption.

The hydrotherapy pump delivers pressurised water to the water inlets. The velocity of water flow increases when the water flows from the larger diameter pipe into the smaller opening in the fitting. When the water exits the orifice in the fittings, it is at a lower pressure than the air in the air supply pipe. Air is thus drawn into the lower pressure water stream and mixes with the water. This is termed as the “Venturi principle”. The explosion of the air bubbles combined with the turbulence of water massages the bathers like countless tiny hands. Without the air, the water jet is like a garden hose held under water. It is important that the air supply pipe be installed above pool water level to draw in the air.



Anti-vortex Plate Installation Details
Figure 10-10

Besides providing hydro-massage, the bubbling aerated water can serve as a water feature to the pool as shown in Figure 10-9. In Figure 10-9, bathers are able to lie down on the shallow end of the pool for their hydro-massage.

Not too long ago, an unfortunate bather was drowned in a hydro-pool in a local condominium. He was sucked in and stuck to the hydrotherapy pump suction pipe at the main drain when he went too near to it. From the photograph published in the local newspaper, the plastic main drain grate was damaged and the suction pipe for the hydrotherapy pump was pointing upwards to the sky. This is similar to having an operating vacuum cleaner hose directed at a person.

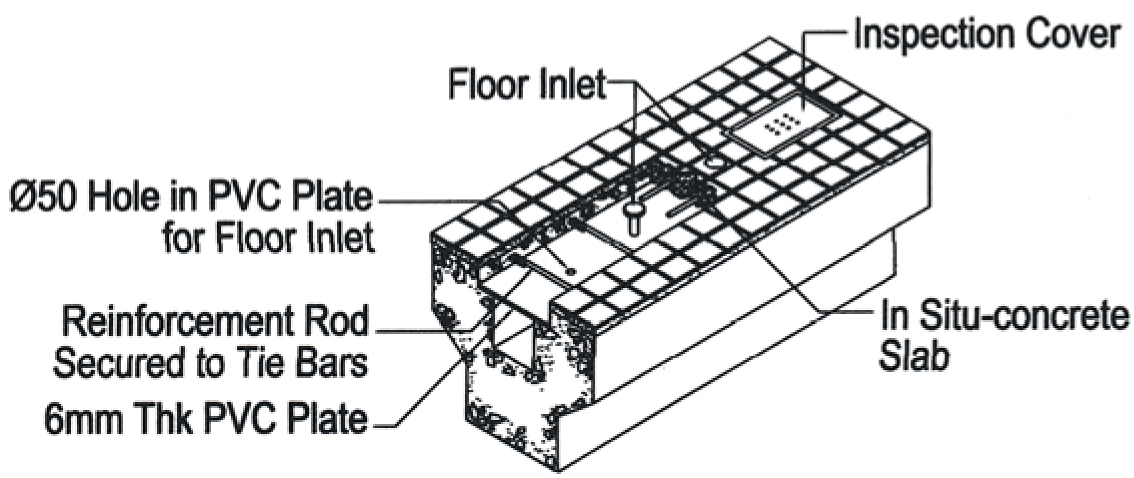
Such an uncalled-for accident would not have happened if the engineer and installer responsible for the project had exercised some precautions. Presumably, the hydro-pool must have been on the ground level with the plant room below it. In this incidence, the suction pipe penetrated the base of the main drain and was pointing upwards to the sky. The main drain sump should have been enlarged and deepened so that with the use of pipe elbows, an inverted “U” could be formed to direct the suction pipe towards the sump base.

Floor Inlet
Figure 10-11

(***courtesy of Hayward Inc.***)

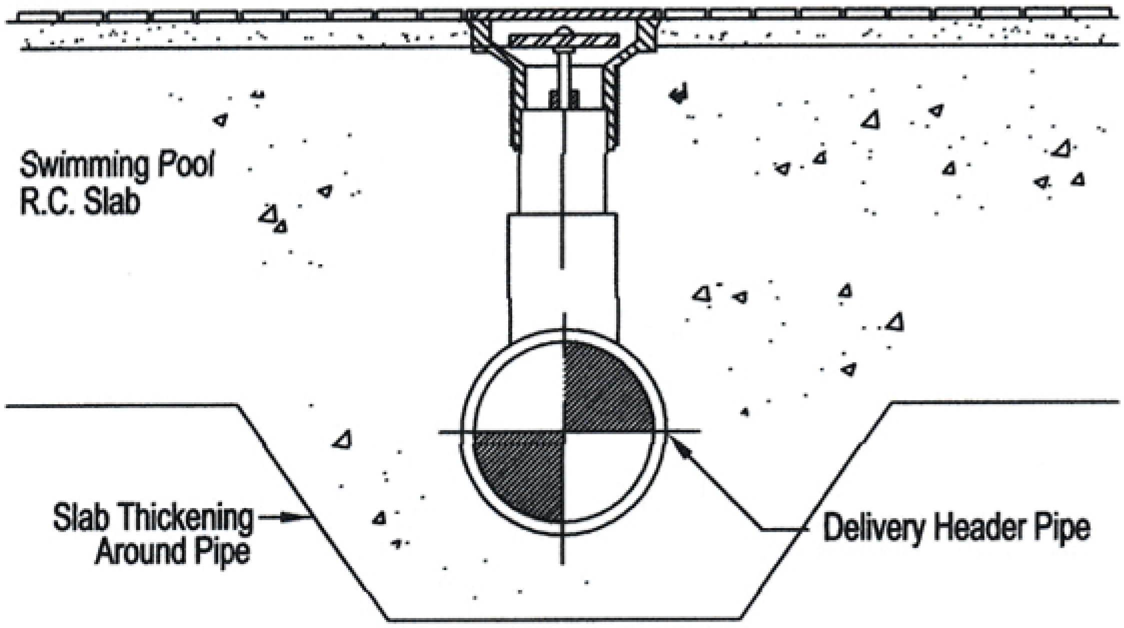
Alternatively, an anti-vortex plate as shown in Figure 10-10 could have been installed in the main drain sump for the safety of bathers. Plastic materials deteriorate after long exposure to the sun. As a safety measure, the drain cover should have been fabricated preferably with stainless steel.

For swimming pools with “surflo circulation system”, treated water enters the pool through floor inlets installed in the pool floor. Contaminated water is drawn-off mainly at the surface using high capacity overflow drains. The pattern of circulation is essentially up-flow. The adjustable floor inlet, as shown in Figure 10-11, provides an uniform 360^0-water distribution.



Floor Inlet Installation Details A
Figure 10-12

Floor inlets can be installed on specially constructed inlet channels or with pipes on the pool floor as shown in Figure 10-12 and Figure 10-13 respectively.



Floor Inlet Installation Details B
Figure 10-13

For installation of a specially formed inlet channel on pool floors, a recess is provided at the top of both sides of the formed channel to enable a support to be placed so as to permit the top slab of the channel to be casted. The support must be of sufficient thickness to sustain the weight of concrete that is to be placed on it and the elevated concrete temperature when it is curing.

A business associate was tasked to supply PVC pipes for casting into concrete columns to serve as rainwater down pipes for a highway flyover. Due to their slight administrative errors, pipes of slightly thinner thickness were supplied to the building contractor. All the pipes in the 28 columns collapsed during the casting due to the elevated concrete temperature. The trading company was forced to wind up to escape costly legal recovery actions by their clients.

For the installation of a specially formed inlet channel on pool floors, before the casting of the top slab, short pipes are positioned at determined intervals with polythene foam wrapped around the pipes close to the finished casting level of the concrete. When the casting of the top slap of the inlet channel is completed, the polythene foam around the pipes will be removed. This is to enable ease of adjustment of the floor fittings to suit the tiling level without having to hack the concrete slab. Reinforced rods must be secured to the tie bars before the in-situ concrete is poured, without which the whole slab will be ripped off by the force of the water when the circulation system operates. The pressure of water must never be under-estimated.

A well-renowned Japanese contractor did not heed our advice in one of the construction projects and had to pay a high price for remedial works. When the top slab of the inlet channel was ripped off, the pool was drained to clear all debris to expose the inlet channel. The sides of the inlet channel had to be drilled, with great difficulties due to tight space constraint, to plant rebars with epoxy grout to serve as tie bars. The Japanese contractor was humbled by this incidence.

For installation of floor inlets with pipes, the floor slab is thickened around the location of the delivery header pipe. Polythene foam is also wrapped around the short pipes at the finishing casting level of the concrete. When the casting of the pool floor is completed, the polythene foam around the pipes will be removed. This is also to enable ease of adjustment of the floor fittings to suit the tiling level without having to hack the concrete slab.

Another notable pool fitting is the underwater lights. These are usually installed on the pool walls. At the intended locations to be installed, the wall thicknesses will have to be increased. The main consideration of underwater light installation is to ensure the light emission fitting can be replaced without having to drain the pool. Also of major importance is the connection of the cables between the underwater light fittings and the power supply cables from the electric control panel. These connections must be above water level and watertight.

In the evening, residential pools are illuminated for aesthetic and safety reasons by underwater lights installed on the pool walls. The illumination of pool surround is supplemented by bollard lights or other types of pole lights. The light intensity is of secondary importance, as most house owners will prefer to create an ambience around the pool.

Conventional pool lights use PAR56 lamps that are usually 300 watts 12 VAC. The voltage is reduced from 230 volts to 12 volts by an electrical transformer for the safety of bathers. In the event of any electrical leakage, the low voltage will not pose any danger to the bathers. With advancement in technology, lighting by fibre optics, halogen lamps and LED lights are now readily available.

Commercial pools are usually lit in the evening during pool opening hours by floodlights installed around the pool deck. A mean light intensity of 400 lux will suffice to light up the pool area for use. Light intensity of competition pools over starting platforms and turning ends must be not less than 600 lux to comply with FINA Standards. Pools used for synchronised swimming and water polo in Olympic Games and World Championships must have a light intensity of not less than 1500 lux. Pools used for water polo or other competitive events will require a light intensity of 600 lux. To save on operating costs, the floodlights must be able to be controlled by different switches, so that during non-competition periods, the light intensity on any point in the pool can be lowered to reduce electrical power costs.

For a competition pool, rope anchors are also casted at both ends of the pool to enable the racing lanes to be installed. Anchors are also casted on the pool decks on both ends of the pool for the installation of starting blocks when required. Underwater windows are installed in some pools for observation of the swimmers during training and competition.

In this chapter, the major fittings to be installed in pools had been elaborated. Of course, the many other pool deck equipment which can be of interest to readers could be explored at their leisure.

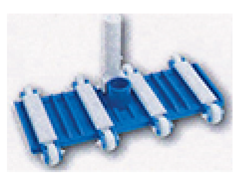
11: Maintenance Equipment

This book will be incomplete without a mention of the various types of equipment available for pool maintenance. To maintain a clean and sanitary pool, the debris that has sunk to the pool floors must be removed. The pool decks must also be cleaned as bathers will transfer the dirt accumulated into the pool water when they walk bare-footed around the pool.

For domestic pools, the frequency of cleaning is dependent on the cleanliness of the pool surrounds and bathing loads. In Singapore all public pools are cleaned daily and the pool decks cleaned thoroughly with high-pressure water jets. As a matter of interest, daily, the cleaning contractor has to provide at least one personnel to be stationed in the swimming complex during pool operation hours for cleaning purposes.

Swimming pools can be cleaned by using the suction side of the filtration pump or an external self-priming vacuum pump mounted on a two-wheeled trolley for mobility around the pools. An external booster pump can also be employed to propel automatic pool cleaners. With advancement in technology, robotic pool cleaners are readily available.

Most residential pools in Singapore are manually cleaned by pool cleaning contractors. Some residential pools are cleaned by the owners' trained domestic helpers. Most public pools employ robotic pool cleaners for cleaning and supplement with manual cleaning of those areas reachable from the pool decks.



Vacuum Head
Figure 11-1

(*courtesy of Pahlen*)

Manual Cleaning of Pool

Cleaning a swimming pool is not much different from vacuuming the house with a vacuum cleaner. For cleaning a pool, a vacuum head as shown in Figure 11-1 is required, as well as a vacuum hose as shown in Figure 11-2 for connection to the vacuum head. The vacuum hose has a fixed cuff and a swivel cuff at opposite ends of the hose.

Vacuum Hose
Figure 11-2

(***courtesy of Pahlen***)

To vacuum the pool manually, the following procedure can be followed:

1. Connect the swivel cuff of the vacuum hose to the vacuum head.
2. Attach the telescopic pole, Figure 11-3, to the vacuum head.
3. Lower the vacuum head to the pool floor, holding on to the other free end of the vacuum hose.
4. If it is a residential skimmer-type pool, push the vacuum head further away from the skimmer to fully extend the hose to enable the hose to be filled with water.
5. Lower the fixed cuff of the hose into the pool and incline it slightly to fill the hose completely with water. The hose will sink slightly below the water surface when it is completely filled with water.

Telescopic Pole

Figure 11-3

(*courtesy of Pahlen*)

6. Avoid bringing the cuff of the hose above the water level. With the circulation pump in operation, connect the cuff of the hose to the circulation pump opening in the skimmer through the front of the skimmer mouth.
7. Once all the air has been fully expelled from the vacuum hose as observed through the return water of the wall inlets, the vacuuming operation can commence.

Leaf Rake
Figure 11-4

(*courtesy of Pahlen*)

8. If an external vacuum pump is employed for the vacuuming operation, ensure the power plug provided on the two-wheeled-trolley-mounted pump is connected to any 13A-switch-socket outlet provided around the pool before commencing step one.

Wall Brush
Figure 11-5

(*courtesy of Pahlen*)

9. Next, follow steps one to four. Connect the vacuum hose to the suction pipe of the vacuum pump and fill some water into the hair and lint strainer of the vacuum pump. Close the strainer cover.
10. Switch on the electrical power supply for the vacuum pump.

11. Ensure all the air is fully expelled in the vacuum hose before commencing vacuum cleaning operation. This can be observed through the transparent strainer cover or the return water to the pool overflow drains.

Vacuum Pump
Figure 11-6

(***courtesy of Pahlen***)

12. Commence vacuuming the pool floor by pushing the vacuum head slowly with the telescopic pole so as not to agitate the debris.

13. Before commencing vacuuming operation, the leaf rake can be attached to the telescopic pole to fish out any floating leaves or debris from the water surfaces.

In some swimming pools with “surflo circulation system”, dedicated vacuum fittings are installed on the pool walls to provide connections for the vacuum hose for vacuuming the pool when the circulation pump is in operation. As such all debris will be removed before the water is returned to the pool. With the use of an external vacuum pump, all the dirt together with the water will be delivered into the overflow drains to return to the balancing tank for treatment. This debris will ultimately sink to the floor in the balancing tank. Periodically, the balancing tank must be cleaned as otherwise the dirt will accumulate to an unacceptably high level.

In the past, our assistance was sought by a few bewildered pool owners on the sudden disability of their sand-filtration systems to maintain clarity of their pool water despite all attempts to unravel the problem. On investigating these problems, we learnt that the balancing tanks were never cleaned for years. By cleaning the balancing tanks and introducing alum into the systems, followed by backwashing the filters after one and two filter cycles, the problems were resolved. By not specifying this cleaning requirement in the cleaning and maintenance contract, it can be sure the ignorant cleaner will never clean the balancing tank.

To prevent such occurrences, a cartridge filter can be provided to the external vacuum pump as shown in Figure 11-6. The debris will be removed by the cartridges before the water is returned to the balancing tank or directly into the pool.

Always handle the maintenance equipment with care to enable it to provide years of useful service.

Before the availability of robotic automatic pool cleaners to clean large and Olympic-size pools, the pools were cleaned manually.

A heavy 900-millimetre-wide bronze, roller-mounted vacuum head would be attached to a long 50-millimetre-diameter vacuum hose. The fixed cuff of the vacuum hose will be connected to the suction pipe of a trolley-mounted self-priming vacuum pump. Instead of a motor-driven vacuum pump, more often than not it would be an engine-driven vacuum pump due to the non-availability of electrical switch socket outlets around the pool surround. The vacuum head would be lowered into the pool with tow ropes.

Two cleaning personnel positioned on the opposite sides of the deep end of the pool would hold on to the towing ropes attached to the vacuum head. Once the vacuum pump was in operation and the air in the vacuum hose fully expelled, the vacuuming operation would commence. Each cleaning personnel would take turns to pull the vacuum head slowly towards him attempting to tow the vacuum head in overlapping parallel paths so as to clean every inch of the pool floor.

For the shallow ends of large and Olympic-size pools, the cleaners could get into the pool to vacuum the floors with narrower vacuum heads. To enable the whole pool to be cleaned completely, the trolley-mounted vacuum pump must be shifted in tandem with the towing of the vacuum head across the pool. Such a cleaning process is slow, tedious and extremely unproductive.

Hayward Automatic Pool Cleaner
Figure 11-7 *(courtesy of Hayward Inc.)*

For residential and condominium pools, the time of cleaning can be arranged easily to be performed at non-peak usage hours of the pools. For public and hotel pools, the cleaning operations are usually performed during the non-operating hours of the pools, either after the closure of the pools for public use or in the wee hours of the morning.

Automatic Cleaning of Pool

Automatic pool cleaners are gaining popularity as they become relatively inexpensive and affordable. Automatic pool cleaners can be classified under three broad categories by their source of power and drive mechanism. They are:

- Suction-side
- Pressure-side
- Robotic cleaner

The suction-side automatic pool cleaners are largely confined to use in residential pools as they work off the filtration pumps. They are usually connected to the automatic skimmers or dedicated vacuum fittings installed on the pool walls. The suction force will propel the cleaner to vacuum the debris on a random course to traverse the floor and walls of the pool. The debris will be filtered and the clean water returned to the pool as in a normal filtration cycle. Such cleaners usually use a 40-millimetre diameter vacuum hose for attachment to the vacuum point.

This is the least expensive and most popular automatic cleaner for residential pools. The strainer basket of the filtration pump must be cleaned and the filter backwashed after each cleaning operation. A Hayward automatic suction-side cleaner is shown in Figure 11-7.

In the pressure-side design, the water pressure is usually provided by a secondary booster pump. It can work off the existing circulation system by restricting the flow from other return fittings, but will not operate effectively if the filter is dirty due to a greater pressure drop. The high-pressure water is used to propel the cleaner on a random course and to create a Venturi effect to vacuum the debris usually into a filter bag. The high water pressure will stir some of the debris that had settled to the pool floor causing some to re-float to the pool surface to be treated by the filtration system. Such cleaners can be employed for residential and moderate-size public pools.

Electric robotic pool cleaners work off electrical power plugs similar to household vacuum cleaners. These cleaners are independent from the pool circulation systems and are employed to clean commercial and Olympic-size pools. For safety, the operating voltage is stepped-down by electrical transformers to a low voltage. All electric robotic pool cleaners have two low voltage motors. One propels the cleaner and operates the front and rear roller brushes to scrub the pool floor and walls and to direct the debris and dirt into the internal filter. The other motor operates the pump to draw in water together with the debris and dirt to the self-contained filter and return the filtered water to the pool.

With advancement in technology, most robotic pool cleaners can be manually controlled and operated with wireless remote controls. They can also be set to operate on automatic mode.

On automatic mode, the pre-programmed microchip in the cleaner will switch the unit on and off automatically and reverse the direction of the drive motor to cause the cleaner to change direction when it hits the pool walls or the water surface after cleaning the pool walls. However, most robotic pool cleaners, on automatic mode, clean the pool floor and walls in a random course with no fixed patterns, except for one technologically advanced model that can clean the pool in overlapping parallel paths. This is the Mariner 3s as shown in Figure 11-8.

Mariner 3s Automatic Pool Cleaner
Figure 11-8 *(courtesy of Mariner 3S AG)*

Most commercial pool robotic pool cleaners employ bag filters as their self-contained internal filters. The Mariner 3s uses cartridge filters. With their innovative technological design, this manufacturer sets new standards for pool cleaning since 1970. The Mariner 3s will automatically float to the water surface on completion of the cleaning operations.

12: Maintenance of Correct Pool Water Chemistry

The proper and constant use of chemicals is required in all swimming pools to kill bacteria to prevent the spread of germ infection and to maintain clean, sanitary water. Pool water may be contaminated by swimmers and other sources such as organic material from decaying leaves, bird droppings, fungi-infested rain water or dead organisms. The quality of pool water must equal or exceed the standards prescribed by WHO for drinking water. Knowledge of basic pool water chemistry is required to use chemicals effectively and economically.

Although the pH and disinfectant levels are vital to ensure proper quality of pool water, it is also necessary to check the alkalinity and hardness of the pool water fortnightly. As highlighted in Chapter 9, the water supplied by our water supply agency is considered soft with an average hardness of 59 mg/l $CaCO_3$. This is not advantageous to concrete pools. Figure 9-2 shows how badly the cement screed of the tiles had been etched by the soft water. This is a common phenomenon in our public swimming pools. Public pool maintenance personnel have been trained on the importance of maintaining correct chemical balance of pool water but unfortunately were never provided with the necessary chemicals and test kits to ensure its implementation. Swimmers in public pools are often inflicted unknowingly with minor cuts on their feet and hands. When swimmers are soaked in water, their skins will become soft. When the screed between the tiles is etched by the soft water, the edges of the tiles become razor sharp. Any quick movement across these tile edges will inflict swimmers with undesirable cuts just like a cut can be inflicted to your finger if you swipe the side of a thin paper swiftly across your finger. Sadly to this day, our public pools have never maintained a correct chemical balance of the pool water. In fact almost all local swimming pool maintenance companies never conduct tests of the water alkalinity and hardness of the pools that they maintain, as they have poor and no knowledge of pool water chemistry. These tests are required to determine whether the water has a scale-forming tendency or a tendency to corrode. It is a test to safeguard the health of the pool — unlike the pH and free chlorine tests that are to safeguard the health of swimmers. Maintenance of correct pool water chemistry incurs additional costs, but it is imperative to safeguard the health of the pool. It is more economical than having to re-tile and re-plaster the pool.

Hopefully, this chapter will be able to raise the understanding of pool water chemistry of pool owners and pool maintenance personnel by one or two notches. Such a result will resonate as the success and intent of this book.

Commercial sodium hypochlorite is used to provide clean sanitary water in our public pools and is injected during filter operations. For most private and condominium pools, powder chlorine is commonly used. The amount of chlorine required is dependent upon the amount of contaminants in the water, the bathing load as well as the sun and wind. The chlorine residual is maintained between 1.0 and 3.0 ppm (parts per million parts of water). As highlighted in Chapter 6, DPD tablets are gaining popularity for testing chlorine levels in pool water.

When commercial sodium hypochlorite is injected into the pool water, hypochlorous acid is formed, as mentioned in Chapter 6. Sodium hypochlorite disinfects the same way as gaseous chlorine, but increases the alkalinity of the water. Hence, hydrochloric acid is required to lower the pH of the water. For every kilogram of sodium hypochlorite consumed, about half a kilogram of hydrochloric acid is required to lower the pH of the pool water.

When added to water, chlorine reacts to form hypochlorous acid and hydrochloric acid as shown in the following chemical reaction:

Cl_2	+	H_2O	$\rightleftharpoons$	HOCl	+	H^+	+	Cl^-	

If ammonium is present due to the introduction of perspiration, urine and saliva, chloramines will be formed as follows:

NH_4^+	+	HOCl	$\rightleftharpoons$	NH_2Cl	+	H^+	+	H_2O	(monochloramine)
NH_2Cl	+	HOCl	$\rightleftharpoons$	$NHCl_2$	+	H_2O			(dichloramine)
$NHCl_2$	+	HOCl	$\rightleftharpoons$	NCl_3	+	H_2O			(trichloramine)

It is therefore important to insist that swimmers shower before swimming and remind all swimmers especially kids not to pee and spit in the pool, or their bodily secretions will consume the hypochlorous acid formed from either the sodium hypochlorite or chlorine intended to disinfect the water.

Chlorine as part of the hypochlorite ion or the chloride ion in hydrochloric acid does not contribute to the purification reactions. Hypochlorous acid is the actual molecule that kills the microbial bodies and prevent algal growth, but only if the pH of the pool water is kept to the appropriate range. The pH of the pool water affects the disinfecting capabilities of the HOCl as shown in the following formula.

HOCl	$\rightleftharpoons$	H^+	(acid)	+	OCl^-
(Hypochlorous acid)		(Hydrogen ion)			(Hypochlorite ion)

The HOCl is in equilibrium with the hydrogen ion (H^+) and the hypochlorite ion (OCl^-). Lowering the pH of the water will increase H^+, which causes the equilibrium to move to the left. Thus as the pH is lowered, there is more HOCl or hypochlorous acid and less OCl^- or hypochlorite ions.

When the pH is raised, the acid concentration, H^+, is lowered and more of the hypochlorous acid is converted to the hypochlorite (OCl^-) or non-disinfecting form. The proper pH of the pool water to be maintained is 7.2 to 7.6. In this range, there is a favourable balance between the HOCl and OCl^-. A pH test is usually done by colour comparison as mentioned briefly in page 38 of Chapter 6. A test cell is filled with water from the pool. A pH indicator is added and the developed colour is compared to colour standards to obtain the reading.

Table 12-1 shows the equilibrium between HOCl and OCl^- at various pH readings.

pH	% of Chlorine as OCl^-	% of Chlorine as HOCl
6.0	3.5	96.5
6.5	10	90
7.0	27.5	72.5
7.2	34	66
7.6	55	45
8.0	78.5	21.5
8.5	90	10

Effect of pH on Chlorine Activity
Table 12-1

Public swimming pools in Singapore have been using yellow polyethylene tanks to store sodium hypochlorite and red polyethylene tanks, to denote dangerous chemical, for hydrochloric acid. The sodium hypochlorite pipe painted yellow at the chemical receiving bay, is provided with a 50-millimetre-diameter male hose quick-connection coupling. Prominent signs are also displayed to indicate it is solely for receiving sodium hypochlorite. Adjacent to this pipe, the hydrochloric acid pipe painted crimson red, is provided with a 40-millimetre-diameter male hose quick coupling to receive the hydrochloric acid, with prominent signs also displayed. This is to enable the chemicals supplier to easily identify and connect their correct chemical supply hoses to the couplings to pump the chemicals into the respective storage tanks.

This is a fool-proof method to ensure that correct chemicals are delivered into the correct storage tanks. No accidental mistakes had occurred until early 2000. A social club for reservist military personnel had an Olympic-size swimming pool with the filtration plant room in the basement.

On that eventful day, hydrochloric acid was pumped at the ground level chemicals receiving bay into the sodium hypochlorite storage tanks in the basement. All hell broke loose, when the instant chemical reactions caused chlorine gas to be discharged intensely into the basement car parks causing immense damages to the property and suffocating several members and visitors to the social club. The only logical conclusion for such a silly incidence is that the supply pipes installed for both chemicals were of identical diameters to cause such an unforgivable accident. Attention not paid to minor details can result in serious accidents.

Acidity and alkalinity are measured on a pH scale of 0 to 14. This is a base-ten logarithmic system with values below 7.0 indicating the water is acidic, above 7.0 for alkaline, 7.0 being neutral (neither acidic nor alkaline). A pH of 4 is ten times more acidic than a pH of 5, which in turn is ten times more acidic than a pH of 6 — making pH 4 one hundred times more acidic than a pH of 6.

Acidic water is corrosive to metallic parts of pool equipment, which can lead to expensive and frequent replacement of metallic valves, filters and other pool equipment. Alkaline water plays a role in prevention of corrosion, however, excessive alkalinity causes mineral deposits and interferes with disinfection. Cloudy water that irritates bathers' skins, eyes and breathing passages is typical of a pool where the pH is too high or too low. It is essential that the pH of pool water be maintained between 7.2 and 7.6.

As commercial sodium hypochlorite is employed for treatment of our public pools, this will result in an excessive alkaline condition (pH above 7.6) and muriatic acid will have to be added to properly balance the condition.

Muriatic acid, a colourless liquid with an irritating odour, is the commercial name for 20 degree Baume hydrochloric acid with the chemical formula: HCl. It is highly corrosive and has many industrial applications. It is used for reducing the pH of pool water, but requires careful handling by trained personnel as it is a dangerous chemical. It is also used as an acid wash for calcified sand filters and for scrubbing pool walls to get rid of established algae. This acid is produced by dissolving hydrogen chloride gas in water. By burning hydrogen and chlorine gases together, hydrogen chloride gas is formed.

Chlorine and pH probes or sensors used in automated dosing systems must be calibrated and replaced at the intervals recommended by the manufacturers to ensure the accuracies and effectiveness of monitoring the automatic control of chlorine and pH levels.

For those unfamiliar with some of the basic terms used in chlorination and pool water balance, the following explanations may be helpful.

Chlorine Residual
Chlorine residual is the amount of chlorine available after a specified contact period. It is necessary to maintain a chlorine residual level to assure complete and proper treatment — the margin of insurance against subsequent contamination. When the break point is passed, the free chlorine residual rises in step with the chlorine added and will rapidly disinfect any new contaminants in clean water.

Chlorine Demand
Chlorine demand is the amount of chlorine required to eliminate all contaminants in the pool water.

Super-chlorination
Super-chlorination is necessary to destroy build-up of chloramines. Bad chlorine-like odours in pool water are caused by chloramines.

Super-chlorination involves closing the pool to apply heavy doses of chemicals to raise the chlorine residual to 5.0 ppm or more, and allowing the excess residual to dissipate overnight. It is undesirable to super-chlorinate the pool with trichloroisocyanuric acid tablets as it will result in excessive build-up of stabiliser that will reduce the effectiveness of the chlorinating agent in controlling bacteria and algae.

Breakdown Chlorination

Breakdown chlorination usually applies to the chlorine dose that is initially added to oxidise any reducing compounds present in the pool water, then increased to form chloramines with any ammonia present, increased still further to destroy the chloramines and increased finally to build up the highly effective bactericidal free residual chlorine. This is call the break point, at which most of the chlorine in the water is in the free state. As it passes through the third stage of destruction of the chloramines, there is a drop in the chlorine residual present in the pool water and this is termed as the break point.

Hardness

"Hardness" is a term that indicates the amount of dissolved mineral in the water. Hardness is defined as the effect of any particular water on soap. The lesser the soap needed for lather, the softer is the water. Calcium and magnesium, found in varying amounts in practically all water supplies, make it "hard" for soap to lather. Hardness of water is due mainly to the solids and rocks over which the water flows and dissolves. Calcium and magnesium are the primary ions contributing to water hardness with calcium accounting for the major part of the hardness. The greater the concentration of calcium and magnesium present in the water, the more soap is needed before a lather will form and the harder the water is said to be. In some waters, iron and manganese also contribute to hardness.

Hardness is stated in parts per million or milligrams per litre expressed with calcium carbonate, $CaCO_3$, as reference or standard.

Hardness can be removed by ion exchange softening. Although hardness is not advantageous for domestic applications such as bathing, shaving, washing your dishes, car and laundry, swimming pool water must contain a substantial concentration of calcium hardness to prevent it from etching the plaster.

The cliché that “water seeks its own level” is certainly true here. If calcium hardness levels are too low, the water is under-saturated. If it is under-saturated, the water will become aggressive as it attempts to obtain the calcium it needs. It will dissolve plaster in the pool and the balancing tank walls causing the surfaces to be pitted and etched. In some installations where ductile iron cement-lined pipes are used, the cement lining will be badly etched, leaving the interior of the metallic pipes unprotected. Slowly and surely the unprotected metallic pipe will be attacked by the chlorinated water causing it to rupture resulting in the loss of pool water. Damages from corrosive water cannot be reversed. Replacement of damaged pipes and re-plastering and re-tiling of pool walls and floors are the only remedy.

If the hardness or calcium concentrations are too high, the water will deposit some of its content in the form of scales in pipes, on pool walls and the filters. The scales can be removed by lowering the pH of the pool water to an acidic level for a short period of time. Such an action will result in the cement screed between the tiles and the balancing tank walls to be dissolved and the metallic components of the filtration system to be attacked. Increasing the amount of calcium hardness in the pool water is easily done by adding calcium chloride. Ideally, the calcium hardness of pool water should be maintained at 200-400 ppm.

Total Dissolved Solids

Total dissolved solids is defined as the amount of all materials dissolved in water.

Total Alkalinity

Total alkalinity is the sum of all the alkaline minerals in the water, primarily the carbonates, bicarbonates and hydroxides of calcium, magnesium, potassium and sodium. It is the measure of the pool’s buffering capacity to resist pH change. It is often necessary to adjust the total alkalinity for proper water balance. It is increased by the addition of sodium bicarbonate (baking soda) and decreased by adding acid to the water. It is essential that the total alkalinity of the pool water be maintained at 80-100 ppm. Total alkalinity is measured by performing a simple acid-base titration. Colour change in a known volume of water sample is detected using a total alkalinity indicator.

Cyanuric Acid

Cyanuric acid is a chemical that will help reduce the loss of free residual chlorine in the pool water due to sunlight and evaporation. It is also called a stabiliser or conditioner as it casts a UV shield on the pool water surface to minimise the loss of chlorine due to the exposure to the UV rays of the sun. Once added to the pool water, it does not dissipate. It is removed from the pool by splash out and through filter backwash. Ideally, the cyanuric acid level should be maintained at 30-50 ppm. Excessive cyanuric acid levels can interfere with the disinfection process. At concentrations above 100 ppm, it may cause “chlorine lock” which decreases its sanitising effect and clouding of the pool.

Balanced Water

Balanced water is defined as water that is chemically stable and will not corrode nor scale pool surfaces and equipment. The concept of balanced water is based on the fact that water will dissolve and hold minerals until it becomes saturated. In chemistry, a solution is saturated when no more of a substance will dissolve in it at the given temperature. Balanced pool water creates a carbonate alkalinity buffer, which prevents the water’s pH from drifting too high or too low when acidic or alkaline substances are added to the pool.

In 1936, Dr. Wilfred Langelier of the University of Southern California developed a relatively simple formula to predict the calcium carbonate stability in water. It indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate. This water balance calculation is known as the Langelier Saturation Index. The equation is as follows:

Saturation index (SI) = pH + TF + CH + TA - 12.1

Where, TF is a temperature factor, CH is calcium hardness, TA is total alkalinity and 12.1 is a constant. Compact water test kits that can test each parameter in the above formula are readily available. It is important that the indicators and reagents used in these kits are stored properly, away from heat and direct sunlight. These tests are necessary to maintain balanced clean water. Newer testing methods have become available in the past few years including digital test strip readers and portable multi-parameter photometers. Recordings of results of all tests done objectively should be stored for future analysis.

Calculating the SI of pool water is essentially doing simple arithmetic and is used to determine the degree of calcium carbonate saturation. On examining the formula, we will realise that pH is the single most important element in swimming pool water chemistry affecting every other chemical balance in the pool water. The actual pH reading of the pool water is inserted into the formula for computation, whereas the other parameters in the formula employ numerical factors for calculations. Due to the weightage of pH in this formula, the pH of the pool water should be tested and adjusted to the ideal range, before other SI parameters are adjusted.

To calculate the Saturation Index, measure the pool water for pH, temperature, calcium hardness and total alkalinity. Refer to Tables 12-2 and 12-3 for the assigned numerical factors for your temperature, calcium hardness and total alkalinity readings and add these to your pH value. Subtract 12.1 which is the constant value assigned to Total Dissolved Solids and a resultant number will be produced.

Most non-salt pools will use Langelier's original constant of 12.1, when the total dissolved solids (TDS) are below 1000 ppm. However, saline pools or pools with high TDS may need a slight adjustment to this numerical constant as shown in Table 12-4.

Pool water temperature is perhaps the easiest and least significant factor of all the parameters in the SI to measure. Unlike pH, the actual temperature measurement is not the figure used for calculating the SI. Instead the SI uses a temperature factor (TF), which is a number corresponding to the measured temperature. Tables 12-2 and 12-3 provide the TFs for a wide range of pool water temperatures.

Temperature		Calcium Hardness		Total Alkalinity	
^{0}C	TF	mg/l $CaCO_3$	CF	mg/l $CaCO_3$	AF
22	0.56	25	1.0	25	1.40
24	0.6	50	1.30	50	1.70
25	0.62	75	1.50	70	1.86
26	0.64	100	1.60	80	1.92
27	0.66	120	1.68	90	1.96
28	0.68	140	1.76	100	2.00
30	0.72	150	1.80	120	2.08
32	0.76	170	1.84	150	2.20
34	0.8	200	1.90	200	2.30
41	0.9	250	2.00	300	2.50
		300	2.10	400	2.60
		400	2.20	800	2.90
		800	2.50	1000	3.00

Numerical Factor for Saturation Index Calculation for Water Temperature in ^{0}C
Table 12–2

Temperature		Calcium Hardness		Total Alkalinity	
^{0}F	TF	mg/l $CaCO_3$	CF	mg/l $CaCO_3$	AF
32	0.0	25	1.0	25	1.40
37	0.1	50	1.30	50	1.70
46	0.2	75	1.50	70	1.86
53	0.3	100	1.60	80	1.92

60	0.4	120	1.68	90	1.96
66	0.5	140	1.76	100	2.00
76	0.6	150	1.80	120	2.08
84	0.7	170	1.84	150	2.20
94	0.8	200	1.90	200	2.30
105	0.9	250	2.00	300	2.50
128	1.0	300	2.10	400	2.60
		400	2.20	800	2.90
		800	2.50	1000	3.00
		1000	2.60		

Numerical Factor for Saturation Index Calculation for Water Temperature in ^{0}F
Table 12-3

Total dissolved solids, ppm	<1000	1000	2000	3000	4000	5000
Adjusted Langelier's Constant	12.1	12.19	12.29	12.35	12.41	12.44

Constant used for Pools with High Total Dissolved Solids
Table 12-4

An important aspect of pool water temperature is the unique property of calcium. Calcium is more soluble at lower pool water temperatures than at higher water temperatures. That is colder pool water temperature is more corrosive to the plaster in the pools.

Calcium hardness measures the amount of calcium that is dissolved in pool water. Together with pH and total alkalinity, calcium hardness must be properly controlled to maintain the pool water in stable chemical balance. Total hardness in pool water consists of both magnesium and calcium salts. However, only the calcium hardness is relevant in the pool water calculations.

Although test strips are available to conduct calcium hardness tests, the range of the resultant readings is too wide — with only about five readings for 0 to 1,000 ppm. The calcium hardness test must be conducted at least once a month to safeguard the pool from unbalanced pool water. Drop test will enable the concentration of calcium hardness to be determined in ten-ppm increments. Add 12.99 grams of hydrated calcium chloride ($CaCl_2$) (77% strength), to every cubic metre of pool water to increase the hardness by ten ppm. Alternatively, you can add ten grams of anhydrous calcium chloride (100 % strength) to each cubic metre of pool water to increase the hardness by ten ppm. The hardness of the pool water can be lowered by backwashing the filters to replenish the pool with soft city water supply.

Heat will be generated when calcium chloride is dissolved in water. It is advisable not to pre-dissolve the calcium chloride in a bucket, but to broadcast it over the pool water surface with the circulation pump or pumps in operation. Pool water treated hours earlier with baking soda (sodium bicarbonate) or soda ash (sodium carbonate) will turn milky when calcium chloride is added.

Total alkalinity indicates the pool water's buffering ability to resist pH shifts. When the total alkalinity of the pool water is too low, the pH is low, the water is aggressive. Sodium bicarbonate is used to increase the low total alkalinity. Add fourteen grams of sodium bicarbonate (75% purity) for each cubic metre of pool water to increase the total alkalinity by ten ppm. Highly alkaline pool water leads to high pH and scale forming. Higher levels of total alkalinity can cause "pH lock", when the pH gets stuck at a certain level and is difficult to change. Muriatic acid or sodium bisulphate will be required to lower the total alkalinity.

Cyanuric acid is often added to the pool as a stabiliser. Add 10.1 grams of cyanuric acid (99% purity) to every cubic metre of the pool water to raise the cyanuric acid level by ten ppm. This chemical contributes to another kind of alkalinity known as cyanurate alkalinity. The total alkalinity of a pool with the stabiliser added will indicate a higher total alkalinity than is actually present. As SI calculation is based on bicarbonate alkalinity, the measurement obtained for total alkalinity must be adjusted as follows:

Carbonate Alkalinity = Total Alkalinity – (Cyanuric Acid x CyF)

where CyF is the cyanuric acid factor shown in Table 12-5.

pH	7.0	7.2	7.4	7.6	7.8	8.0
CyF	0.22	0.26	0.30	0.33	0.35	0.36

Cyanuric Acid Factor of Cyanurate Concentration according to pH
Table 12-5

For example, if a pool water has pH = 7.2; Total Alkalinity = 110 ppm; and Cyanuric Acid = 50 ppm, then

$$\text{Carbonate Alkalinity} = 110 - (50 \times 0.26)$$
$$\text{Actual carbonate alkalinity} = 97 \text{ ppm}$$

Once all the values have been converted to usable factors, the SI can be determined by inserting all these figures into the formula. Swimming pool water with a calculated SI between -0.5 and 0.5 is considered balanced. Above 0.5, the unbalanced water is over-saturated (scale forming) and below -0.5, the unbalanced water is under-saturated (corrosive). The following examples will illustrate the procedure for calculating the SI of pool water.

Example 1:

The water of a swimming pool has a pH of 7.2, water temperature of 28^0C, calcium hardness of 200 ppm, total alkalinity of 110 ppm, cyanuric acid at 50 ppm and total dissolved solids of less than 1000 ppm. Determine whether the pool water is balanced.

Saturation Index = (pH) 7.2 + (TF) 0.68 + (CF) 1.90 + (AF) 2.0 – 12.1
= -0.32

Table 12-2 shows that when:

- Water temperature = 28^0C, the temperature factor is 0.68
- Calcium hardness = 200 ppm, the calcium factor (CF) is 1.9
- Total alkalinity = 110 ppm with cyanuric acid = 50 ppm, from the earlier example actual alkalinity = 97 ppm, Alkalinity factor (AF) is 2.0.

From the calculations, it indicates the pool water is balanced as the final result is -0.32.

Example 2:

The water of a swimming pool has a pH of 7.6, water temperature of 84^0F, calcium hardness of 400 ppm, total alkalinity of 80 ppm, no cyanuric acid is added and total dissolved solids of less than 1000 ppm. Determine whether the pool water is balanced.

$$\text{Saturation Index} = \text{(pH) } 7.6 + \text{(TF) } 0.7 + \text{(CF) } 2.2 + \text{(AF) } 1.92 - 12.1 = +0.32$$

Table 12-3 shows that when:

- Water temperature = 84^0F, the temperature factor is 0.7
- Calcium hardness = 400 ppm, the calcium factor (CF) is 2.2
- Total alkalinity = 80 ppm with cyanuric acid = 0 ppm, Alkalinity factor (AF) is 1.92.

From the calculations, it indicates the pool water is balanced as the final result is +0.32.

Reflecting on this subject of achieving good pool health, it is imperative to maintain the parameters within the following values:

- pH: 7.2-7.6
- Calcium hardness: 200-400 ppm; Add 12.99 grams of hydrated calcium chloride (77% strength), to every cubic metre of pool water to increase the hardness by 10 ppm. Alternatively, you can add 10 grams of anhydrous calcium chloride (100 % strength) to each cubic metre of pool water to increase the hardness by 10 ppm.
- Total alkalinity: 80-100 ppm; Add 14 grams of sodium bicarbonate (75% purity) for each cubic metre of pool water to increase the total alkalinity by 10 ppm.

For swimmers' health, the chlorine level must be maintained at 1-3 ppm and the cyanuric acid, if in use, at 30-50 ppm. Add 10.1 grams of cyanuric acid (99% purity) to every cubic metre of the pool water to raise the cyanuric acid level by ten ppm.

Appendix 1 enables a monthly swimming pool servicing and maintenance record chart to be kept to ensure satisfactory water balance.

13: Common Problems and Suggested Solutions in Swimming Pools

With properly designed filtration systems and proper maintenance, many of the pool problems encountered can be avoided. The following lists some of the problems found in the operation of surflo-system swimming pools together with suggested solutions. Knowledge of the following can save pool operators and owners a good deal of time, anxiety and money.

High water consumption	
Possible causes	**Suggested solutions**[1]
Leakages of pipe and equipment in the filtration plant room or underground delivery pipe.	Inspect all the visible filtration system equipment for leakages. If no leakages are found, the underground delivery pipe will have to be pressure tested to determine its condition.
Ball float installed in the balancing tank has malfunctioned.	Replace the ball float with electronic level switches to control the water level in the balancing tank. As indicated in Chapter 9, the ball float is a wrong device to be installed in the balancing tank.
Continuous hot dry days through the months.	On a hot day, it is possible for ten millimetres of water on the pool surface to be lost through evaporation. Cumulative loss will be substantial for continuous hot days. Place a container filled to the brim with water near the pool. Observe the drop of water level in the container. If evaporative loss is confirmed, replenish the water when necessary.
Under-sized balancing tank.	The circulation pump must be in operation continuously, resulting in high electrical power consumption. Once the circulation pump stops, as the balancing tank is inadequate to hold the returning overflow water, some water will overflow through the balancing tank. When the circulation pump starts again, city water supply will be required to replenish the earlier loss. If possible, enlarge the balancing tank. Screed all gaps of the tiles on the overflowing edges of the pool.
Filter sand found in the pool	
Faulty filter nozzles or laterals.	Open the filter for inspection. There will be a deep indentation of the sand bed surface confirming the discharge of sand to the pool. Replace the faulty nozzles or laterals.
Corroded nozzle plate.	Filter fabricated with nozzle plate has two manholes. Open the manholes for inspection to confirm the faults. Repair the corroded nozzle plate.
Corrosion of pool walls, overflow edges and filtration equipment	
pH, hardness and alkalinity of pool water are low.	Balance the pool water.

The delivery valve must be carefully and delicately throttled

Possible causes	Suggested solutions[1]
Insufficient and incorrectly-sized pipes provided to connect the overflow drains to the balancing tank strainer chamber causing overflowing from the overflow drains if the delivery valve is not carefully throttled.	When certain works are not done correctly in the beginning, it could be a terrible mess to put it right. Increase the quantity of the incorrectly-sized pipes to assist in the draining of water from the overflow drains to the balancing tank. The throttling of the delivery valve will cause the treatment rate to be adversely affected causing cloudy water. To combat the cloudy water problem, most maintenance personnel will increase the dosage of chlorine to overcome the defective design problems. If the required filtration rate cannot be achieved due to the throttling of the delivery valve, instruct the design engineer or the builder, if it's a design and build contract, to rectify the defects at no additional costs to the owner.
Oversized circulation pump.	The impeller of the circulation pump could be trimmed to reduce the flow rate.
Cloudy milky swimming pool water	
Cause similar to the above throttling problem.	Remedy as stated for above problem.
Not operating the circulation pump for sufficient length of time.	Increase the operating hours of the circulation pump by adjusting the timer control.
Adding calcium chloride and sodium bicarbonate to the pool at the same time.	Refrain from adding the two chemicals simultaneously. Allow at least one turnover period before adding the other chemical.
For pool using DE filters: torn or damaged DE elements causing DE to leak into the pool.	Replace the faulty DE elements.
Pool water not properly balanced.	Ensure all the parameters of the SI including the recommended levels of sodium bicarbonate and calcium chloride are maintained.
Failure to provide shorter pool turnover period to cater to heavy bather load.	Poor filtration system design and installation. Difficult to solve as the whole filtration system has been under-sized, including the size of all pipes and filters, unless a major overhaul is initiated. Residents in the western part of Singapore could be aware of a swimming complex that has to be closed on every Monday for "maintenance", as the pool water is so cloudy and brownish due to the inability of the filtration systems to cope with the overwhelming weekend crowd.
Sand filter not backwashed over a period of time or not properly and completely backwashed.	Ensure the filters are backwashed periodically and thoroughly.
Insufficient sand in the sand filter.	Inspect the filter to ensure the sand is at the correct level.

Cloudy milky swimming pool water	
Possible cause/s	**Suggested solution/s[1]**
Excessive cyanuric acid in pool water.	Keep the cyanuric acid levels to 30-50 ppm. Cyanuric acid level in excess of 100 ppm causes "chlorine lock", decreasing the sanitising effect of chlorine.
Strainer basket of circulation pump fully choked.	Regular cleaning of the strainer is good house-keeping

	of the pool.
Circulation-pump impeller worn down due to cavitation.	Replace the faulty pump impeller.
Control valves not in correct operating positions.	Ensure all control valves are in their correct operating positions.
Commencement of algal growth. Algal spores are introduced into the pool water by the wind, rain, contaminated swimsuits and equipment.	Super-chlorinate the pool and backwash filter after 24 hours.
Strong chlorine odour	
High content of chloramines, the disinfectant by-product of chlorine, due to impurities introduced into pool water by swimmers, decaying leaves, bird droppings and fungi-infested rainwater.	Super-chlorinate the pool water.
Cloudy greenish swimming pool water	
Low chlorine level allowing algae to bloom. Green algae can be free floating, cling to pool walls or settle on pool floors especially in areas of poor water circulation.	The best algae remedy is called "prevention". Super-chlorinate pool water. Scrub all pool surfaces and operate the circulation pump for 24 hours. Backwash filter after 24 hours.
Excessive cyanuric acid level.	Lower the cyanuric acid level to 30-50 ppm by backwashing the filter instead of wastefully draining water to waste, to enable fresh make-up water to dilute or lower the cyanuric acid content in the pool water.
Blonde or tinted hair turns green	
High copper content in pool water, either from corroding copper fittings in the filtration system or copper-based algaecides.	Backwash filter instead of draining water wastefully, to enable fresh make-up water to dilute or lower the copper content in the pool water. Wash the affected hair with lemon juice or vinegar or aspirin solution.
The strainer in the balancing tank chokes easily causing water to overflow on the pool deck	
Pool surrounded by many trees	Clear the strainer more frequently.
Provision of inadequate strainers.	Provide additional openings for provision of additional strainers by coring through the strainer chamber slab.
The strainer length is too short.	The strainer length must extend beyond the thickness of the strainer chamber slab to enable water to flow through the sides of the strainer when the bottom of the strainer is choked with debris.

Scaling	
Possible causes	**Suggested solutions**[1]
Pool water not balanced, a combination of high water hardness, pH and alkalinity of the pool water.	Balance the pool water.

[1]DISCLAIMER

The author has provided rational solutions to rectify the common problems encountered in swimming pools. However, the author does not warrant the suggested solution or solutions will solve similar problems encountered by swimming pool operators or owners as other unknown unforeseeable factors could have contributed to such problems. No responsibility is taken for any action or actions taken on the basis of any information contained herein, whether in whole or part, nor for any errors or omissions in the suggested solutions. The reader has sole responsibility to determine the compatibility of the suggested solutions.

14: Troubleshooting of Swimming Pool Filtration Systems

This chapter lists some of the common problems likely to be encountered in the operation of filtration systems. It will save pool operators time and money if they trouble-shoot the problems before activating and seeking external assistance.

1.0 Motor won't run. Check whether:	
a.	The electrical supply is on.
b.	The circuit breaker has tripped.
c.	There is an open switch, blown fuse or loose or incorrect wiring in the supply line.
d.	The motor shaft is locked due to pump impeller obstructed by debris.
e.	The motor winding is burnt or the contactor is stuck.
f.	The pump is in "off" mode of a timer-controlled circuit.
2.0 Circulation pump has insufficient output. Check whether:	
a.	Circulation pump has been primed properly.
b.	Circulation pump is losing prime due to air leaks in the suction line.
c.	The control valves in suction and discharge lines are fully open.

d.	The hair and lint strainer is choked with debris.
e.	The filter is dirty.
f.	The control valve in the discharge line to the pool is fully open.
g.	The pump strainer is missing or damaged. Missing or damaged strainers will allow debris to clog the impellers resulting in restricted flow.
3.0 Circulation pump loses prime. Check whether:	
a.	There are leakages in the suction line. This will include valve stems and glands.
b.	The mechanical shaft seal of the circulation pump is leaking.
c.	The hair and lint strainer is choked with debris or closed properly and tightly.
d.	The suction or discharge valves are closed.
e.	There is insufficient water in the balancing tank.
f.	For skimmer pools, the floating weirs are stuck at the sidewalls of the skimmers in upright positions.

4.0 Noisy pump and motor. Check whether:

a. The hair and lint strainer is choked with debris.
b. The bearings are worn.
c. The impeller is rubbing on the pump casing.
d. The suction valve is partially closed.
e. NPSHA is lesser or smaller than NPSHR as highlighted in Chapter 5.
5.0 Air in pool return. Check whether:
a. There are leaks in the suction line.
b. The hair and lint strainer cover is closed tightly.
c. The water level is above the suction line.
6.0 Water overflowing from the overflow drains. Check whether:
a. The balancing tank is overflowing due to heavy rain.
b. The strainer baskets installed in the balancing tank are choked.
7.0 High filter pressure (low flow). Check whether:
a. The filter is dirty.
b. There is a restriction in the delivery pipe.

c.	The pressure gauges are faulty.
8.0 Low filter pressure (low flow). Check whether:	
a.	The pump strainers are choked with debris.
b.	There is a restriction in the suction pipe.
c.	There are leakages in the suction line. This will include valve stems and glands.
d.	The pump impellers are clogged.
e.	The pressure gauges are faulty.

15: Fun Pools

In Singapore, a swimming complex is built in almost every satellite public housing estate to provide recreational facilities for the residents and to cater for the curricular activities of neighbourhood schools. For most of the older satellite housing estates, these swimming complexes will merely have a children pool, a one-metre constant depth training pool and a competition pool. In the newer housing estates, swimming complexes are built to have interactive water-play equipment, interactive water-play structure and water slides added to the children pool as added attractions. Water can shoot out from aboveground water features, dump from tipping vessels above and provide various desired water effects. The spouting and cascading water create a dynamic water display to joyously liven the atmosphere in the pool surrounds. The plurality of play stations including net climbs, water cannons and frolicking water jets create a centre of fun. When older swimming complexes were renovated with the availability of space, these attractions were added to convert the pool into a water playground. As expected, the number of bathers surged following the introduction of the interactive water play equipment and structures.

WhiteWater Watershooter
Figure 15-1 *(courtesy of WhiteWater*)

Interactive water-play equipment are products which have self-contained pumps. Figure 15-1 illustrates a typical interactive water-play equipment. When the boy cranks the turning wheels of the water shooter, the concealed manual piston pump in the support draws water from the pool for the water shooter. By installing two water shooters facing each other in the pool, the children can compete with each other on their shooting skills. Figure 15-1 is provided by M/s WhiteWater Inc., a Canadian company specialising in signature waterslides and a global leader in the supply of innovative products including interactive water play structures, water rides and wave-producing equipment.

The most prevalent attraction in the newer swimming complexes is the water slide. A water slide allows bathers to slide down steeply twisting sloping flumes before a splash landing into the children pool. Figure 15-2, again courtesy of M/s WhiteWater, illustrates a water play structure that provides an excellent aquatic playground with a water slide at the rear.

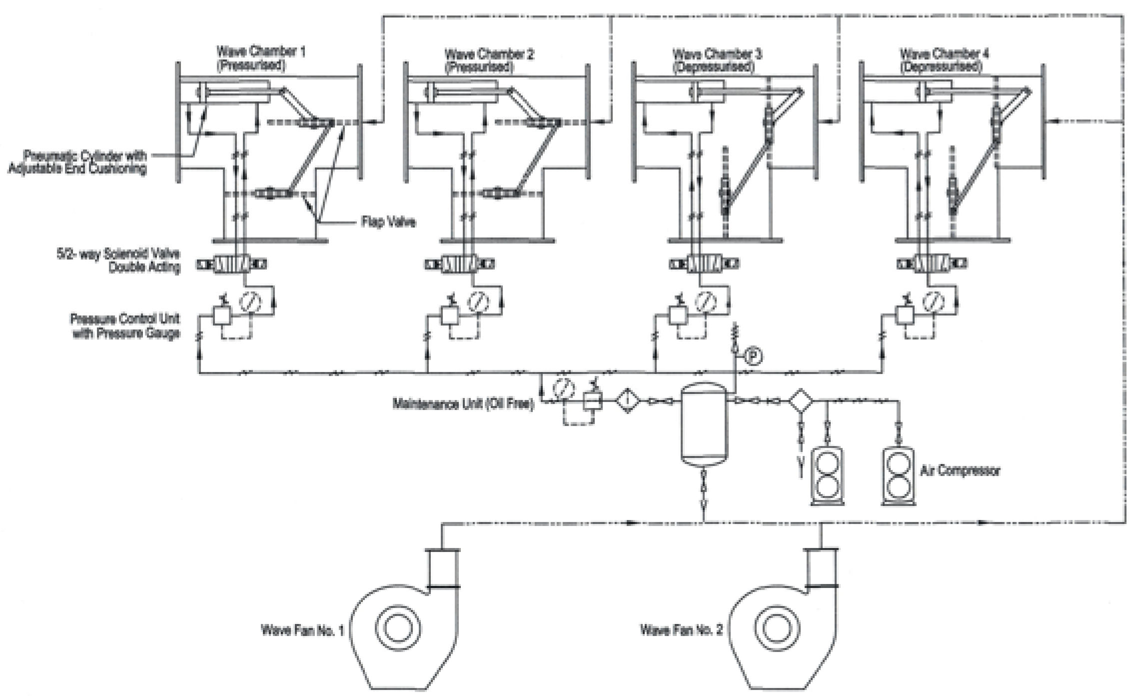
WhiteWater Interactive Water Play Structure
Figure 15-2 *(courtesy of WhiteWater)*

The water play structure requires an external pump to provide the water for the water display. The control of the external pump is not automatic. The control switches are normally located near the life-guard station to enable the pool personnel control of the operation of the pump. In the lull hours of the pool, the pump is switched off to save energy consumption.

In the newer swimming complexes, wave pools are also installed as an added attraction. Water in motion excites bathers through the decades. Artificial waves in swimming pools are great draw cards.

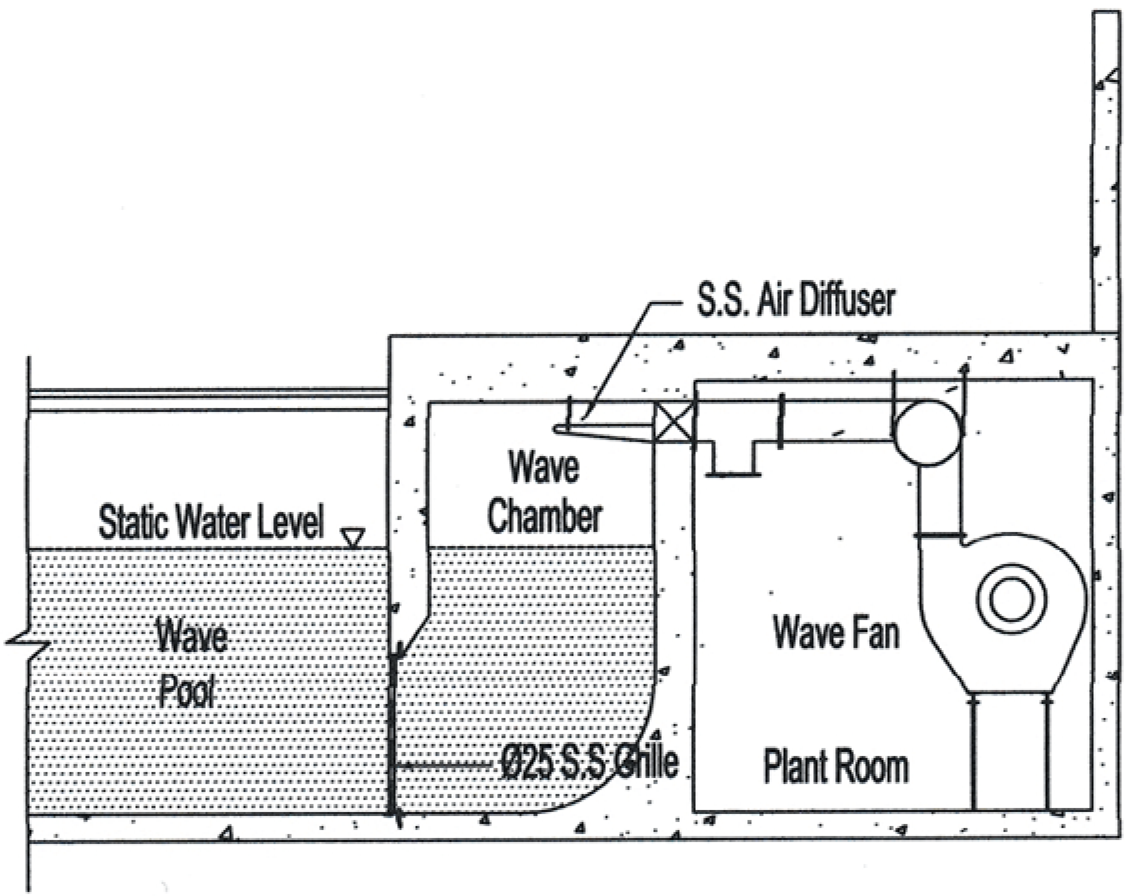
Waves are formed when the static water surface is disturbed. A huge heavy ball that is dropped into a serene swimming pool sets water waves in motion. The ball is called the source of the waves. The peak of the wave is called the crest and the bottom part of the wave the trough. The height of the crest above the static water level is called the amplitude of the wave. Amplitude can also be measured from the bottom of the trough to the static water level. When we bounce the huge floating ball rapidly on the pool water surface, we create more waves on the water surface. Such an action has increased the frequency of the waves as more waves pass any point in one second. When we increase the frequency of the waves, we shorten the distance between the crests or troughs. This distance is called the wavelength. The wave-length is the distance between one peak or crest of the wave to the next corresponding peak or crest.

In the past, travelling waves were generated mechanically by crankshaft-operated piston machines or the flap-type systems. The reciprocating motions of the pistons or flaps were the source of the waves. The waves generally are made to travel from the deep end of the pool to the shore of the wave pool. With advancement in technology, waves are now generated either pneumatically or hydraulically. These wave-producing machines consume immense electrical energy. Usually, the wave-producing equipment is operated only for not more than fifteen minutes at the beginning of every hour during the pool operating hours.



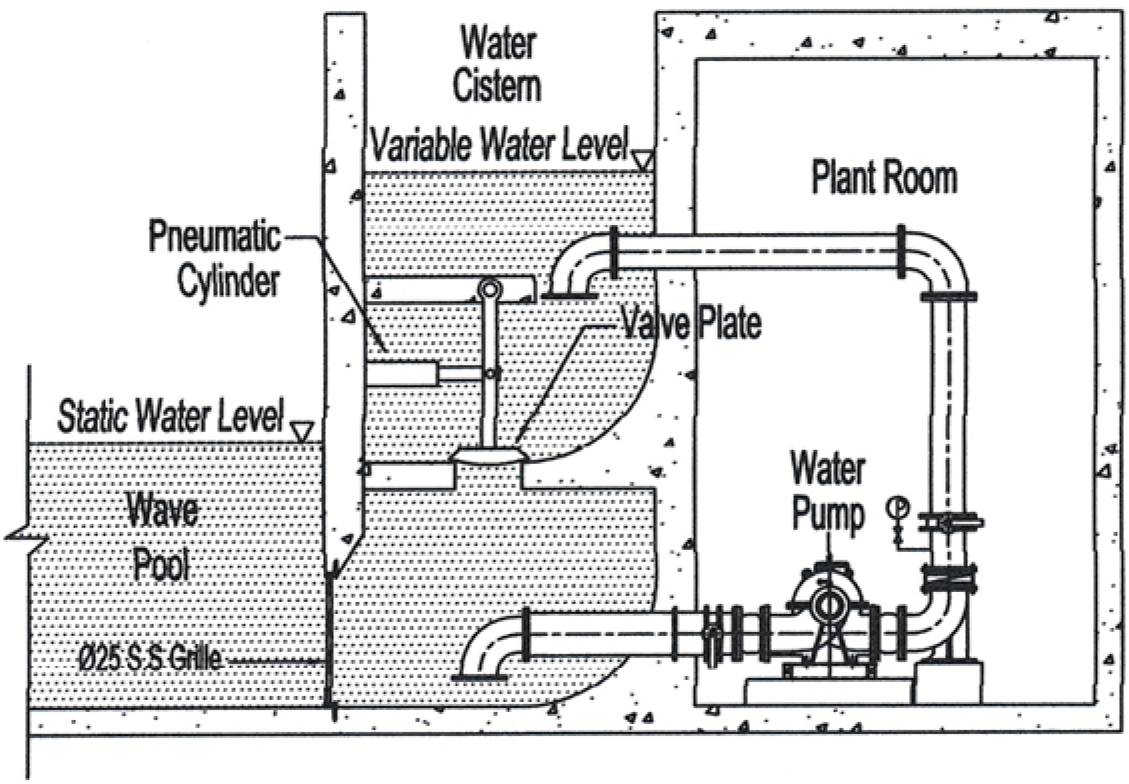
Schematic Diagram of a Four-chamber Pneumatic Wave Generating System
Figure 15-3

Figure 15-3 depicts the equipment and accessories required to pneumatically generate waves. Each 100-horsepower wave fan blows air to pressurise the wave chambers. If the four wave chambers are pressurised and depressurised simultaneously, parallel waves will be created in the wave pool. Different wave patterns can be produced by pressurising and depressurising the different wave chambers. The sequence of pressure changes to the wave chambers will dictate the type of wave patterns to be created. Five different wave patterns can be generated by this pneumatic wave equipment. To obtain high waves, both wave fans will be operated simultaneously.



Cross-section of a Typical Pneumatic Wave Chamber
Figure 15-4

Figure 15-4 illustrates that when the short bursts of pressurised air is applied to the water surface in each wave chamber in the deep end of the wave pool, the wave created will extend outward along the surface of the water into the open pool. When the wave chamber is depressurised, the water from the pool will oscillate into the wave chamber. It is imperative to ensure that the stainless steel air diffuser be installed beyond the maximum height of the wave crest as otherwise the pool water will surge into the wave plant room, when the wave chamber is depressurised. A few installations in Singapore had overlooked this simple requirement.



Cross-section of a Typical Hydraulic Wave Chamber
Figure 15-5

The operating noise level in the pneumatic wave plant room is extremely high. The wave plant room is usually enclosed with an acoustic double door and acoustic silencers are also provided for the air intake and air exhaust to reduce the noise to a tolerable level. All personnel entering the wave plant room when the wave equipment is in operation will have to wear ear protection. As a safety measure, a corrosion-resistant stainless-steel grille is installed at the wave chambers to keep bathers at bay.

In stark contrast, the hydraulic wave plant room is relatively quiet with no requirements for acoustic treatment. The waves produced by hydraulic wave technology can have infinite wave heights and variable wave frequencies. Instead of pushing the water by piston, flap or air, the wave machine dumps a high volume of water into the deep end of the pool. This creates the wave that travels all the way to the beach as the water tries to determine its proper level. The amplitude of the wave can be easily adjusted by varying the height of drop of the water.

Water is drawn from the wave pool into the water cistern as shown in Figure 15-5. The water cistern is divided into eight chambers, each with its own release valve, to enable the creation of different wave patterns. The sequence of opening of the release valves to dump the water into the pool will determine the type of wave pattern. When the water level in the cistern is high enough, the PLC-controlled pneumatic cylinders will push the release valves to open at the bottom of the cistern. This is similar to our toilet flushing system. It dumps all the collected water into the pool creating the waves.

To create huge waves, the water pumps to be installed can each be of at least 300-horsepower and capable of delivering 450 cubic metres of water per minute per pump. Each pump will be capable of filling an Olympic-size swimming pool in less than five minutes.

When water is drawn from the pool, there will be a slight drop of the static water level in the pool. This is not noticeable if the wave pool is huge. It is common to have wave pools of more than one hundred metres in length with an average width of fifty metres. The drop in the static water level will be less than one hundred millimetres in one minute and the same amount of water will be dumped back to the pool.

A recent innovation creates the surfing pool. The pool floor is shaped to resemble a stationary wave. With a 100-horsepower pump or another suitably size pump for the width of the surfing pool, the water nozzles installed at the top of the wave form generates a thin film of water above the stationary wave form to enable the riders to surf on the water surface. Such pools usually excite the teens.

Corrosion-resistant gymnasium equipment that can be installed in the pool is also gaining in popularity. Such equipment can provide beneficial cardiovascular exercises for all users. Water makes working out a pleasurable and comfortable experience.

In short, swimming pools can now be converted into fun pools to provide an exciting venue for kids to frolic in the water and to have fun.

16: Drowning Prevention Technologies

An important and often overlooked design consideration is the design of the pool to minimise the risk of drowning.

Today, drowning is "the 3rd leading cause of unintentional injury-related deaths worldwide, accounting for 7% of all injury-related deaths", according to the 2014 WHO fact sheet. Key risk factors include:

- Age – young children are particularly at risk – with lapses in supervision being recorded as the primary issue
- Gender – incidence rates are higher with men
- Access to water – including swimming pools

Quite often, the risk of drowning is downplayed, with many believing that it is an unlikely occurrence. As an example, when a parent is asked, "Would you prefer your toddler to walk towards a road or a river bed?" the answer would inevitably be a river bed. In actuality, in this circumstance, the risk is higher in the river bed because there may or may not be a car present on the road, but the risk of drowning is virtually 100% in the river bed.

For swimming pools there are a number of strategies that can be taken to reduce the risk of a drowning incident. These can broadly be split into two categories – preventative measures and reactive measures.

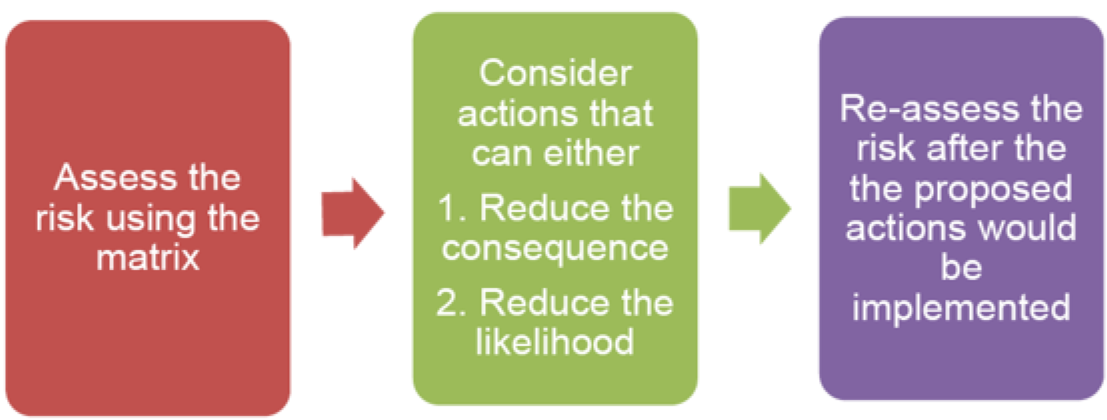
Preventative measures focus on reducing the likelihood of a drowning occurring. Reactive measures focus on improving the chances of survival if an incident occurs. The decision of which measures should be adopted usually depends on the risk assessment process and usually involves both preventative and reactive measures. The exact framework used varies in country to country, region to region, but more or less has the same basic principle as shown in Figure 16-1.

Risk Matrix

Consequence	Likelihood: Rare	Unlikely	Possible	Likely	Almost Certain
Severe *Eg. Potential Fatality*	MEDIUM	HIGH	EXTREME	EXTREME	EXTREME
Major *Eg. Potential Long Term Injury or illness with permanent disability*	MEDIUM	MEDIUM	HIGH	EXTREME	EXTREME
Moderate *Eg. Potential Lost Time Injury (but nonpermanent disability)*	LOW	MEDIUM	HIGH	HIGH	HIGH
Minor *Eg. Potential First Aid or medical treatment required but no lost time*	LOW	LOW	MEDIUM	MEDIUM	HIGH
Minimal *Eg. Hazard or near miss requiring reporting and follow up action*	LOW	LOW	LOW	LOW	MEDIUM

Risk Assessment Process
Figure 16-1

Typically the overall process undertaken will involve three steps. This is an ongoing system used to cover all risks that a swimming pool may have. Legislation typically states that this process is mandatory in all workplace or public access areas.



Steps on Risk Assessment
Figure 16-2

So in relation to risk assessment process, preventative measures are used to reduce the likelihood of an incident occurring. Reactive measures are used to reduce the consequence when an incident occurs. As such, both strategies are necessary to minimise the risk profile of any pool environment.

The key preventative measures undertaken at swimming pool environments are:

1. Ensure adequate supervision
2. Increase swimming pool skills of patrons
3. Install physical barriers to prevent unauthorised water entry

The main reactive measures used at swimming pool environments are:

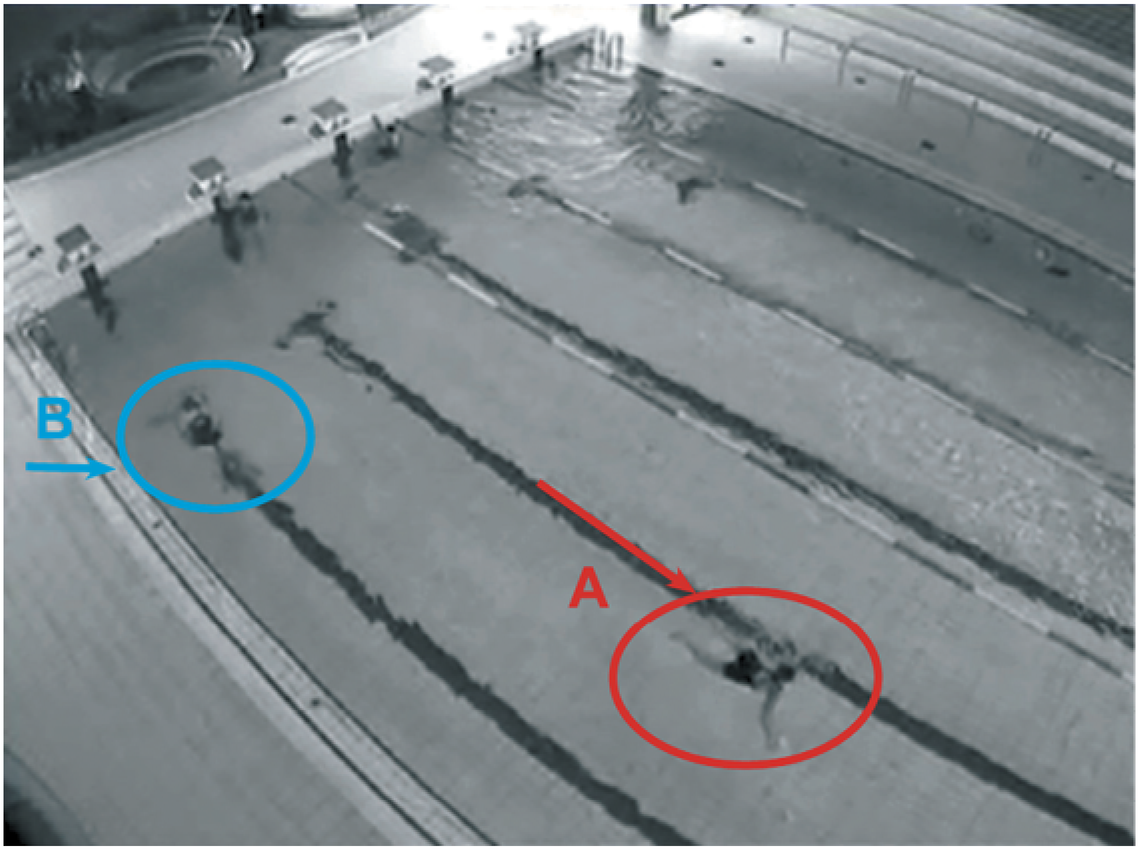
4. Technology to provide early detection
5. Qualified lifeguards /medical staff to provide early resuscitation.

Each of these points will be explained in more detail below.

1. Ensure Adequate Supervision & the role of lifeguards

Adequate supervision can be seen from a number of perspectives. Firstly, young children and patrons of swimming pools that are unable to swim themselves, require 100% supervision. This means one supervisor for one patron. A key consideration here is the drowning process. Unfortunately, the media often portrays drowning as loud, with lots of splashing to attract attention. In reality drowning is more often than not the opposite of this. The time taken from being on the surface to under the water is often very quick (within a few seconds) with little or no splashing at all. As an example, Figure 16-3 shows:

The time taken for Swimmer A (circled in red) to move from the start of the red arrow to the end of the red	=	Time taken for swimmer B to completely submerge, with no splash whatsoever



Requirement for Adequate Supervision
Figure 16-3

The corollary of this is that while lifeguards are essential for both rescue and for ensuring swimming pool behaviours are in accordance with pool safety guidelines, it is very difficult for lifeguards to provide adequate drowning detection supervision. This statement is controversial, but must be taken in the context that it is very difficult for lifeguards because of a number of factors including:

i. **Temperature effects** – According to Mackworth & Pepler (1950) as temperature rises, performance reduces.

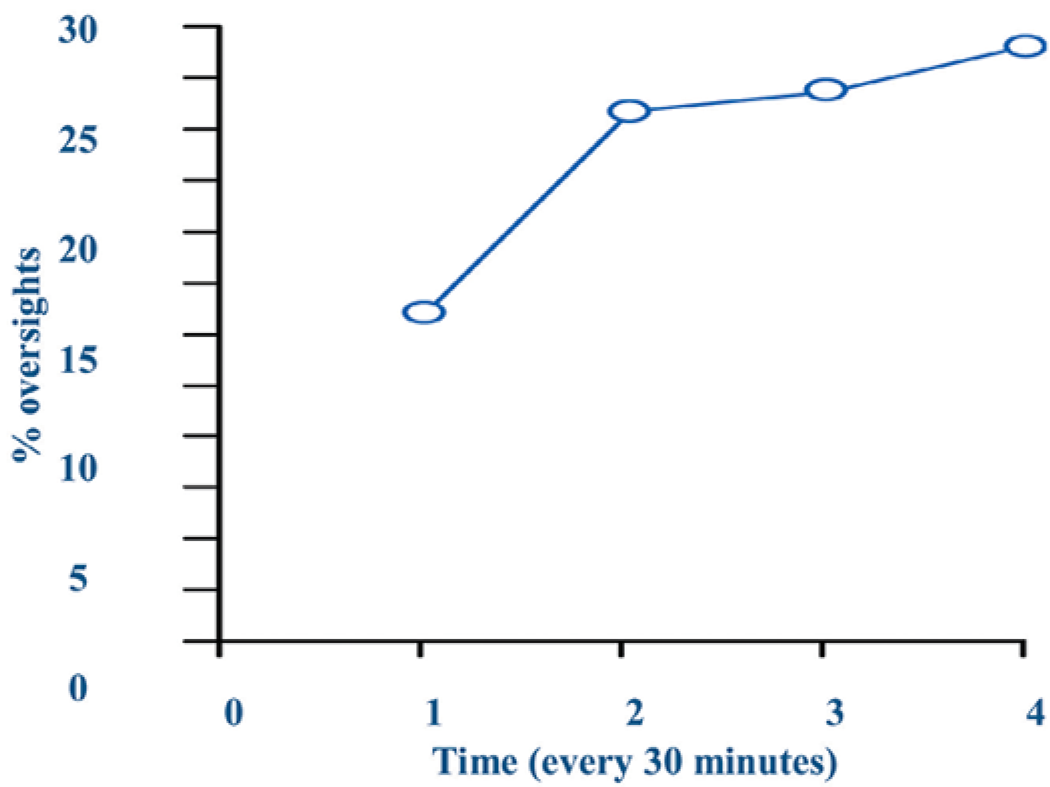
Temperature	Performance Reduction
26 degrees Celsius	30% reduction
30 degrees Celsius	45% reduction

Temperature Effects on Performance
Table 16-1

ii. **Duty time** – the longer a lifeguard is on duty, the more difficult to concentrate and be aware of all drowning risks. (*Sources:*

a. *MACKWORTH N.H. – Researches in the measurement of human performance. MRC spec. Report 268 HMSO, 1950*

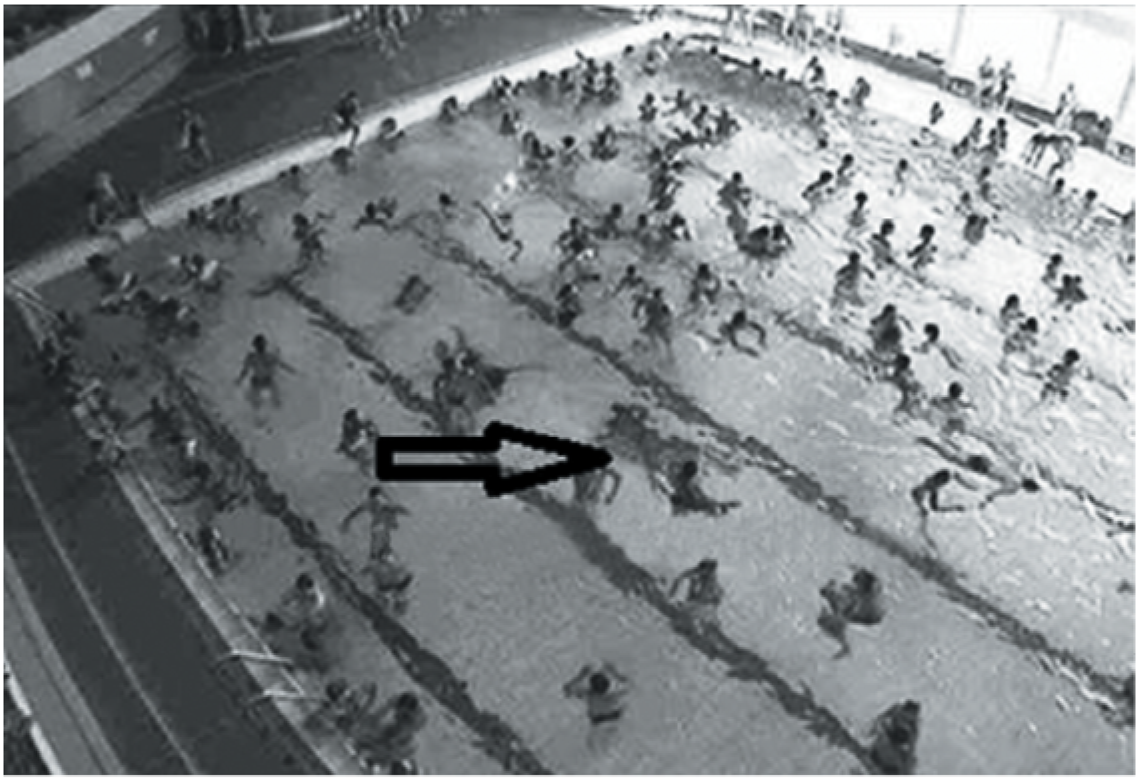
b. *MACKWORTH J.F. – Vigilance and attention, Penguin Books, 1970.)*



Effects of Duty Time
Figure 16-4

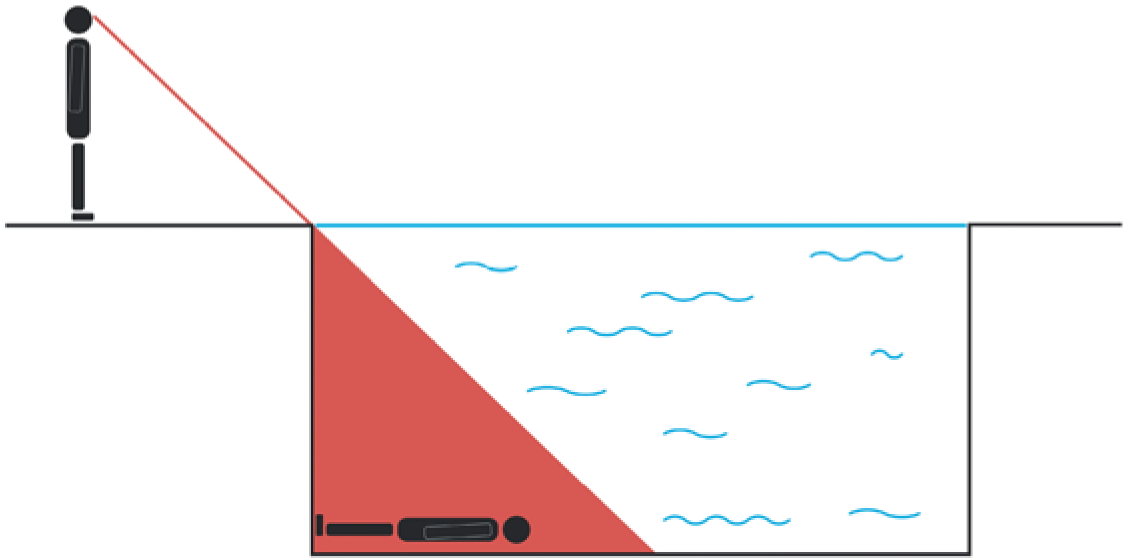
iii. **It's not possible to see all patrons at all times** – Two specific aspects should be mentioned here in relation to this area.

The first is the ratio of patrons to lifeguards which is often specified by local standards. The reality is that a lifeguard has only a few seconds to see someone drowning before they go underwater. As an example, as shown in Figure 16-5, a drowning was undetected by lifeguards – quite understandably given the sheer number of people in the pool.

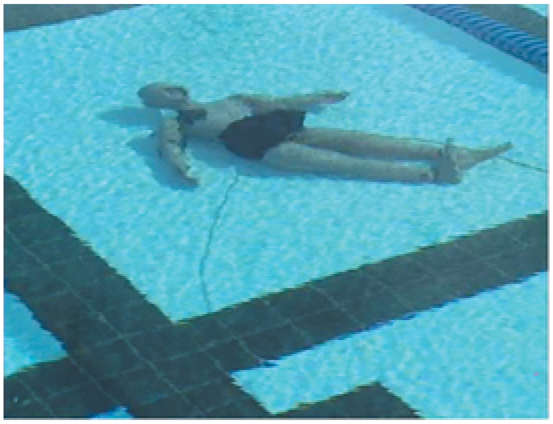


Drowning in a Crowded Pool
Figure 16-5

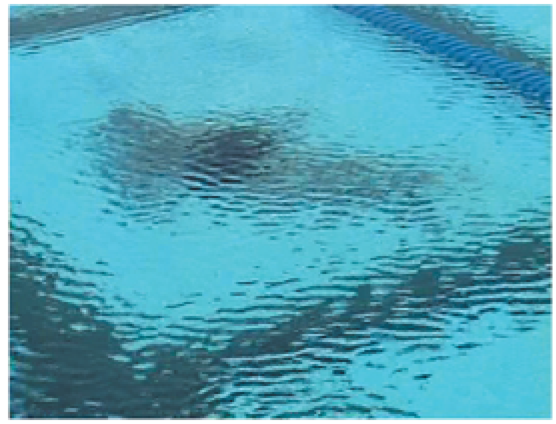
The second is that lifeguards cannot see what they cannot see. Once a person is underwater, it is very difficult, if not impossible, to see the person. This may sound untrue, given that water is a clear liquid, but two factors work against every effort of even the most astute lifeguard. Firstly, there may be physical barriers preventing visibility as shown Figure 16-6. Secondly, and present in the vast majority of pools, unless there is only 1 patron, the effects of light refraction on the surface of the pool water means that it is almost impossible to see the person underwater as shown in Figure 16-7.



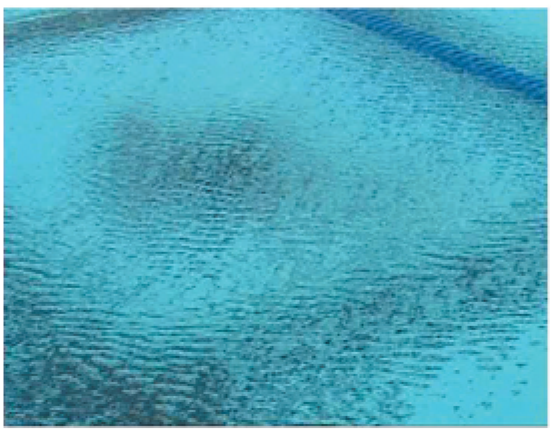
Physical Constraints Affecting Ability to See
Figure 16-6



1. Manikin visible



2. Going...



3. Going...

4. Gone...

Disappearing Dummies
Figure 16-7 *(courtesy of Tom Griffiths)*

2. Increase swimming pool skills of patrons

Every effort should be made as a society to ensure that all people are able to swim at as early an age as possible. The likelihood of drowning occurring reduces when a person becomes able to swim. Wherever possible learn to swim programs should be actively encouraged to ensure the swimming ability of a local community is maximised.

3. Install physical barriers to prevent unauthorised water entry

It is essential for every pool environment to have adequate physical barriers to ensure only authorised patrons can use the facility. This helps reduce the likelihood of drowning for three higher incidence rate patrons – children (if unable to swim), adolescents (more likely to engage in risk taking behaviours), patrons who swim while intoxicated. Physical barriers include fencing as shown in Figure 16-8 and fixed cover as shown in Figure 16-9.

Pool Fence
Figure 16-8

Pool Cover
Figure 16-9

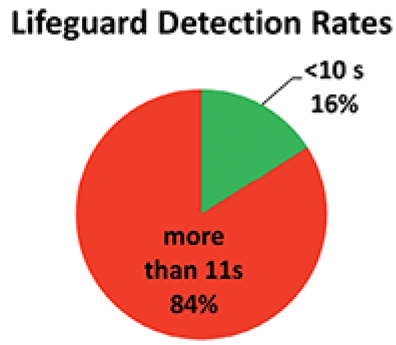
4. Technology to provide early detection

In many industries, technology has created tools to assist people in their workplaces or leisure environments. Technology has now been developed for the swimming pool environment with the primary objective of alerting parents or lifeguards when a drowning incident is occurring. The primary benefit of this is to minimise the time that someone is drowning. This is vital because the longer someone is drowning, the higher the chance of death or permanent disability. There is a widely acknowledged 10:20 rule:

- 10 – 15 seconds to detect from stationary
- 20 seconds to rescue

When the 10:20 rule is adhered to, the most likely outcome is only a minor to moderate injury. Beyond these times the probability of a major or severe injury increases exponentially.

As noted above, it is extremely difficult for supervision, other than 1:1, to detect a person drowning in this timeframe and studies have shown that the likelihood of lifeguard detection within this timeframe is only 16%.

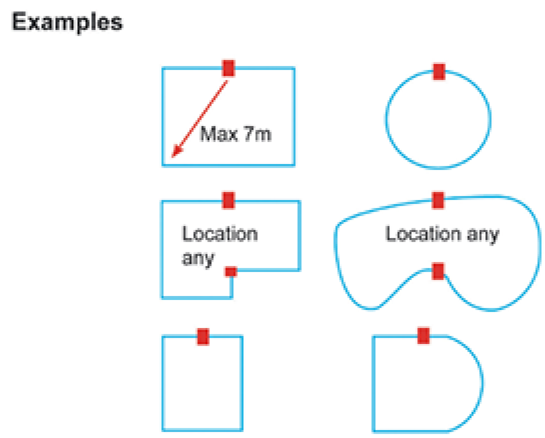


Lifeguard Detection Rates
Figure 16-10

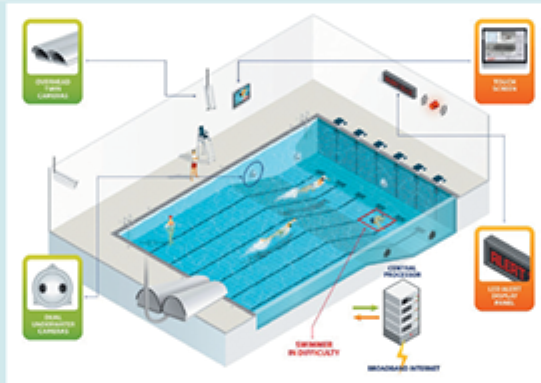
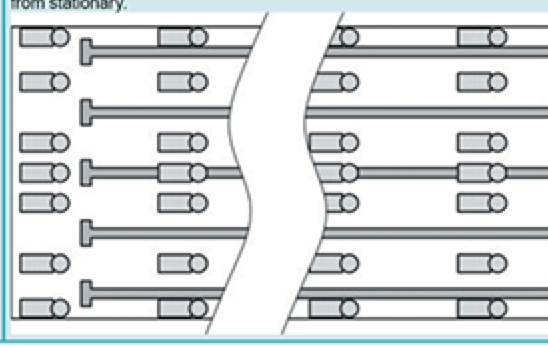
(Source: 2001-2002 Jeff Ellis, Lifeguard Vigilance Study, 682 mannequins)

So the purpose of technology must be to assist lifeguard/parents to detect within these parameters. The two main types of technologies available are shown below.

Water Pressure Wave System

Characteristic	Performance Level
Diagram	 Domestic water pressure sensor *(courtesy of Maytronics)*
Type of pool	Domestic
How it operates	Is in alarm state when nobody is swimming. When an unauthorised person (child) falls into the water, this creates a water pressure wave that activates the alarm.
Range	Typically, each alarm may cover approximately seven-metre radius. Examples of locations of alarms for domestic pools are shown below. 
Activates	Automatically once swimmers have left the water (after a short delay)
Limitations	Does not actively detect a swimmer drowning

Computer-Aided Drowning Detection System

Characteristic	Performance Level
Diagram	 Drowning Detection System *(courtesy of Poseidon Technologies)*
Type of pool	Public/Commercial Pool
How it operates	Utilises high technology cameras, with images sent to computer for analysis. The complex computer algorithm determines if a person is drowning and provides an alarm to the lifeguard
Effective when	Pool in operation. Actively detects swimmers that are drowning
Performance level	>80% average detection. This is verified by regularly verifying alarm rate across regular pool intervals when using mannequins within fifteen seconds from stationary. 
False alarm rate	Maximum five per day average rate. In excess of this level and the system has a higher chance of alarms being ignored by the lifeguards or the system inactivated.
Detection time from stationary	Max 15 seconds
Cautionary note	There is a significant difference between motionless detection (CCTV) systems and computer-aided drowning detection systems. Motionless detections systems have been attempted in pool environments and have struggled to achieve the combination required – low false alarms, high performance rate, low detection time. All three factors are critical to the success of the technology and its ability to adequately support the lifeguards at the pool.

The patented technology of the Poseidon drowning detection system is a computer-aided detection system. Overhead and underwater cameras are connected to a computer vision system that recognises texture, volume and movement within the pool. It is able to differentiate between “normal” and “suspicious” activity.

The algorithms in the system provide the lifeguards a precise 3D position of the bather in difficulty within ten to fifteen seconds. This will contribute to faster rescues by lifeguards and heighten the safety in swimming pools.

The Poseidon systems (www.maytronics.com.au) have been installed in more than 200 pools in the world and have saved many lives in Australia, Belgium, Canada, Denmark, France, Germany, Japan, Sweden, United Kingdom, United States of America and other countries.

5. Qualified lifeguards or medical staff to provide early resuscitation

Once a person has been rescued, early intervention from a qualified lifeguard or medical personnel is vital, and this may require use of basic and advanced airway equipment, or access to a defibrillator. The use of these is dependent on the training of the rescuer. Even with the most sophisticated technology available, the role of lifeguards cannot be underestimated because of their specific skills in CPR and resuscitation.

Defibrillator Equipment
Figure 16-11

17: Testing and Commissioning Procedures

Once the concrete pool structure is fully completed, it must be subject to ponding tests for water tightness. This has to be performed prior to backfilling the pool surrounds and the application of waterproofing before tiling of pool walls and floors. This will enable easy visual detection of leakages. All pipes installed in the pool must be capped and plugged to conduct proper ponding tests. The pool must be filled with water completely and left standing for a week. A container filled to the brim with water is placed near the pool to subject it to the same climatic conditions as the pool water. If the height of drop of water level in the pool is similar to the drop of water level in the container, this will represent the evaporative loss of water not leakages of the pool. Any area of the external pool wall found with signs of dampness will indicate a defect in the concrete pool structure and must be rectified before proceeding with further works. If water is seen leaking at certain spots of the external walls of the pool, these areas can be immediately pressure grouted to stop the leaks from the external wall with water stops, an engineered cement compound capable of sealing the holes and crevices in the concrete. This specially engineered compound is capable of setting in the presence of water. On completion of the grouting processes, the water level should be topped up again to the test level for further monitoring. Should there be a rapid drop of water in the pool with no leakages on the external walls of the pool, this phenomenon should be allowed to continue. In such an event it could be that the pool floor is leaking or the water is leaking through the main drain. In most instances, the main drain is usually the cause of the leakages as it is relatively easy to compact the concrete when concreting the pool floors. It will be wise to check the water-tightness of the main drain before filling the pool for testing. Once the rectification is completed, the pool should be filled again for a re-test. It is important to note that the balancing tank and overflow channels of the pool must also be subject to ponding tests as any water leakages in these two locations can also be substantial.

Once the ponding tests are completed, the pool is unlikely to leak with the application of water proofing compound to the pool walls and floor.

On completion of installation of all underground pipes, these pipes must be pressured tested to ensure all connections are watertight. Proper records must be maintained to certify these pipes have been satisfactorily tested. Such tests must be witnessed and endorsed by all parties involved in the project. On successful completion of the pressure tests, the water pressures in these tested pipes should not be released fully, but maintained at half the tested pressure while backfilling the trenches. Should there be a drop in the water pressure in these lines while backfilling the trenches, it will be a good indication of a problem in the underground lines. The underground lines can then be exposed easily to rectify the problem or problems before finishing works are performed on the pool decks. The water pressure should preferably be maintained throughout the execution of other installation works of the filtration system until the final connection to the other equipment is required. Likewise all underground cables must be subject to continuity tests to ensure the cables are not damaged in the course of installation.

Once the pool is fully tiled, cleaned and filled with water, a few pre-commissioning items must be checked before commissioning the circulation system. These items are as per listed below.

Pre-commissioning check of filtration system

- Check to ensure the filtration system has been fully completed and correctly installed as per approved drawings.
- Check to ensure all equipment has been properly wired and terminated.
- Ensure all pipes are properly supported.

- Check the availability of electrical power supply to the control panel of the filtration system.
- Check the alignment of all pumps to the motors.
- Check to ensure the correct directional rotation of all motors.
- Check to ensure that the rotation of all pumps and motors are free from obstruction.
- Briefly operate all pumps to ensure no abnormal vibrations.
- Observe for any abnormal vibration of all motors.
- Observe for any abnormal noise when the pumps are briefly operated.
- Ensure all filter manholes are properly closed.
- For non-self-priming pumps, fill the suction line completely with water and ensure the strainer covers are tightly and properly closed.
- For self-priming pumps, fill the pump strainers with water and ensure the strainer covers are tightly and properly closed.
- Ensure the availability of chemicals for treatment of the pool water.
- Check to ensure the correct positioning of all valves.
- Ensure the balancing tank and swimming pool have been properly cleaned and filled with water.
- Megger (measurement of electrical insulation resistance) all pump motors and provide a record as follows:

Pump No.	Insulation Resistance (Megaohms) - Between Phases						To Motor Coil Earth		
	R-E	Y-E	B-E	R-Y	Y-B	B-R	U1 TO U2	V1 TO V2	W1 TO W2

Testing and commissioning check of filtration system

Once the pre-commissioning checks have been performed, the commissioning of the filtration system can commence. To operate the filtration system, the following procedure must be followed:

- Ensure the circulation pump is or pumps are primed. Ensure all components installed on the suction line are properly tightened to prevent ingress of air before operation of the pumps.
- Select the duty pump or pumps by setting the “**AUTO-OFF-MAN**” selector switch or switches on the main electrical control panel to “**MAN”** mode.
- Ensure all valves are placed to **Filter** position by ensuring the inlet and outlet valves of the pumps and filters are opened. The valves to the backwash line and filter drain-pipe must be closed.
- Manually operate the duty pumps by depressing the green “**START**” push-button on the main electrical control panel.
- Open the air release valve of the filter or filters to release all entrapped air.
- Record and verify the following:

1.0	**Circulation Pump**	
	1.1 Type/Model	
	1.2 Impeller size	
	1.3 Motor type	
	1.4 Motor kW & rpm	
	1.5 Thermal overload setting	
	1.6 Overload range	
	1.7 Type of motor starters	
	1.8 Operating current	
	1.9 Starting current	
	1.10 Electrical characteristics	
	1.11 Operating pressure	
	1.12 Suction pressure	

	1.13 Flow rate	
	1.14 Noise level	
2.0	**Filter**	
	2.1 Make	
	2.2 Type/Model	
	2.3 Maximum working pressure	
	2.4 Inlet pressure (when clean)	
	2.5 Outlet pressure	
	2.6 Inlet pressure when main delivery valve to pool is closed.	
3.0	**Chlorine Dosing Pump**	
	3.1 Pump model	
	3.2 Type	
	3.3 Dosing rate	
	3.4 Electrical characteristics	
4.0	**Acid Dosing Pump**	
	4.1 Pump model	
	4.2 Type	
	4.3 Dosing rate	
	4.4 Electrical characteristics	
5.0	**Balancing Tank**	
	5.1 Check operation of high level switch	
	5.2 Check operation of low level switch	

On completion of the testing and commissioning of the filtration system, all filters should be set to **Filter** cycle. Ensure all the inlet and outlet valves of all the pumps and filters and the valve on the delivery line to the pool are fully opened. All other valves connected to the filter or filters should be closed.

Ensure all the "**AUTO-OFF-MAN**" selector switches on the main electrical control panel are set to "**AUTO**" mode. On "**AUTO**" setting at the pre-determined timing, the duty pump or pumps programmed to operate will be energised accordingly.

Appendix I: Monthly Servicing and Maintenance Record Chart

Date	Name of Serviceman	Time In	Time Out	pH Value	Chlorine Content	Water Temperature	CA_1	TA_2	SI	1	W 2	o 3	r 4	k 5	6	7	D 8	o 9	n 10	e 11	12	Owner's Rep Signature

1) Check chemical level in chemical tank
2) Check and clean strainers in overflow channel/suction line
3) Check and alternate filtration pumps
4) Check complete filtration system
5) Check operation of chemical feed pumps
6) Check flowmeter/s
7) Test, record and adjust pH and chlorine content of water
8) Skimming leaves on water surface
9) Vacuum pool
10) Add chemical to adjust calcium hardness of water, if necessary
11) Check exhaust fan, if applicable
12) Submit water samples for testing

CA_1 – Calcium Hardness
SI – Saturation Index
TA_2 – Total Alkalinity

Place a tick in the above column to confirm work performed

Appendix II: Glossary of Terms

- **Acidity**. Any water with a pH value below 7 is termed acidic. Water with low pH values is often corrosive.
- **Algae**. Microscopic plantlike organisms that form on walls, floors and surfaces of pools.
- **Alkalinity**. Alkalinity when used without qualification, means the total alkalinity. This is a measure of the buffering ability of the pool water to resist pH change. Alkalinity is caused by the bicarbonates, carbonates and hydroxides of calcium, magnesium, potassium and sodium. High alkalinity is often associated with high dissolved solids and high pH.
- **Alum**. Aluminium sulphate, the most widely used coagulant, is used as a coagulant with sand filters to give improved clarity to the water.
- **Backwashing**. This is a process by which water is reversed through the filter to wash out all dirt and impurities that have been filtered out.
- **Balanced Water**. Balanced water is defined as "water that is neither corrosive nor scaling".
- **Base**. A chemical with a pH greater than 7 such as sodium hydroxide, sodium carbonate (soda ash) and sodium bicarbonate (baking soda).
- **Buffer Solution**. A chemical that assists water to resist pH change when an acid or base is added.
- **Chloramine**. A chemical compound that forms from the reaction of chlorine with ammonia and other nitrogen-based contaminants.
- **Chlorine Demand**. The amount of chlorine required to react with the organic and inorganic substances and to kill the bacteria contained in the water.

- **Chlorine Residual**. The amount of chlorine remaining after a specified contact period. It is necessary to maintain chlorine residual level to assure complete and proper treatment —— the margin of insurance against subsequent contamination.
- **Coagulant**. A substance used to coalesce suspended solids in water to form a floc.
- **Colloids**. These are suspended matter in finely divided state remaining in suspension in the water.
- **Colour**. Many water have a distinct colour, expressed in platinum-cobalt scale (Hazen units), even after all turbidity has been removed.
- **Conductance** (G,g) - Siemens. The siemens is the electrical conductance of a conductor in which a current of one ampere is produced by an electric potential difference of one volt. One siemens is the reciprocal of one ohm.
- **Conductivity** (γ) – Siemens/Metre. The conductivity of a material is the dc conductance between the opposite parallel faces of a portion of the material having unit length and unit cross-section.
- **Dosage**. The amount of chemicals added into the water, expressed in parts per million (PPM) or milligrams per litre (mg/L).
- **Hazen Units**. The means of expressing the degree of colour in water and are numerically the same as those of the platinum-cobalt scale.
- **High-rate Sand Filter**. Sand filter that permits a maximum of 600 litres of water per minute to flow through one square metre of the filter area, i.e., Filtration Rate 600 $l/min/m^2$.
- **Liquid Chlorine**. Terminology used in swimming pool industry to refer to sodium hypochlorite solutions.

- **Odour**. Odour is measured in threshold odour numbers (TONs). The number represents the number of times a sample has to be diluted with pure water before the odour can be barely detected. Numbers 0 to 2 are considered acceptable, 3 and 4 are increasingly unpalatable and 5 and upwards are likely to cause complaint and become progressively unacceptable.
- **pH**. Indication of acidity or alkalinity (also known as basicity) of a liquid or solution. The pH common scale ranges from 0 to 14. pH7 being taken as neutral. 6 to 0 increasingly acid, and 8 to 14 increasingly alkaline.
- **Platinum-cobalt Scale**. A scale used for measuring colour in water against different concentrations of a platinum-cobalt solution. One milligram of platinum per litre equals one unit of colour.
- **PPM and mg/L**. Abbreviations for parts per million and milligrams per litre. PPM and mg/L are numerically identical measurements.
- **Pressure Filter**. Filter that is contained in a steel or fiberglass pressure vessel and can operate under pressure if hydraulic conditions in the system require it to do so.
- **Rapid-rate Sand Filter**. Sand filter that permits a maximum of 200 litres of water per minute to flow through one square metre of the filter area, i.e., Filtration Rate 200 $l/min/m^2$.
- **Raw Water**. Water in its untreated state as it enters the treatment plant.
- **Scaling**. Mineral deposits on pool walls and floors and in the filtration systems that are both unsightly and can affect proper pool operations due to the reduction of pipe diameters and calcified filters thus restricting the circulation flow rate.

- **Stabiliser**. Also known as a conditioner. A chemical such as cyanuric acid that assists to reduce the loss of free residual chlorine in the pool water due to sunlight and evaporation.
- **Super-chlorination**. Applying heavy doses of chemicals to raise the chlorine residual to above 5.0 ppm.
- **Suspended Solids**. Solid particles in the water that can be filtered out, dried and weighed and then expressed in terms of milligrams per litre.
- **Turbidity**. This is caused by suspended solids but is an optical effect caused by dispersion of and interference with light rays.
- **Turbidity Units**. Turbidity units are expressed in JTUs, FTUs, NTUs, APHA units. These units are numerically the same except for units expressed in parts per million on the scale.

Appendix III: WHO Standards for Potable Water Supplies

Substance or property	Upper limit in high class water	WHO Highest Desirable concentration	WHO Maximum Permissible concentration
Colour, units on platinum-cobalt scale	3	5	50
Odour	0	<2	<2
Taste	0	<2	<2
Total solids, mg/l	300	500	1500
Turbidity, Jackson turbidity units	0.2	5	25
Alkyl benzyl sulphonate (ABS) (surfactants) mg/l	0	0.5	1
Arsenic, mg/l	0.05	0.05	0.05
Calcium, mg/l	<75	75	200
Carbon chloroform extract (CCE) (organic pollutants), mg/l	0.05	0.2	0.5
Chloride, mg/l	100	200	600
Copper, mg/l	0.2	1	1.5
Cyanide, mg/l	0.1	0.2	0.2
Hardness ($CaCO_3$), mg/l	80	200	300
Iron, mg/l	0.1	0.3	1
Lead, mg/l	0.05	0.05	0.05
Magnesium, mg/l	<50	50	150
Magnesium and sodium sulphate, mg/l	200	500	1000
Manganese, mg/l	0.02	0.1	0.5
pH	7.0-8.3	7.0-8.5	6.5-9.2
Phenol, mg/l	0	0.001	0.002
Sulphate, mg/l	<200	200	400

Zinc, mg/l	1	5	15

Appendix IV: Flange Table

Flange size		Japanese Standard				DIN Standard / British Standard							
		JIS 5 kgf/cm² B-2212				NP16 PN16 DIN 2501 BS4504				NP25 PN25 DIN 2501 BS4504			
Nominal Pipe Size		Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes	Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes	Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes
mm	ins	mm	mm	mm		mm	mm	mm		mm	mm	mm	
16	1/2	80	60	12	4	95	65	14	4	95	65	14	4
20	3/4	85	65	12	4	105	75	14	4	105	75	14	4
25	1	95	75	12	4	115	85	14	4	115	85	14	4
32	1 1/4	115	90	15	4	140	100	18	4	140	100	18	4
40	1 1/2	120	95	15	4	150	110	18	4	150	110	18	4
50	2	130	105	15	4	165	125	18	4	165	125	18	4
65	2 1/2	155	130	15	4	185	145	18	4	185	145	18	8
80	3	180	145	19	4	200	160	18	8	200	160	18	8
100	4	200	165	19	8	220	180	18	8	235	190	22	8
125	5	235	200	19	8	250	210	18	8	270	220	26	8
150	6	265	230	19	8	285	240	22	8	300	250	26	8
200	8	320	280	23	8	340	295	22	12	360	310	26	12
250	10	385	345	23	12	405	355	26	12	425	370	30	12
300	12	430	390	23	12	460	410	26	12	485	430	30	16
350	14	480	435	25	12	520	470	26	16	555	490	33	16
400	16	540	495	25	16	580	525	30	16	620	550	36	16

Appendix IV: Flange Table

Flange size		Japanese Standard				British Standard							
		JIS 10 kgf/cm² B-2212				Table D BS 10: 1962				Table E BS 10: 1962			
Nominal Pipe Size		Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes	Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes	Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes
mm	ins	mm	mm	mm		mm	mm	mm		mm	mm	mm	
16	1/2	95	70	15	4	95.3	66.7	14.3	4	95.3	66.7	14.3	4
20	3/4	100	75	15	4	100	73.0	14.3	4	100	73.0	14.3	4
25	1	125	90	19	4	114.3	82.6	14.3	4	114.3	82.6	14.3	4
32	1 1/4	135	100	19	4	120.6	87.3	14.3	4	120.6	87.3	14.3	4
40	1 1/2	140	105	19	4	133.4	98.6	14.3	4	133.4	98.6	14.3	4
50	2	155	120	19	4	152.4	114.3	17.5	4	152.4	114.3	17.5	4
65	2 1/2	175	140	19	4	165.1	127.0	17.5	4	165.1	127.0	17.5	4
80	3	185	150	19	8	184.2	146.1	17.5	4	184.2	146.1	17.5	4
100	4	210	175	19	8	215.9	177.8	17.5	4	215.9	177.8	17.5	8
125	5	250	210	23	8	254.0	209.6	17.5	8	254.0	209.6	17.5	8
150	6	280	240	23	8	279.4	235.0	17.5	8	279.4	235.0	22.2	8
200	8	330	290	23	12	336.6	292.1	17.5	8	336.6	292.1	22.2	8
250	10	400	355	25	12	406.4	355.6	22.2	8	406.4	355.6	22.2	12
300	12	445	400	25	16	457.2	406.4	22.2	12	457.2	406.4	25.4	12
350	14	490	445	25	16	527.1	469.9	25.4	12	527.1	469.9	25.4	12
400	16	560	510	27	16	577.9	520.7	25.4	12	577.9	520.7	25.4	12

Appendix IV: Flange Table

Flange size		American Standard				DIN Standard / British Standard							
		Class 125 / 150 lbs ANSI B16.1& ANSI B16.5				NP6 PN6 DIN 2501 BS4504				NP10 PN10 DIN 2501 BS4504			
Nominal Pipe Size		Max. O.D	Bolt Circle Ø	Ø of holes	Number of holes	Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes	Max. O.D.	Bolt Circle Ø	Ø of holes	Number of holes
mm	ins	ins	ins	ins		mm	mm	mm		mm	mm	mm	
16	1/2	3 1/2	2 3/8	5/8	4	80	55	11	4	95	65	14	4
20	3/4	3 7/8	2 3/4	5/8	4	90	65	11	4	105	75	14	4
25	1	4 1/4	3 1/8	5/8	4	100	75	11	4	115	85	14	4
32	1 1/4	4 5/8	3 1/2	5/8	4	120	90	14	4	140	100	18	4
40	1 1/2	5	3 7/8	5/8	4	130	100	14	4	150	110	18	4
50	2	6	4 3/4	3/4	4	140	110	14	4	165	125	18	4
65	2 1/2	7	5 1/2	3/4	4	160	130	14	4	185	145	18	4
80	3	7 1/2	6	3/4	4	190	150	18	4	200	160	18	8
100	4	9	7 1/2	3/4	8	210	170	18	4	220	180	18	8
125	5	10	8 1/2	7/8	8	240	200	18	8	250	210	18	8
150	6	11	9 1/2	7/8	8	265	225	18	8	285	240	22	8
200	8	13.5	11.75	7/8	8	320	280	18	8	340	295	22	8
250	10	16	14.25	1	12	375	335	18	12	395	350	22	12
300	12	19	17	1	12	440	395	22	12	445	400	22	12
350	14	21	18.75	1 1/8	12	490	445	22	12	505	460	22	16
400	16	23.5	21.25	1 1/8	16	540	495	22	16	565	515	26	16

Appendix V: Conversion Tables

Pressure and Head

		Mercury (Hg)		Water		kg/cm^2	bar	kPa	psi	atmos
		mm	inch	m	ft					
m	Water	73.55	2.806	1	3.281	0.0999	0.098	9.81	1.42	0.0968
ft		22.419	0.883	0.3048	1	0.0305	0.02989	2.989	0.434	0.0295
mm	Hg	100	3.937	1.36	4.46	0.136	0.1333	13.4	1.94	0.132
inch		25.4	1	0.345	1.133	0.0345	0.0338	3.386	0.491	0.0334
kg/cm^2		735.5	28.958	10.0	32.809	1	0.981	98.1	14.223	0.968
bar		750	29.53	10.2	33.455	1.0197	1	100	14.504	0.987
kPa		7.44	0.2953	0.101	0.335	0.0101	0.00993	1	0.145	0.00981
psi		51.7	2.036	0.703	2.307	0.070	0.089	6.894	1	0.068
atmos		760	29.92	10.34	33.9	1.0332	1.0132	102	14.696	1

Volume

		m^3	l	cc ml	UK Gall	US Gall	ft^3	Water	
								kg	lb
kg	Water	0.001	1	1000	0.219	0.264	0.0353	1	2.204
lb		0.000455	0.455	454.6	0.1	0.120	0.016	0.045	1
m^3		1	1000	10^6	219.97	264.17	35.315	1000	2204
l		0.001	1	1000	0.2199	0.2642	0.0353	1	2.204
cc / ml		10^6	0.001	1	0.00022	0.00026		0.001	
UK Gallon		0.004546	4.546	4546	1	1.20095	0.160	4.435	10
US Gallon		0.003785	3.785	3788	0.83267	1	0.133	3.78	8.33
ft^3		0.0283	28.316	28316	0.2288	7.4805	1	28.3	62.23

Flow Rate

	m^3/h	l/h	l/min	l/sec	UK gpm	US gpm
m^3/h	1	1000	16.66	0.278	3.666	4.40
l/h	0.001	1	0.01667	0.000 278	0.00366	0.00439

l/min	0.060	60	1	0.0167	0.2199	0.264
l/sec	3.60	3600	60	1	13.2	15.83
UK gpm	0.272765	272.7	4.546	0.0757	1	1.2
US gpm	0.227	227	3.785	0.0632	0.833	1

Length

	m	mm	ft	inch
m	1	1000	3.281	39.372
mm	0.001	1		0.03937
ft	0.3048	305	1	12
inch	0.0254	25.4	0.08333	1

Appendix V: Conversion Tables

Weight

	kg	g	metric ton	long ton	short ton	lb	oz
kg	1	1000	0.001	0.000984	0.001023	2.204	350
g	0.001	1				0.002204	0.035
metric ton	1000		1	0.9842	1.1023	2204.6	
long ton	1016		1.016	1	1.12	2240	
short ton	907		0.907	0.8929	1	2000	
lb	0.4535	454	0.000454	0.000446	0.0005	1	16
oz	0.028	28.349					1

Power

	metric hp cv ps	kW	Bhp	ft ib/sec
metric hp cv ps	1	0.735	0.985	542.4
kW	1.359	1	1.341	737.56
Bhp	0.7457	0.7457	1	550
ft lb/sec	0.001843	0.001356	0.001818	1

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