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THE PURIFICATION OF THE WATER OF SWIMMING BATHS.

I. INTRODUCTION

The earliest artificial swimming pool in Britain of which we have knowledge is that at Bath, dating from the first century A.D. This Roman bath, which measures 82 feet by 40 feet, is still watertight and fed from its original source, but although the pool is filled with water, it is not now in use.

The latter part of the eighteenth century saw the commencement of popular sea-bathing, which may be said to have begun in 1750 with the publication of a book on the remedial effects of sea bathing by Dr. Richard Russell of Brighton. This beginning was followed by a new demand for swimming baths which had been found hitherto only in palaces and at spas.

In 1846 Local Authorities were enabled by the first Baths and Washhouses Act to provide public baths, including open air swimming baths.

The Amateur Swimming Association was founded in 1869 and, in line with the increasing demand for swimming facilities, the Baths and Washhouses Act of 1878 empowered Local Authorities to provide covered swimming baths. Prior to this Act, all indoor swimming baths in this country had been privately owned.

The first plant for filtration and aeration of water in an indoor bath is said to have been installed at Bury in 1905. Many years before this, however, a floating covered swimming bath, with a pool 135 feet by 25 feet and a capacity of 150,000 gallons, was moored in the Thames near Charing Cross Pier. This pool was filled by a continuous flow of river water, pumped through a filtering apparatus (said to remove all suspended matter), heated, and then aerated by discharge in fountains. The pump and filtering apparatus could fill the pool in six hours.

During the present century swimming has greatly increased in popularity and in the years prior to 1939 much progress was made with the provision of swimming baths. Important factors in stimulating action were the encouragement given by the National Fitness Council to the promotion of swimming facilities, and the terms of the Physical Training and Recreation Act, 1937.

Swimming can be of immense service to the citizen. Its value from the life-saving and life-preserving standpoint requires no emphasis. Apart from this aspect, swimming is possibly the best method of exercising every muscle of the body in the briefest time. But, for the achievement of all the benefit and pleasure which swimming can give, the water of the swimming pool must be safe and attractive. To induce many persons to bathe often and to ensure for all bathers healthy exercise in safety, the pools must be full of fresh, clear and sparkling water, free from harmful bacteria.

II. POLLUTION IN SWIMMING BATHS

It is easy to fill a public swimming pool with water of potable quality, but quite another matter to maintain the cleanliness of the water. At some indoor pools of moderate size it is common to have from 1,300 to 1,500 bathers in one

day, in which circumstances it is evident that, unless the condition of the water is carefully controlled by continuous treatment, it can become so contaminated as to fall below any reasonable standard of cleanliness.

If a swimming pool is filled in the first instance with potable fresh water or sea-water free from pollution, any contamination will be caused chiefly by the bathers themselves, though there are minor sources.

A. Pollution not derived from the persons of bathers

Atmospheric pollution may cause some nuisance. A film of dust and soot may collect on the surface of open-air pools and a deposit may form on the bottom. Even indoor baths, and especially those placed near refuse incinerators for the purpose of obtaining power and heat, may suffer in this way, but this is unpleasant from the æsthetic point of view rather than from any other.

In many swimming baths, the floor space around the pools is used by bathers as a means of access to dressing boxes from the entrance to the building, and by spectators as a promenade. Consequently the floor must become dirty from filth carried by the shoes of bathers, spectators and staff. Although this floor space may be drained, some of the dirt is taken into the water on the bathers' feet. This pollution can be reduced by designing the lay out of the entrance to the dressing boxes on the outside, separate from the means of access to the pool.

Some discoloration of the water is derived from non-fast dyes in the cheaper qualities of bathing suits and, of course, a suit which is not properly cared for may become a source of pollution to the water.

B. Pollution derived from the persons of bathers

Pollution from the bathers is derived from the hair, skin, mucous membranes and urine. Mucus from the nose, saliva from the mouth, sweat and dead epithelium even from the cleanest persons, hair oil and lotions, the oils and creams used by sun-bathers, dried secretions and accumulated dirt from the less clean, micturition (which is said to occur involuntarily when some persons enter cool water) and even spitting, all add their quota to the pollution of bath water. The amount of this pollution could be reduced if all bathers would have baths before entering the swimming bath. To stand for a few seconds in a shower bath and to walk through a foot bath are of use and the appropriate facilities should be provided, but to be really effective, warm water, soap and brushes ought to be used in the preliminary bath, and some minutes should be spent by each bather in washing himself. But most bathers will not go to this trouble and on a warm day when baths are crowded the preliminary cleansing is bound to be perfunctory, even if it is compulsory. Some bathers are careful to have preliminary baths, and for their benefit, shower and foot baths should be provided. The habit, which some bathers practise, of having a bath at home before proceeding to a swimming pool is to be commended.

The pollution which is added to the water of swimming pools would, unless continuously destroyed, cause rapid deterioration of the quality of the water. Effective filtration will remove some of the pollution, and sterilization will kill bacteria and other flora, but filtration will not remove soluble matter. There can be a considerable increase in the quantity of such soluble matter as nitrates and chlorides without affecting the usability of the water, but it should be changed periodically, at least once a year.

C. Bacterial pollution

As would be expected, the numbers and varieties of bacteria added to swimming bath water by the bathers are considerable, but the majority are non-pathogenic. Most of these organisms live in vast numbers as harmless parasites on healthy people and only in exceptional cases do they become pathogenic. A few are known causes of disease, but in a well ordered swimming bath their numbers in the water should be negligible. The risk of infection is much greater from the overcrowding of the bath and dressing boxes and from the sharing of towels by bathers.

Transmission of infection by the water of swimming baths.

It is possible, however, that various diseases are occasionally, though rarely, transmitted by the water of swimming pools, and some remarks follow regarding the infections which may be thus conveyed :—

- (a) Gastro-intestinal infections are very seldom transmitted by swimming bath water. The polluting materials causing these diseases are much diluted and the quantity of water swallowed by a bather whilst swimming is usually very small. The only recorded epidemics were undoubtedly due to water grossly polluted with sewage entering the pools.
- (b) Skin infections are occasionally associated with swimming baths, e.g., furunculosis, scabies, ringworm and pediculosis—but it is likely that they are transmitted by towels, swimming suits and seats rather than by the water. Inflammation of the ear seems generally to be due to the swelling of wax and skin casts by bath water.

Erythema and rashes due to chemicals used for water purification have been described: except in hypersensitive persons, they indicate gross chemical overdosage which should not occur in a properly managed pool.

- (c) Conjunctivitis is sometimes ascribed to swimming bath water. It is perhaps more commonly spread by towels. Overdosage of the water with chemicals will, of course, cause conjunctivitis. Owing to the difference in composition between lachrymal secretion and bath water, any prolonged swim causes a slight mechanical or osmotic conjunctivitis. Diving, under-water swimming, and swimming by a semi-submerged stroke tend to cause this condition.
- (d) There are considerable opportunities for the spread of nasopharyngeal and respiratory infections in crowded baths, corridors, dressing rooms and cubicles, but remarkably little is heard of the transmission of the ordinary infectious diseases in relation to swimming baths. Bathers may contract infections by contact with "carriers" outside the water and one of the factors which may determine whether disease will follow is lowered resistance from fatigue and chilling due to over-long immersion in cool water.

For the prevention of air-borne infections, proper ventilation of the bathing hall must be provided and overcrowding should be avoided.

- (e) Otitis media (middle ear disease). There are several recorded instances of this disease following swimming. It cannot be said whether the causal organisms were actually derived from the bath water or whether the condition was due to the mechanical pressure of the water forcing

infected mucus from the sufferer's nasopharynx into the eustachian tubes owing to inefficient respiration while swimming. An investigation of the types of organisms causing otitis media was carried out over a period of ten years at Guy's Hospital. In acute disease, the bacteria found were nearly always hæmolytic streptococci, whatever the clinical picture. Occasionally, pneumococci were found and, more rarely, Friedlander's bacillus and Bact. coli. It was concluded that hæmolytic streptococci and pneumococci were the organisms principally concerned. Records of the recovery of hæmolytic streptococci and pneumococci from swimming bath water are very few. The bacteriology of chronic ear disease was the same as that of the skin and, therefore, of polluted bath water.

Experience suggests that the likelihood of harm being done by bathing to persons with established chronic otitis media is infinitesimal compared with the mental damage which may be inflicted on a young patient by the prohibition of bathing making a distinction between the patient and other children.

When one considers the number of children who now go to swimming baths, it is remarkable that so few cases of otitis media are reported: most school children are subject to medical supervision and it is difficult to believe that, if an outbreak of middle ear disease were caused by polluted bath water, this fact would escape notice.

- (f) Poliomyelitis (infantile paralysis). At times of unusual incidence of infantile paralysis, it may be said, generally speaking, that the balance of evidence is in favour of keeping open *properly controlled* public baths and swimming pools. While no precautions can entirely remove all the opportunities for infection by the virus of this disease, special attention should be given to (i) the prevention of overcrowding both in and out of the water, (ii) the effective laundering and sterilizing of towels and costumes, and (iii) the thorough cleansing and sterilization of dressing boxes and W.C.'s.

Conclusions as to the possibility of transmission of infection by the water of swimming baths.

The conclusions to be drawn from the available evidence are that polluted water can be a source of infection, but infectious disease caused by this means is of relatively rare occurrence. Generally, in properly controlled swimming baths the risk of the water becoming sufficiently polluted to cause harm is extremely remote: adequate ventilation should minimise the risk of air-borne infection, and overcrowding of the baths should not be allowed to occur.

III. METHODS OF PURIFICATION OF BATH WATER

Continuous Flow

The water in some swimming pools is constantly changing through a natural flow. This occurs in the numerous bathing places in rivers and also in certain indoor baths which are fed by strong springs. The most remarkable of the latter are the two indoor swimming baths at Bath in which the water is maintained at a temperature of 83° F. by mixing cool mains water with hot mineral water which comes from the spring at a temperature of 120° F. The water is filtered and chlorinated before it enters the pools. These two swimming

baths are used periodically by orthopaedic patients, and there are also special remedial baths and a small hot pool, all taking water from the hot springs, which are used for special treatment and exercises with beneficial results.

At Buxton the baths are built over some of the principal springs. Perforated marble slabs in the floor of the pools, are resting on the surface of the rock from which water issues at a temperature of 82° F. There are three pools, but they are small for ordinary swimming and are now used mainly for rehabilitation treatment by exercises.

Matlock has two indoor baths, privately owned, which are fed by springs coming from the hillside at a constant temperature of 69° F. which is an ideal temperature for a physically robust swimmer.

Natural Purification

Natural purification can be relied on only when a pool is of great size, and receives spring water to compensate for evaporation and to allow full development of natural pond vegetation. The bathing ponds at Hampstead and Highgate depend for purification upon these natural processes, and also receive water from other ponds containing more vegetation. There is a degree of water changing by a certain flow between these ponds, and by flushing and drainage after rain.

The bacterial analyses of the water of these bathing ponds show better results than would be expected.

Fill-and-Empty without treatment system

This system, which was the only one in use during the 19th century, cannot be regarded as satisfactory under modern conditions. It consists in emptying the pool either daily, or every second day, or sometimes weekly, but generally at irregular intervals, according to the number of bathers. If the bath is cleansed, scrubbed down, and washed out when empty, this system affords delightful water for the fortunate bathers during the first few hours after refilling, but the depreciation of the water is very rapid, each bather adding his quota of contamination. Except in slack times, it may be taken that without treatment the water of a swimming bath in the afternoon* after early morning refilling is inferior to the water of a bath in which efficient treatment is provided, although the same water may there have been in use for months.

On the fill-and-empty system the criterion as to the need to refill is almost always the appearance of the water, but this is often entirely deceptive as regards bacteriological condition. Moreover, owing to the length of time taken by refilling and heating, it is impossible to empty and refill during the daytime. The cost of filling a pool is considerable, and a superintendent may be tempted, for the sake of economy, to allow a fair looking water to remain in the pool after one day's use. If the next day is suddenly hot and great numbers of bathers are attracted, the water may be foul and offensive by the evening, and also may be so opaque as to be dangerous.

One of the chief objections indeed to the fill-and-empty system is the financial one, which may discourage frequent changing because of the cost

* The following is an example—a pool of 42,000 gallons was emptied, cleansed and filled afresh with water from the mains in the early morning. A sample of the water was taken at 4 p.m. after use by 263 girls, mostly school children. The appearance of the water was still fair, a 19 wire gauge pin being visible at 5ft. 6 ins. The bacteriological examination showed 6,500 colonies per 1 c.c. on agar at 37° C, and B. Coli present in 0.1 c.c., which was the smallest quantity tested.

(i) of the water ; (ii) of the fuel required to heat cold water from the mains (say about 50° F.) to the bathing temperature of 72° F. usually desired for indoor pools ; (iii) of the larger and more expensive heating installation required ; and (iv) of the extra wages for the night work entailed in cleaning the bath.

Another important objection is the heavy draw upon the main supply involved by daily filling. In many localities summer shortage of water must curtail the frequency of changing.

Treatment by chemical means without filtration.

At night, after bathing has ceased, many pools which are not provided with filtration plants are dosed with solutions of chloride of lime and other preparations of chlorine. A few are treated with copper sulphate in solution.

This treatment, as it cloaks the appearance and masks the odour of deterioration, allows the same water to be used for a longer period before refilling, but it must be regarded as only a doubtful expedient which cannot be recommended as a permanent feature.

Continuous Filtration

This is the method now generally adopted and it is described in the following section.

IV. CONTINUOUS FILTRATION

The type of filter in general use for indoor baths is that known as the Pressure Filter, although for outdoor or large installations the Rapid Gravity Filter may be used, and the system closely resembles that in many waterworks installations.

No useful purpose would be served by giving details of the essential differences between the problems involved in purification of the water in use in swimming baths, and those concerning the treatment of domestic water supplies, but it must be emphasized that the two cases are quite distinct.

Bearing this distinction in mind, it is apparent that the primary object of the filtration of swimming bath water is the attainment and maintenance of a high standard of clarity of the water in the pool, while the bacterial purity is ensured by other means.

The period of turnover

If filtration is to be effective, the water in a pool must be circulated continuously through the filter while the bath is in use, and the success of a filtration plant depends on the "turnover period" (*i.e.*, the time in which the whole of the water in the pool is passed through the filter) being sufficiently short. Adverse impressions of the results obtained with filters can usually be traced to this period of turnover being too long. Earlier practice favoured periods of 8, 9 or more hours, and results were often favourable until hot weather brought large numbers of perspiring bathers to the bath, producing a "peak load." Then the plant failed in its function, just when it was most necessary that the water should be clean.

Various formulæ have been put forward for calculating the turnover period, based on the capacity of the pool in gallons and the maximum number of bathers per day, but in practice these calculations do not appear to be successful.

Conditions vary so greatly that it is not possible to make hard and fast rules, e.g., in the case of a school bath the load can be determined precisely, but the load on a public bath depends on public demand which is influenced largely by climatic conditions. Experience shows that for indoor pools which are much used a turnover period of not more than 4 hours will keep the water clear during peak loads. Some Bathing Superintendents favour a shorter turnover period in view of the advantages of having filtering capacity in reserve to maintain a crystal clear water even with the heaviest bathing load.

In some cases, where baths are out of the way and but little used, a turnover period of 6 hours may be sufficient and economical; but it cannot be urged too strongly that the absolute minimum rate of turnover for a much frequented indoor pool, which is to remain hygienic and popular by the attraction of clean water always, is such as to correspond to a turnover period of not more than 4 hours.

It would be a mistake to install too small a battery of filters for a bathing establishment with several pools, on the assumption that the plant could be switched over from one pool to another. The size of the plant should be sufficient to give a turnover period of 4 hours or less, for the total capacity of all the pools. With this arrangement, however, it may be convenient occasionally to switch the whole plant on to one pool for a short period to remove some special contamination.

As regards very large-pools and open air baths, no general rule can be made; in these the "density" of bathers does not usually approach the number in ordinary indoor baths, and cases have to be considered on their merits. It is wise however, for all pools to keep the turnover period as short as possible. See however page 18.

If there has been a heavy bathing load prior to closing time, it is advantageous to continue the circulation of water through the filtration plant for a period after the bath is closed to the public.

The bathing load

It is apparent that the bathing load in a public bath cannot be completely controlled, and it cannot be judged exactly by the number of persons passing the turnstiles.

Obviously a pool should not be allowed to become uncomfortably overcrowded, nor should the bathing load be so great as to cause the clarity, the bacterial condition and the chlorine residual of the water to be unsatisfactory.

The measurement of clarity of water in swimming baths

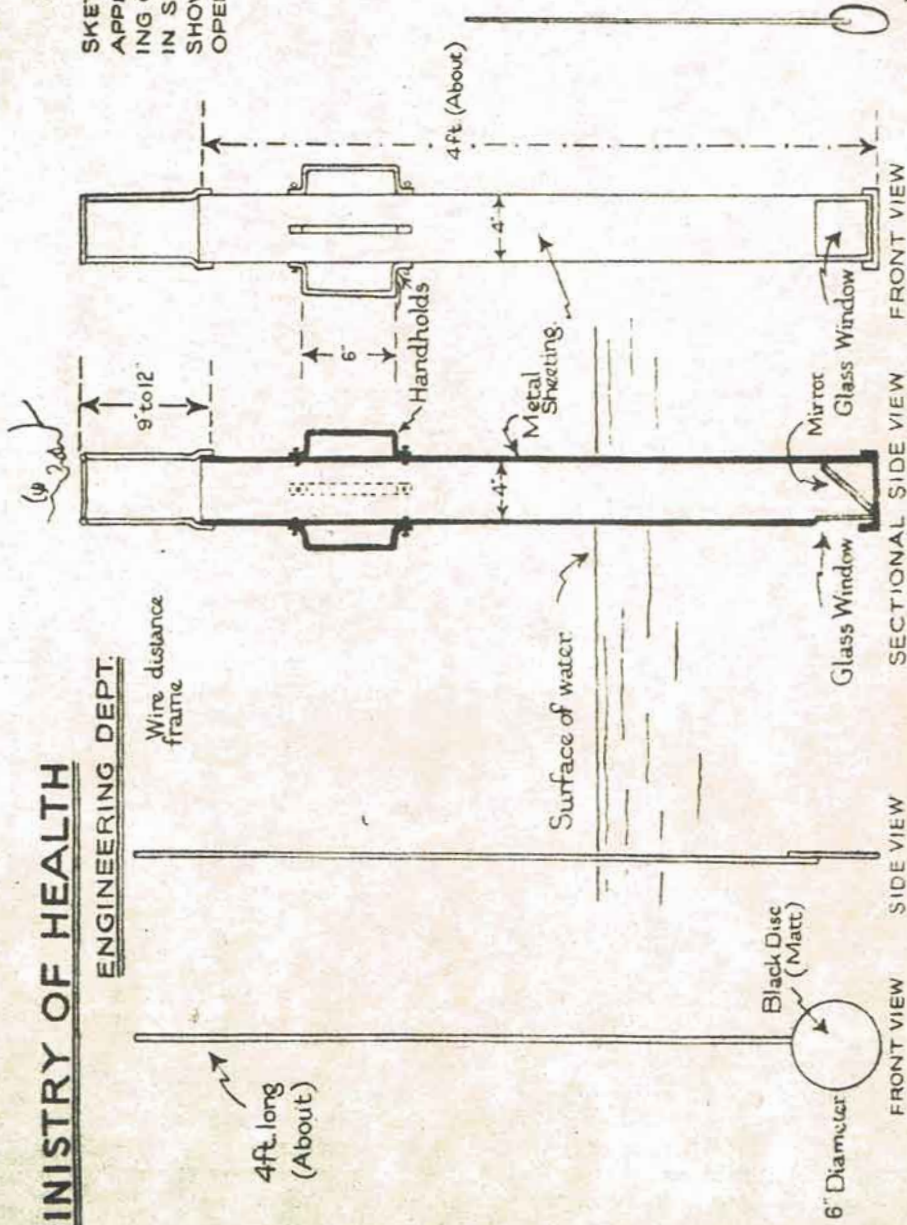
Efficient continuous filtration maintains swimming bath water clear when it would otherwise become progressively more and more turbid. A method of determining clarity in a quantitative way would give useful information, therefore, about the state of the water and the efficiency of the filters. There are several methods by which this can be done, but it is believed that the instrument here described might be particularly suitable for use in swimming baths. This instrument, a sketch of which is shown in Fig. 1, consists of a target and a viewing tube.

The target is a matt black disc, 6 inches in diameter, attached to a black rod of suitable length (4 feet is suggested) the attachment being in such a way that the disc can be held vertically at a depth of 6 inches to 2 feet below the surface of the water in the bath, by a man walking along the side.

MINISTRY OF HEALTH

ENGINEERING DEPT.

SKETCH OF SUGGESTED
APPLIANCE FOR MEASU-
RING CLARITY OF WATER
IN SWIMMING BATHS
SHOWING METHOD OF
OPERATION



FRONT VIEW TARGET SIDE VIEW SECTIONAL SIDE VIEW FRONT VIEW VIEWING TUBE

FIG. 1.

Whitehall, London.
March, 1947

The viewing apparatus consists of a metal sided tube of 4 inches square section and about 4 feet long, closed at its lower end and blackened inside. In one of the sides near the bottom is fixed a plane glass window behind which a plane mirror is mounted at an angle of 45° to the vertical, so that light entering horizontally through the window is reflected vertically through the tube. Surmounting the tube is a simple open frame 9 to 12 inches high, the object of which is to prevent the observer's eye approaching too close to the end of the tube while not preventing changes of position in the horizontal plane. Suitable holds for the hands may be fastened to the tube so that it can be held comfortably by an observer on the side of the bath when the mirror is 6 inches to 2 feet below the surface of the water.

In using the viewing tube, the observer holds it so that the mirror is below the water level and facing the direction in which the target is to be moved. An assistant immerses the target and holds it a few feet in front of the mirror, so that the observer looking down the tube can locate the target. The assistant then moves slowly away from the observer, along the side of the bath. The observer keeps the target in view in the mirror until the turbidity of the water makes the black disc invisible. The distance between target and mirror when the target just ceases to be visible is taken as a measure of the clarity of the water.

It has been found that after a little practice, observers can usually obtain concordant results, independent of personal factors, the lighting of the bath, and the presence or absence of bathers.

It will be understood that the above description of the viewing apparatus is not intended to be a complete specification. Experience may suggest refinements, such as foot rests, which may make the apparatus more easy and convenient to use. The essentials are a plane vertical transparent window about 4 inches square, and a plane mirror of comparable size mounted at an angle of 45° behind the window in order to reflect a horizontal beam of light vertically upwards through a waterproof tube, surmounted by an open frame 9 to 12 inches long to prevent the observer's eye approaching too closely to the top of the tube.

Description of the Filtration Process and Plant

General.—Water from the deep end of the pool is drawn by a pump through a suitable strainer and, after the addition of coagulants to flocculate organic matter and to ensure efficient filtration, the water is pumped to the top of the filter units.

The filter units comprise vertical or horizontal closed cylinders containing sand, and a system of collecting pipes at the bottom which discharge the water after it has filtered through the sand. Means are provided for washing the sand from time to time by reversing the flow of water, which runs to waste during the process and carries the impurities with it.

The filtered water is warmed, aerated and sterilized, after which it enters the pool through a number of inlets at the shallow end.

Suitable filters are manufactured by a number of makers, each of whom has evolved individual details in design.

In the early years of bath filtration, the difficulty was to design plant which could be accommodated in the small and cramped spaces available in the existing buildings which had been planned for the fill-and-empty system, and progress was handicapped by the restriction thus imposed. Now that ample

space for filters can be provided in the plans for new baths, it is hoped that makers will take advantage of the increased facilities to make improvements in design.

When water is taken from the sea or from other natural sources, it is usually necessary to provide settlement tanks to remove sand and heavy impurities.

Whilst most filter plants for swimming baths are of the pressure type, it may be advantageous to consider the merits of rapid gravity filters for large installations, and especially for baths in the open air or on the coast using sea water, as the initial and running costs are less than in the case of pressure filters above a certain size.

Description of filter plant

The success of a filter plant depends to a great extent on the staff who control it, and it is essential that the amount of attention required should not be excessive, and that the plant should be easily accessible.

General. The designer, in planning the building, should provide ample space for the plant in a room which is well lighted, ventilated and free from dust.

The maker of the plant should see that all parts which require attention are readily accessible and that, as far as possible, the plant is fool-proof. He should avoid, for example, lubricators which need filling every few hours, and any type of chemical dosing apparatus which may be easily blocked.

Outlet from Pool to Filter. Outlets from existing baths are usually limited to one situated at the deepest part of the pool. For large new baths, two or more outlets may be found necessary. Gratings of large area should be provided to minimize the effect of suction, and the slots or holes should not be large enough to entrap the fingers of a diver. The water is drawn off through a cast iron pipe by gravitation or suction according to the level of the pump.

Strainer. A strainer box is placed close to the pump and is isolated from the pool by a valve.

The strainer box should be readily accessible. The cover should be hinged and counter-weighted to facilitate opening, and the strainer, in the form of a basket of phosphor bronze or other suitable non-ferrous metal, so arranged that intercepted impurities remain in it and are lifted out with it. The free area through the strainers should be not less than 6 times the area of the opening of the suction pipe. A duplicate strainer should be kept, and the ease of replacement of the strainer is an important point in design.

Pump. This is the heart of the installation and, if possible, should be duplicated.

In most cases the pump is of the direct coupled centrifugal type, driven by an electric motor. Direct acting steam pumps are sometimes used, but they are large and may cause pollution from oil, and it is doubtful if there is much saving in costs over a good design of modern electrically driven centrifugal pump. It must be remembered, however, that the pumping problem is not simple. A pump is required to deliver a constant volume of water per minute against a head which varies considerably from the time when the filter is clean to the time when it has to be washed. Under these circumstances, the ordinary type of centrifugal pump will not deliver at a constant rate, but there are pumps which will comply very closely with the requirements.

In order to reduce running costs, it may be considered desirable to install pumps of unequal capacities, e.g., one third and two thirds of the total flow capacity, so as to allow the rate of turnover to be varied during periods of light bathing loads.

Coagulants

To secure efficient filtration at the desired rate, it is usually thought necessary to use the ancient device of adding to the water an aluminium salt, such as alum, or the less costly sulphate or aluminio-ferric.

The chemical is dissolved in water and added to the bath water as it passes to the filters, in the proportion of one to two grains to each gallon of water to be filtered.

To fulfil its function of forming a film on the sand, sulphate of alumina has to react with an alkaline salt to produce aluminium hydroxide, a flocculent precipitate which forms a coating on the surface and round the grains in the upper layer of sand and so stops the passage of particulate matter and, to some extent, of bacteria, thus enabling the filter to discharge clear water. The aluminium hydroxide also coagulates colloidal matter in the water, so that it, too, with a substantial proportion of the bacteria, is retained by the filter. It will also remove the brown colour from a peaty water, and the blue dyes coming from costumes which sometimes discolour bath water.

The alkaline salts referred to above are present in most hard waters in sufficient quantity to react with sulphate of alumina for a considerable period before they are exhausted. But in the treatment of soft waters it is necessary to add a small quantity of lime or soda ash, and provision should be made for doing this whatever the type of water.

For efficient filtration, the water must be alkaline to methyl orange, but the important question of alkalinity will be discussed later.

The addition of chemicals

The addition of these chemicals requires special apparatus, and many ingenious devices are supplied for the purpose. The usual practice has been to make up solutions of the two chemicals in tanks of sufficient capacity to last for a day's run. For sulphate of alumina, the tanks, fittings and pipes should be made of non-corroding material, as this chemical is slightly acid. Perhaps the best material for such tanks is slate, but the use of lead-lined tanks or wooden tanks is possible. Pipes and fittings may be of lead, phosphor bronze or vulcanite, but the latter is rather liable to fracture. A good class of rubber hose has been used with success and has advantages. The tanks and pipes should be of ample size to obviate clogging in the latter, and to allow dilute solutions to be used, as it is much easier to regulate the larger flow of a dilute solution than to control the mere trickle of a strong solution. Duplicate tanks should be installed so that solutions can be made up ready for the next day's work. Perhaps the best, although the most expensive, method of adding the chemical solutions is to pump them by small ram pumps into the main leading to the filters. These pumps are made with a stroke which can be varied, and they are positive in action. Other methods are based on the use of a Venturi tube, and some of these are simple and effective. It is essential that the apparatus for adding chemicals should be of good design and easily worked. Additional outlay on this part of the plant will be well spent, for good results from the filters cannot be expected if the chemicals are not added exactly in accordance with the requirements of the water.

Filters

The filters are usually mild steel cylinders with dished ends, and are used in both vertical and horizontal positions. The limiting diameter for transport appears to be about 6 feet 6 inches, which gives a vertical unit with a filtration area of 56.74 square feet.

The majority of manufacturers seem to have favoured the vertical design, but there are indications that in large installations horizontal units are being considered.

The pump delivers the water, to which coagulants have been added, into the top of the filters and so through a layer of sand which varies in thickness and grade according to the design. The old practice of making up the sand layer with beds of different graded sands is no longer exclusively favoured, as the agitation of the sand and the upward washing have the effect of mixing the beds. Also the provision of costly crushed quartz sand is giving way to the cheaper and equally effective natural Leighton Buzzard sand.

The sand layer is supported on layers of graded gravel, and generally the arrangement of the filtering medium is similar to that found in the waterworks slow sand filter.

The water is collected from the bottom of the filter by a system of pipes with guarded orifices placed closely together.

At one time great stress was placed on the design of these orifices and strainers, and many ingenious and special arrangements were patented. The tendency of design is now towards simplicity and cheapness with apparently no decrease in efficiency.

Strainer systems are usually embedded in concrete, to obviate the collection of dirt or dead water at the bottom of the filter.

Washing the Filter

Rapid filters differ from slow sand filters in that they are provided with a speedy method of washing sand. This is necessary because washing may be required at intervals of a few hours, whereas the slow sand filter for waterworks frequently runs for months before it needs cleaning.

To wash a rapid filter, two distinct processes are necessary :—

- (i) Breaking up the solidified sand bed by some form of agitation ;
- (ii) Washing the sand by means of an upward flow of water.

Many devices have been introduced to break up the sand bed, and there has been some controversy as to the respective merits of different systems.

In the early days of rapid filters for waterworks purposes, the use was general of rotating rakes worked by power, but this necessitated a circular design of filter of limited size. The demand for large rectangular masonry filter units brought in the method of agitation by means of air admitted under pressure through the collecting orifices at the bottom of the bed.

Air agitation has been replaced by " high velocity wash " in the U.S.A., but in this country, high pressure water for breaking up the sand, and for washing, has not found favour, as it is considered to be uneconomical in water consumption, and is attended with the risk of carrying away sand although this could probably be avoided by a proper design of the filter.

While the use of rotating rakes for circular filters is effective, the apparatus is costly, and in this country most manufacturers have continued to develop the method of air agitation.

A third method of breaking up the sand is found in a horizontal filter, which is rocked backwards and forwards on its axis.

Makers of filter plants naturally praise the merits of their own designs, and it will perhaps suffice to say that the Ministry of Health does not discriminate between air and mechanical methods of agitation, provided a proper breaking up of the sand bed is achieved.

For installations of any size except very small, a power unit is required to work the agitation system and, if rotating rakes are employed, the provision of shafting, gear and belts is a costly item.

Air for agitation is supplied by a compressor or blower according to the size of the plant, and where steam is available, a simple form of Korting air injector worked by a steam jet is effective, but if this is used it is desirable to incorporate an air-flow indicator. Where compressors are used, it is essential to place an oil separator on the compressed air pipe to retain any waste oil from the compressor cylinder which otherwise might form an unsightly film on the bath water.

A filter is washed by isolating the unit and opening a connection at the top leading to waste. The rakes are then worked for a few minutes, or air under pressure is turned on through the orifices at the bottom. After agitation of the sand, water is passed upwards through it from a connection feeding the orifices until the dirty water flowing to waste is observed to be running clear. The filter is then opened for unfiltered water from the top, but it is not opened to discharge from the bottom for a few minutes. This delay allows the sand to settle down and to collect a little flocculent matter on the surface. An alternative way of obtaining the same result is to have the necessary pipe connections to allow the water to be re-circulated through the filter but without entering the pool.

Washwater

It is not difficult to supply washwater for bath filters. In some cases it is possible to wash a unit with the filtered effluent from other units.

Another method is to wash with water direct from the main, but the more usual way is to wash with bath water direct from the pump. The use of clean water from the main for washing filters is open to the objection that fresh water is lost thereby, and is not used to renew the bath water or to keep up the natural alkalinity in the case of hard water.

Speed of Filtration

There has been much discussion on the subject of the proper rate of filtration for swimming bath filters in terms of gallons per square foot of sand area per hour. So far, unfortunately, little reliable data based on careful experimental work have been produced from which conclusions of scientific value can be drawn.

It will be appreciated that the requirements of pressure filtration of swimming bath water are not the same as for water to be used as a public supply. In the latter case, the filtration rate must be such as to give a safe effluent at all times, so that if subsequent chlorination or other sterilization treatment fails, the danger to health is avoided. In swimming pools, treatment with chemicals

is relied on to destroy potentially harmful bacteria in the water and accordingly the speed of filtration need not be lower than that required to give clear water under all conditions of bathing use.

An apparatus for measuring clarity of water in swimming pools has been described (on pages 11 to 13) and it is suggested that water which shows a "disappearing distance" of 30 feet as measured by that instrument can be regarded as clear and attractive, and such a standard ought to be maintained under normal conditions. With a heavy bathing load a reduction in disappearing distance to 15 feet need not cause alarm, but the purification system ought to be such as to prevent any further deterioration of the water.

In recent years, in this country, it has become common for indoor baths to operate with a filtration rate of 200 gallons per square foot of sand per hour, coupled with a 4 hour turnover period, and a limited experience suggests that such a system can maintain the water in a pool in conformity with the above mentioned degrees of clarity. Probably a shorter turnover period at a greater rate of filtration would achieve equally good clarity and would have the advantage in times of heavy bathing load of permitting more rapid removal of polluted water from the pool. However, such a greater rate of filtration would not necessarily mean that smaller filters could be installed; the increase in circulation rate would itself increase the rate of filtration.

For indoor baths the 4 hour turnover period referred to above must be regarded as the minimum rate of turnover unless the bath is very little frequented, and spare pump capacity to enable circulation to be even more rapid at times of very heavy bathing load is a useful asset. For outdoor baths it is difficult to generalize. In principle there is no reason to suppose that they require a smaller rate of circulation; in practice, however, the average load is so much below the peak load, and the latter occurs so seldom, that it may be economical and quite satisfactory to work with a somewhat longer turnover period and to rely upon night working of the filters to keep the water in good condition when the bathing load is very heavy. This is so at least with very large baths, in some of which skilled operation maintains satisfactory water at a turnover period of 6 hours. Where it is known, however, that heavy loads are likely to be frequent, for instance at holiday resorts, more rapid circulation is advisable. Whatever is provided, it is for the operator to ensure that the water remains satisfactory, if necessary by reducing the bathing load.

No suggestion is made that the rate of filtration which has come to be regarded as more or less standard should be increased. But it may be possible, by suitable design of filters and better methods of operating them and of sterilization, to maintain the necessary clarity with a higher filtration rate. If filter manufacturers believe this to be so, there is no reason why proposals based on this belief should not be investigated, provided that a suitable guarantee is given. It should be borne in mind, however, that greater rates of filtration will entail greater power costs for pumping, and a saving in capital costs should not be effected at the expense of increased running costs. It would be wise on the part of all concerned to depart from present practice by slow stages, each stage being justified by experience before proceeding to the next.

Much practical research still remains to be done on the subject of filtration in order to obtain greatest efficiency of performance combined with economy of working. Besides filtration rates, turnover period and bathing load, there are other factors which have an important bearing on the subject, including the amount of coagulant used, the frequency of washing of filters, and possibly the

method of sterilization. The relationship between all these factors is not yet fully understood.

Heating

The best method of heating is by the use of a calorifier, though it is sometimes done by the injection of steam. In the latter case, if exhaust steam from an engine be used in direct contact with the water, perfect elimination of oil is essential. In any case, it is highly undesirable and dangerous for steam to be injected directly into a pool.

From the point of view of economy it is one of the great virtues of the continuous purification method that the loss of heat involved is comparatively small, so that re-heating is inexpensive compared with the cost of the large quantity of fuel which is required when operating a bath on the fill-and-empty system; it is then necessary to heat the whole volume of the fresh water from the temperature (about 50° F.) at which it leaves the mains, to the desired temperature of about 72° F.

Aeration

Aeration of the water after filtration is normally practised and is useful, though it is uncertain to what extent, when the water is chlorinated, it plays a part in maintaining bacterial purity.

The usual form of aerator is a closed chamber through which the water passes, and into which air is blown by means of a compressor or blower.

More air is used than the water will take up, and means should be provided for the surplus air to discharge through a pipe leading to the open air outside the filter house.

The usual method of supplying air is by motor driven blowers or compressors. An oil filter should be used to eliminate oil from the air, and care should be taken to ensure that the plant is of ample dimensions to saturate the water, and that it is not worked at an excessive speed and has proper cooling arrangements.

In the grounds of an open air bath, a cascade or ornamental fountain is often fitted through which the water passes on its way to the bath. This system of aeration can be made efficient if attention is paid to the design, and costly blowers or compressors which use a large amount of power can thus be omitted. In such cases (and indeed in most) it is advisable to chlorinate after aeration.

V. STERILIZATION

In some of the older plants, sterilization is performed before filtration, but there seems to be no doubt that the proper position of this process is after filtration, though whether it should precede or follow aeration is a matter upon which there are differences of opinion.

As has been pointed out, the "safety" and bacterial purity of the water depend largely on sterilization and it is essential, therefore, that this process should be done efficiently.

The water in the pool is subject to continual pollution and for this reason it is desirable that the sterilizing agent used should have a "residual" action such as that possessed by chlorine, in order that pollution may be attacked as it occurs. If the sterilizing agent used does not possess this "residual" or prolonged effectiveness, it may be necessary, by way of compensation, for the turnover period to be shortened very considerably.

Sterilization should always be a continuous process, and it would be regrettable if filtration plants, originally intended to run with continuous chlorination, were allowed to degenerate (for there is no other word) into filtration systems in which chlorination is merely done each night when bathing has ceased. Such intermittent chlorination can be regarded only as an unsatisfactory makeshift.

Chlorination

The sources of chlorine used in this country for sterilizing swimming bath water have been :—

- (a) bleaching powder in solution ;
- (b) other liquids containing a considerable concentration of available chlorine ;
- (c) chlorine gas.

Modern practice favours the use of chlorine gas which, in our opinion, admits of much more easy and accurate control of dosage to meet the varying requirements of the water than either of the other two methods. It is employed in most modern baths.

Satisfactory chlorination can, however, be obtained from any of the above sources of available chlorine provided that the composition of the reagent can be relied upon, that the dosing apparatus is of proper design, and that skill, care and continuous supervision are given. It should be emphasised, however, that the great variation in the bathing load, the consequent large variation in the pollution added to the water, the complicated reactions which may occur, and the risks attendant upon both overdosage and underdosage, render the problem of efficient chlorination without giving rise to complaints by no means a simple one.

During the last few years there have been important developments in the understanding and technique of chlorination, and in this respect the previous edition of this pamphlet is now much out of date. At the time of its issue (1929) it was not possible to distinguish clearly between the different types of residual chlorine, and the tests then in use for chlorine also responded to chlorine combined with ammonia as chloramines. It was then recommended that the total chlorine, as determined by the ordinary orthotolidine test, should be maintained at a concentration not less than 0.2 or more than 0.5 parts per million of water. A good deal of evidence was put forward indicating that this was adequate to ensure satisfactory sterilization and at the same time small enough to avoid complaints of smell and smarting eyes. These limits were very widely adopted and gave general satisfaction. So far as we are aware no cases of disease occurred which could be attributed to infection transmitted by swimming bath water maintained in the recommended condition, though there have been some cases where the water failed to maintain the highest bacterial purity. These cases have occurred chiefly when the ammonia content of the water has been very high, e.g., 1 p.p.m., a condition which might arise as a result of a very high bathing load or from the use of a water supply containing particularly high contents of free and saline ammonia. In these circumstances it is plain that if an increase in the residual chlorine content to above 0.5 p.p.m. can be effected without serious complaint (as in many cases it can), limits higher than those previously recommended should be adopted. The matter, however, cannot be dismissed so simply as this, but demands more detailed consideration.

The Chemistry of Water Chlorination

Water is chlorinated because it is, or may be, polluted bacteriologically. The chlorine is intended to react with and destroy harmful bacteria and it reacts at the same time with polluting substances which invariably accompany the bacteria. Some of the chlorine added to the water is therefore converted to chlorine compounds which cannot by any test be mistaken for free chlorine. This is one reason why chlorination of swimming bath water must be continuous, since chlorine is continually being lost by reaction with polluting substances derived from the bathers and perhaps other sources; part is, of course, also lost by volatilisation and other means. Among the substances in water with which chlorine reacts is ammonia, but the primary products of this reaction, known as chloramines, must be distinguished sharply from other compounds of chlorine. The reason is that to a considerable extent they behave like chlorine—they are bactericides, they react with polluting matter and they respond to the usual colour test for chlorine.

Chloramines, however, differ from chlorine in important respects. Firstly, although they are bactericides they are neither so rapid nor so powerful in action as free chlorine. The difference in speed of killing is very marked indeed. Thus a bath water containing, say, 0.2 p.p.m. of chlorine combined as chloramine may show a content of bacteria, when another bath water showing a similar amount of free chlorine is of the highest standard. Secondly, although chloramine reacts with polluting organic matter, it does so very much less readily and more slowly than free chlorine; a residual of chloramine therefore tends to remain as such when one of free chlorine would quickly diminish or vanish altogether because of reaction with polluting matter. A residual of chloramine is in a sense more stable than one of chlorine. A third difference in properties, which will be referred to in a later section, permits of chloramines being distinguished from free chlorine by a chemical test.

Although chlorine in the form of chloramine is undoubtedly in chemical combination it would be misleading to term it combined chlorine as this would fail to distinguish between it and other forms of combined chlorine, such as chlorides and organic chlorine compounds, which are of no value as sterilising agents. It has therefore been given the name of "combined residual chlorine" which allows uncombined chlorine to be described as "free residual chlorine." Even the latter, of course, is not all in the elemental state in solution, but this additional complexity need not be dealt with here.

When chlorine is added to water containing ammonia, chloramines are always formed. They are, however, unstable in the presence of excess chlorine and they break down to form hydrochloric acid and nitrogen. The chlorine in combination as hydrochloric acid is useless as a sterilizing agent. The incidence of this reaction is responsible for the so-called breakpoint curve obtained by treating water containing a trace of ammonia with increasing amounts of chlorine and plotting the amount added against the residual as determined by the ordinary orthotolidine test. What happens is that at first the residual is entirely chloramine (combined residual chlorine) which, being relatively unreactive, increases as the chlorine dose is increased. Later, however, a stage is reached when decomposition of the chloramine to hydrochloric acid and nitrogen occurs and, because of this, increased additions of chlorine cause the determined residual, not to increase, but to diminish. Finally, when the chloramine has been largely decomposed, an increase in the chlorine dose again causes an increase in the residual, this being now free residual chlorine. The water has now been chlorinated beyond the breakpoint.

This process of breakpoint chlorination allows free residual chlorine to be present in water which originally contained ammonia. It is used extensively in the U.S.A. and to a growing degree in this country in the treatment of public water supplies and during the last 3 or 4 years it has been applied to swimming bath water where, with proper understanding and control, it has given very satisfactory results. In the previous edition of the booklet two processes of chlorination were described, namely, chlorination with small amounts of chlorine, and chlorination with the additional use of small amounts of ammonia so as to form chloramines deliberately. To these must now be added a third, namely breakpoint chlorination. It may well be doubted whether these do, in fact, constitute three different processes, but it is convenient to discuss them under three separate heads.

The Use of Chloramines

The use of chloramines is a modification in the use of chlorine gas and consists in the administration of ammonia gas or sulphate of ammonia which is given a short period of contact before the administration of the chlorine. The dose of ammonia is usually something less than a quarter of that of the chlorine, and probably the best way to administer it is to deliver the solution of ammonia gas or ammonium sulphate into the effluent main from the filter before the water enters the aerator, and to place the delivery pipe for the chlorine gas solution on the same main between the aerator and the entry to the bath.

It should be borne in mind that, whilst continuous addition of chlorine to a bath water is necessary in order to replace chlorine which reacts with polluting matter added by the bathers, ammonia undergoes no such reaction and, if added continuously, its concentration must progressively increase. Too great an increase is undesirable because the rate of sterilization by chlorine diminishes as the ammonia content increases and it ultimately becomes too slow. Where chloramine treatment is used, therefore, regular determinations of the ammonia in the water should be made to ensure that this does not reach an undesirable high figure. Generally, there would appear to be no reason to add further quantities of ammonia when its concentration in the water exceeds one quarter that of the chlorine.

We can think only of rare cases where the chloramine process should be preferred. In the case of a little-frequented bath, for instance, where an ammonia-free water is used as a source of supply and where it is desired to retain a chlorine residual with as little supervision as possible, it may be justifiable to add ammonia deliberately until it reaches a suitable concentration, say, 0.1 p.p.m., and then add chlorine to maintain a combined residual of 0.2 to 0.5 p.p.m. Under these conditions bacteriological analysis might invariably show a satisfactory water which would be maintained with a minimum of attention (although not without it). For more usual cases, however, there is little to commend the deliberate use of chloramine.

Ordinary, or marginal, chlorination

This is a process which has been generally used during the last 2 or 3 decades. It consists simply in the continuous addition of chlorine to the water after filtration so as to obtain a total residual within given limits without regard to its exact nature. The residual must, of course, be either free chlorine or chloramine. If it is the latter the process might well have been included in the preceding section; if the former, it could quite logically be included in the following section dealing with breakpoint chlorination. In most cases,

the residual is doubtless chloramine; indeed, the whole aim of the change over to breakpoint chlorination, which a number of baths have recently adopted, is to ensure that the residual is largely free chlorine. In some cases, however, marginal chlorination may itself have given a residual of free chlorine. Mention has sometimes been made of difficulties in maintaining a residual throughout a pool in the early days after filling. This may well have been due to the residual being free chlorine, which tends to react with polluting matter more quickly than does chloramine. Later in the season, when a small quantity of ammonia had accumulated, this defect would not occur, since the residual would now be chloramine. With this exception, it has generally been possible to maintain a residual of not less than 0.2 p.p.m. at all points in the pool while not exceeding 0.5 p.p.m. at the inlet. Apart from a few cases where the ammonia content has been abnormally high, and possibly where the bathing load has been exceptionally heavy, bacteriological examination has generally confirmed that with a chlorine residual held between the above limits the water has maintained a high standard of quality. Where it fails to do so it is obviously the course of wisdom to step up the chlorine residual, provided that the water remains pleasant to bathe in and does not give rise to complaint.

Breakpoint Chlorination

Where an existing purification process is simple, familiar to the operator, and gives uniformly satisfactory results, there is obviously no compelling reason to change it or to modify it. Even so, no existing process can be assumed to be ideal, and if a better one is developed and can be adopted at no great cost most people would, quite rightly, make the change. Experience so far appears to support the early promise of breakpoint chlorination to possess substantial advantages over marginal chlorination, and it is essential therefore to discuss this new development.

The principles of breakpoint chlorination have already been explained. It involves the use of larger concentrations of chlorine than usual so as to ensure the breakdown of most of the ammonia to nitrogen instead of its combination to form chloramine. A residual of chlorine is then obtained which is "free residual." This form of residual is much more rapidly bactericidal than chloramine and therefore deals much more promptly with bacterial pollution introduced into the pool by bathers. Furthermore, there seems little doubt that higher residuals of free chlorine can be tolerated by bathers without discomfort. This is fortunate because, in fact, these higher residuals are necessary in order to operate breakpoint chlorination successfully. The principal reason for this is that the free residual chlorine acts quickly upon some of the organic pollution and is thus lost from the system. It also reacts with and destroys ammonia as it is formed in the water, thus maintaining what may be termed breakpoint conditions within the pool.

Thus, breakpoint chlorination must consume more chlorine than the marginal process. Furthermore, owing to the acid produced when chlorine reacts with organic matter and ammonia, an increased consumption of lime or soda ash to neutralize this acid is also inevitable. The pH will tend to change more rapidly and should therefore be checked more frequently in order to keep it within the desired range. Moreover, in order to be certain that the residual is largely free chlorine the test used for determining the residual must be able to distinguish between free chlorine and chloramine. The operation of breakpoint chlorination must therefore be somewhat more expensive than the usual process, and supervision and control needs to be close and skilled. These

requirements represent the price to be paid for the advantages offered by the process and it must remain generally a matter for local determination whether they are worth it.

The advantages of the process lie primarily in the stronger and more rapid bactericidal action of free chlorine compared with chloramine, though there may well be others. Attempts have been made to express the relative speeds of sterilization quantitatively, but it is unwise to attempt to arrive at a figure representative of all conditions. It is sufficient to say that generally the one is many times more rapid than the other, a point of particular importance at times of high bathing load. If experience shows that in a given case a chloramine residual usually gives a bacterially satisfactory water there should be no doubt that a similar residual of free chlorine will invariably do so. There seems therefore no justification for maintaining abnormally large free residuals merely because this can be done without complaint, though an increased residual to prepare for an expected heavy bathing load might be a wise precaution. In breakpoint chlorination, however, a residual exceeding the previously recommended 0.5 p.p.m. appears to be desirable for another reason. In the absence of such relatively high residual at the inlet of the pool it may fall to too low a level while in the pool, or alternatively may fail to decompose the ammonia produced from polluting matter, and the water may revert to the chloramine condition. Exactly how high the residual should be may depend upon a number of factors, including bathing load, turnover period and possibly other local conditions. Obviously, the residual should not be as high as to cause a complaint of smell, taste or irritation, but current opinion is that the concentration of free chlorine likely to cause trouble in these directions is at least several p.p.m. and it should not therefore be necessary to approach this. Recently, however, it has been found that free chlorine in swimming bath water may be accompanied by a smaller quantity of nitrogen trichloride, which is a gas with a pungent odour and an irritating effect on the eyes and mucous membrane. For this reason and in view of the very strong bactericidal action of free chlorine it is felt that the aim should be, not to maintain as high a concentration of free residual as can be tolerated by the bathers, but as low a one consistent with the satisfactory operation of the process. This might be found to be in the region of 1 p.p.m. under normal conditions, with increases to perhaps double that value when the bathing load is heavy and perhaps during the night, to allow its action to proceed as near to completion as possible. Although the interaction of chlorine and ammonia is fairly rapid, the production of ammonia from organic matter added to the water may be much slower, and reactions occurring during the hours of night may be important.

If the account which has just been given of breakpoint chlorination had been strictly true the residual chlorine in water treated beyond the breakpoint would be entirely free chlorine. In point of fact, however, there always seems to be some combined residual though it should be smaller than the free residual. The truth is that the course of events subsequent to chlorination just described is an over-simplification of the matter. Several secondary factors have been ignored and others may later prove important. It is quite certain that the last word has not yet been said about the breakpoint chlorination of swimming bath water, and authorities operating the process should keep abreast of future developments. Several papers have recently been read on the subject, some to the National Association of Bath Superintendents, and they should be studied. The above account must not be regarded as a complete set of instructions on how to operate the process.

Two additional points may be mentioned. The first applies to all forms of chlorination, but is most important with breakpoint. It is that frequent tests of the quality of the water are necessary and the results of these should be recorded on special log sheets and carefully preserved for reference. Free and combined chlorine residuals and pH values should be determined at least several times each day.

The second point applies to the time when breakpoint conditions are first established. If the water contains more than minimal amounts of ammonia the initial dose of chlorine may have to be very large and until the chloramines begin to decompose the residuals may be very high indeed. Clearly this part of the process should not be undertaken during a bathing period and it is obviously desirable to carry it out with water as organically pure as possible, for instance, with water freshly drawn from the mains.

In addition to its germicidal action, the use of chlorine prevents the growth of algae, which often cause trouble in indoor baths by unsightly and slippery green growths on the sides and bottom of the pool, and which may even in a few hours discolour the water to a serious extent.

Open air baths are more liable to trouble from algae, which may sometimes lead to such complete opacity of the water that it is not possible to see the bottom of the pool at the shallow end. Several fatal accidents from drowning have resulted from opaque water.

Another advantage of continuous chlorination is the elimination of the musty smell which used to haunt many old fashioned swimming baths.

Tests for Residual Chlorine

To equip a swimming pool with modern purification plant (using the method of continuous filtration and chlorination) without providing the officer responsible for its working with the apparatus and the skill necessary to determine the presence and amount of the residual chlorine in the water (i) of the filter effluent, and (ii) even more important, of the pool itself, will be lost endeavour and wasteful parsimony which will invite trouble.

The determination of residual chlorine, including chloramine, in the bath water presents no practical difficulty. The confusion which is theoretically possible owing to oxidizing substances, such as nitrites and ferric salts, producing similar colour reactions to those produced by chlorine does not arise in practice when dealing with bath water to which it is known that considerable quantities of residual chlorine are being added, and in which nitrites, even if present, are only in extremely minute quantities.

The orthotolidine method appears to have been suggested first by E.B. Phelps, who used a solution of orthotolidine in acetic acid. According to Phelps, a yellow colour could be detected by this method in the presence of 0.05 parts of chlorine per million. Dittoe and Van Buskirk working at this method, were followed by Ellms and Hauser,* who improved it by using hydrochloric acid instead of acetic acid, giving a solution which does not deteriorate on standing. A convenient strength for use is one gramme of orthotolidine in one thousand c.c. of 10 per cent. hydrochloric acid, one c.c. of this solution being added to one hundred c.c. of the water to be tested.

It is said that 0.005 parts per million of chlorine can thus be detected.

* J. W. Ellms and S. J. Hauser (*Jour. of Ind. and Eng. Chem.*, 1913, 5, 914-916).

Various firms are now making several neat forms of apparatus for using this method, some with standard solutions of bichromate and copper sulphate for comparison, others with tintometer glass of varying depth of colour. These are now well known and widely used and it seems unnecessary to describe them further. In using them the makers' instructions should be carefully followed.

Employed in the normal way, the orthotolidine test measures the amount of chlorine both in the free form and as chloramine. Where break-point chlorination is used, however, it is necessary to know that free chlorine is present. Theoretically, under these conditions, all the residual chlorine should be as free chlorine, but this is not always so in practice. The precise determination of the proportion of free chlorine and chloramine is by no means an easy matter, and tests which are suitable for routine use have still to be perfected. Meanwhile, it may be sufficient to determine the total residual chlorine in the usual way and to establish that a good proportion of it is free chlorine. One way of doing this is to observe whether an immediate colour is produced by the orthotolidine reagent; if so, then free chlorine is present. This is the so-called "flash" test attributed to Laux and described in the U.S. Standard Methods for the Examination of Water and Sewage, 9th Edition, 1946. It is clear that this method is hardly more than qualitative, since the subsequent development of colours due to chloramines prevents accurate measurement of the intensity of the initial colour, but it should achieve its purpose. Alternatively the orthotolidine arsenite test may be used. In this modification, immediately after mixing the sample with the orthotolidine solution, a solution of sodium arsenite is added and the colour compared with standards as quickly as possible thereafter. The arsenite reduces the chloramines and prevents colour development due to them. This modification is also described in the U.S. Standard Methods.

Another test which distinguishes between free chlorine and chloramines is based on the use of *p*-Aminodimethylaniline. It is described by Palin (*The Analyst*, 1945, June, 70, 203) in the following terms:—

"Reagents—(1) A 0.2 per cent. soln. of pure *p*-aminodimethylaniline hydrochloride in industrial methylated spirit (kept in amber bottle).

(2) 0.5 M phosphate buffer solution, pH 6.8, prepared by dissolving 35.5g of anhydrous Na_2HPO_4 (AnalaR) and 34.0g of KH_2PO_4 (AnalaR) per litre. The mixture was allowed to stand for several days and any ppt. filtered off (the ppt. appeared mainly to be due to iron).

(3) Solid potassium iodide.

(4) Dil. iodine soln. (1ml \equiv 0.05 mg of Cl_2). prepared as required from N-10 iodine solution.

Method—(a) *Chlorine*. Place 100 ml of the sample in a 100-ml Nessler tube containing 2 ml of buffer soln. and 0.5 ml of *p*-aminodimethylaniline soln. Mix, and match the colour immediately by running the standard iodine soln. from a burette into a second 100-ml Nessler tube ("control" tube) containing the same amts. of buffer soln. and *p*-aminodimethylaniline soln. in distilled water. After each addn. of iodine mix with a "plunger type" stirrer. If more than 0.5 p.p.m. of chlorine is present, take less of the sample and place it in a Nessler tube containing the reagents and sufficient distilled water to give a final vol. of 100 ml.

(b) *Chloramine*. Put a crystal of potassium iodide in the sample tube, mix, and again match the colours by further addition of iodine to the

control tube. The additional iodine soln. required represents chloramine-chlorine. Here, again, if more than 0.5 p.p.m. is indicated, colour matching is made easier by taking less of the sample.

Total available chlorine—The total amount of iodine soln. used gives the total available chlorine.

It is important to make the estimations as quickly as possible."

Still another test, based on neutral orthotolidine, allows differentiation to be made between monochloramine, dichloramine, nitrogen trichloride and free chlorine. It is described by Palin, *Journal of the Institution of Water Engineers*, 1949, 2, 100—122.

The provision of a reliable apparatus for the determination of the residual chlorine is an essential part of a modern purification plant, and routine tests of the water of every pool should be made at least three times a day, and accurate records kept. Such tests afford a method of estimating the bacterial safety of the water which is easier, swifter, and more effective than the difficult method of bacteriological determination. For the latter, samples must be taken in the most careful manner and the results cannot be obtained for at least 48 hours, by which time of course, the condition of the water in the pool may have changed entirely. It is recommended that chlorine determinations should be supplemented at intervals by bacteriological examination and if this should be unsatisfactory then the reason should be sought; it might be an excessive ammonia content of the water.

Ozonisation

Since the publication of the earlier edition of this pamphlet, ozone has been used in a few cases for sterilization of swimming bath water. There is no doubt that it is an efficient sterilising agent, but it escapes from the water, or is decomposed, quickly and on this account may not be the equal of chlorine, particularly free chlorine, in its ability to deal quickly with pollution added to the water during its travel through the bath. Further experiments on this point are, however, awaited.

VI. ALKALINITY

The water of a swimming pool purified by continuous filtration must be kept slightly alkaline in reaction, otherwise it may be unsatisfactory in several respects. The water supplied to most indoor baths, and many outdoor ones, usually has some natural alkalinity but, owing to the fact that the reagents (alum and chlorine) commonly used for coagulation and sterilization are acid forming, the alkalinity tends to disappear. Occasionally, the amount of make up water used may compensate for this loss, but usually it is necessary to add an alkali (soda ash or lime) to the water before it reaches the filters. Roughly, about half as much soda ash by weight as sulphate of alumina and about one and a half times as much as chlorine is required to neutralize the acidity produced.

Alkalinity may be assessed in two ways, by titration or by a determination of the pH value. The former measures the amount of alkalinity present and the latter takes into account both amount and type. The pH scale is really a method of expressing the hydrogen ion concentration in the water; a value of 7 indicates neutrality, greater than 7 indicates alkalinity and smaller than 7 acidity. The pH can be determined sufficiently accurately with the aid of indicator solutions and simple forms of apparatus are sold by various firms. They are very simple to work; a small amount of a standard solution of

chemical is added to a given amount of water and comparison is made with colour standards, either solutions or tinted glasses. The provision of apparatus for measuring the right degree of alkalinity is as necessary in its way as the provision of apparatus for measuring the residual chlorine in swimming bath water.

It follows from the statement that swimming bath water should be slightly alkaline, that the pH value should be somewhat greater than 7. At the other extreme it is most inadvisable to allow it to exceed 8 as the operation of the filters might be interfered with and complaints of smarting eyes occur. This gives an operating range of say 7.2 to 8.0. Since the normal tendency of pH is to diminish, due to the addition of acid forming substances in water treatment, most operators will probably prefer to work nearer the upper than the lower of these limits.

At a given pH value the amount of alkalinity may be high or low, depending on its nature. If it is low the pH will tend to change much more rapidly than when it is high. Hence, high alkalinity (due, for instance, to a high figure for temporary hardness of the water) has a kind of stabilising effect on the pH of the water, a condition to be desired, and it has recently been suggested that it should be artificially provided where it is absent naturally.

VII. OTHER DETAILS OF THE CONTINUOUS SYSTEM

Inlets for the filtered water

The purified and re-aerated water re-enters the pool usually at the shallow end. For this, the usual arrangement is to provide several submerged inlets, the number being determined by the size and shape of the pool, so that currents of pure water flow in the direction of the outlets, leaving no stagnant corners or "pockets" where impure water might linger without changing.

With the idea of keeping the water more uniformly chlorinated during its passage through the pool, some recent designs embody a number of inlets along the sides of the pool in addition to those at the shallow end. All these inlets are fitted with valves to control the flow, and an efficient method of supplying the pool should be arrived at by careful regulation of the valves. Circulation difficulties may lead to the adoption of a cross-wise system with supplementary inlets and outlets on opposite sides.

It is desirable, especially for large pools, to have both surface and bottom draw-off. By the introduction of suitable valves, draw-off can be taken either from the top or bottom, or both, as may be necessary.

It cannot be assumed that finality has been reached in the design of inlets, outlets, and circulation of water in a pool.

Meters and gauges

No filter plant is complete without some simple apparatus for indicating the rate of flow of the water delivered from the pump. Expensive meters are hardly necessary to measure either the quantity of water passing through the filters or the amount of wash water used, but it is necessary that the delivery of the pump should be checked from time to time.

Pressure gauges on the filters, showing when the head has increased to the point when washing is required, should be at least 6 inches in diameter, and test cocks and visible flow indicators are necessary to allow the operator to observe the washing of the filters.

Scales should be supplied for weighing chemicals and the chlorine cylinders, and every bath superintendent should keep a log book with daily records of the performance of the filters, and the result of tests.

The time has arrived when the running and maintenance costs of these filter plants should be recorded. Specifications should call for particulars of power consumption, as the possible lowering of the standards of efficiency, due to keen competition in tendering, can be determined only by comparison of the running costs of the different makes of plant.

Guarantees of the efficient working of Filter Plants

In drawing up a specification on which tenders for a filter plant are to be invited, it is desirable that the guarantees in respect of purification and heating of the water should be set out by the Engineer who is responsible for ordering plant. Since the main function of the filtration system is the maintenance of a clear water, the main guarantee will be in respect of clarity, although other points should also be covered such as chemical dosage, aeration and power consumption.

Clarity—One point which has to be decided is whether the guarantees should apply to the water in the pool, or to the water as it is delivered into the pool from the filter, or to both. Clearly, the owner of the bath is interested chiefly in the water in the pool, but the filtration system cannot be blamed if this water has been affected by pollution added after filtration. The filter manufacturer cannot be expected therefore to guarantee a given clarity in the body of the water without having some information as to the bathing load to which the guarantee would relate. However, it should not be impossible to give this information. Baths are, or should be, designed with a bathing load in mind and it should be possible, taking into account the turnover period and the inlet and outlet arrangements of the pool, to provide a filtration plant which would maintain a given clarity in the water in the pool, in the presence of that bathing load. If this clarity, as measured with the instrument described in Section IV, were fixed at 30 feet, then the occasional peak loads of bathers which are liable to occur could be accommodated without the clarity being reduced to less than, say, 15 feet. Prospective tenderers should be furnished, therefore, with information on the desired turnover period, the bathing load, and other relevant factors, in order that they may quote for a plant which would be capable of maintaining a stated clarity under these conditions. A guarantee test could then consist of observing the clarity during a day when the bathing load was approximately that expected as a normal maximum, and showing whether or not a clarity of 30 feet was maintained. It would be understood, of course, that the plant would be operated according to the maker's instructions and the necessary chemicals used in appropriate quantities.

Colour—Some guarantees call for a standard of colour of 15 on the Platinum Cobalt Scale. The usual colouring matter met with is due either to peaty water or to dye from bathing costumes. Treatment of the water with a coagulant before filtration and chlorination, will remove such colours and, unless there are special reasons, guarantees for reduction of colour do not appear to be necessary.

Chemical Guarantees—At present there is no evidence to show that water circulating through an efficient swimming bath purification plant deteriorates chemically to a degree which calls for precautions. Excessive alkalinity is to be avoided, but otherwise, guarantees of chemical content which involve expensive analyses appear unnecessary.

It is considered that if the conditions which have been stated as to the continuous sterilization of the effluent from the filters are maintained, the necessity does not arise for laying down bacteriological guarantees. A guarantee, however, should include the maintenance of not less than 0.2 parts per million of residual chlorine in the water leaving the pool. Where break-point chlorination is not used, then the water entering the pool should not normally contain more than 0.5 parts per million of residual chlorine, but it would be permissible to increase this limit where it is necessary in order to maintain break-point conditions. It is not considered, however, that the previous limits should be greatly exceeded in practice merely because they can be tolerated by bathers, but only if an increased amount of chlorine is accompanied by some very positive advantage.

Guarantees are demanded from time to time with regard to the quantity of wash water used as a percentage of the total quantity of water filtered. As the amount of washing varies according to the use and the pollution of the bath water, a guarantee of this description can only be valid if determined over a period of several months. Unless, too, an accurate meter is provided to measure the wash water, very little guidance can be expected from such a guarantee.

Guarantees of power consumption during a day's run are important.

Cleansing the bottom of the Pool

In a bath having a continuous purification system, it becomes necessary to remove any sediment which may be deposited on the bottom and sides of the pool.

The bottom is dealt with either by brushing with a special long handled brush, or by a suction cleaner running on rubber-tired wheels so that the slot is about half an inch above the floor of the pool, and fitted with a long handle or tow ropes. The suction cleaner should have a flexible hose which can be connected at the side of the pool below the surface of the water to the suction main of the pump, the flow from the pool outlet being either stopped or throttled down to permit the pump to exert a full suction on the cleaner. Scouring the sides of the pool is usually done with a brush, and any visible scum is removed by a long skimming pole.

Prevention of pollution entering the Pool

Many arrangements can be included in the design of a swimming bath to assist the work of the filters in keeping the water clean. The provision of a sufficient number of shower baths, foot baths and lavatories, will do much to prevent pollution, and a preliminary cleansing shower and foot-bath before the bather enters the pool should be made compulsory.

Scum troughs round a pool are to be commended. They are useful for bathers who spit and provide a means of withdrawing water continuously from the surface of the pool direct to the filtration plant. In this way any pollution which tends to accumulate near the surface, together with any dust which settles there, is removed quickly.

In the choice of a site for a bath, consideration should be given to one which is as far away as possible from smoking chimneys. Here it may be mentioned that the siting of baths alongside refuse incinerators, as has sometimes been done to secure cheap fuel, leads to constant trouble from dirt and dust.

Surrounds

If possible, the dressing arrangements should preclude the use of the bath surrounds either by bathers before removing their shoes or by spectators. These surrounds should slope away from the pool and drain to a gutter. The best material of which swimming bath surrounds should be made has never been agreed, and this ought to be the subject of a careful investigation. Most materials when wet become slippery to bare feet and many minor accidents occur in consequence.

Ribbed tiles are said to hurt the feet, while matting cannot be kept clean and becomes smelly. There is, perhaps, an opportunity for use of a ribbed rubber flooring in this position, but it is not certain that such material will adhere properly under the required conditions, or that it will be free from "spreading."

VIII. SUMMARY

1. Swimming bath accommodation in this country falls short of the demand and increased provision is still needed. In present circumstances it is not possible to meet this requirement, so that the maintenance of the purity of the water in existing pools, always a matter of great importance, is even more so now.

2. The danger of the transmission of disease by polluted water in swimming baths has sometimes been exaggerated, but some danger does exist. All public swimming baths should be filled with water which is not only clear, sparkling, and attractive, but which is also practically free from germs of disease and bacteria of excremental origin. This should apply in equal measure to those swimming baths which, although not public, are used by many persons, such as school swimming baths, road house baths, etc.

3. For swimming pools of artificial construction, both indoor and outdoor, which are filled with water from the main supply, the method of continuous rapid filtration combined with continuous sterilization and aeration, properly carried out with modern plant of adequate size, is capable* of keeping the water clear, sparkling and attractive in appearance, and of a bacterial purity approximating to that of drinking water. In addition, the method enables important economies to be made in the cost of water and heating.

4. This method of purification has advantages over the fill-and-empty system, even when refilling in the latter system is done daily. When the refilling is not done daily, the advantages of the continuous filtration-sterilization method of purification become overwhelming, and as daily refilling is usually financially impracticable (besides making, in some localities, large demands upon the water supply at inconvenient times), it follows that, except in very unusual circumstances, artificial bathing pools should always be equipped with adequate continuous purification plants.

5. To maintain water such as has been described in the second paragraph, many conditions must be fulfilled by the plant, and also by the staff who operate it. The following are especially important.

6. The period of complete circulation or "turnover" should be short, i.e., for covered pools up to 150,000 gallons capacity, it should not be more than 4 hours, except where a bath is little used. For example, if the pool contains 100,000 gallons of water, the pumps and filters should be capable of dealing with at least 25,000 gallons per hour. An even shorter turnover period would be an advantage, particularly at times of peak load.

* Provided, of course, that the pool is not hopelessly overcrowded—there is a limit.

For outdoor baths a somewhat longer turnover period, e.g., 6 hours, may be sufficient for normal loads, though recourse to night working of the filters may be necessary at times of very heavy bathing load. Where these are expected to frequent a shorter turnover period is advisable.

7. A rate of filtration of 200 gallons per square foot per hour has been widely adopted and, when properly controlled, has given satisfaction. This may not be the most economical rate, but to decide this it is necessary to have a quantitative method of measuring the clarity of bath water. A simple instrument for this purpose is described and illustrated, and it is suggested that the filters should maintain a clarity of 30 feet (measured with the instrument) with normal bathing loads, somewhat less clarity being tolerable for brief periods at times of very heavy bathing loads.

8. Where coagulants are used, the appropriate and precise dosage previous to filtration is necessary, and the water should always have a slight but definite degree of alkalinity—the pH value should exceed 7 but should not be greater than 8. Accurate dosage of coagulant and alkali is essential for the maintenance of the proper standard of clarity and appearance and for the avoidance of complaints of smarting eyes. Reliable and easily regulated dosing and mixing apparatus is therefore required.

9. Sterilization should be continuous for the whole period of bathing, and during the working of the filter plant. Where marginal chlorination is used, the dosage must be sufficient to maintain residual chlorine in the water of the pool itself. The concentration should nowhere be less than 0.2 parts of chlorine per million parts of water, or much greater than 0.5 parts per million. Water with this residual chlorine content, which has been efficiently clarified by filtration, will normally give satisfactory bacteriological counts approximating to drinking water standards. If break-point chlorination is used, it will be necessary to increase these residuals in order to be certain that the necessary conditions are continuous, but the concentration maintained should not be greater than necessary for this purpose and should not, of course, be such as to cause complaints of smell and smarting eyes.

10. The residual chlorine content can be easily and accurately determined by simple apparatus based upon the orthotolidine test, and similar apparatus can be used with equal facility for determining the alkalinity. If break-point chlorination is used, the method should be adapted to determine both free and combined residual chlorine, and the person making the test should be fully acquainted with the difference between them, and its significance. It is essential for the proper operation of the plant that tests should be made at frequent intervals, both of the effluent water from the filters, and of the pool water. Three times a day should be regarded as a minimum routine for such tests, and accurate records showing the number of bathers, the amount of water pumped, the chemicals used, residual chlorine content, and alkalinity should be kept.

11. Chlorination can be performed by properly constructed plants adapted either for the use of chloride of lime, or for solutions of chlorine, or for chlorine gas. Usually plants using chlorine gas will be found the most satisfactory. In these, dosage can be instantly adjusted and accurately measured, and there is no depreciation of chlorine strength during storage.

12. The success of the purification in such a system depends not only upon the design, sound construction, handiness and easy accessibility of the plant, but also upon the care and skill of those operating the plant. It is unfair to a bath superintendent and his staff to expect them to handle a purification plant

successfully unless they have been given sufficient instruction in the working of the plant and the use of the requisite instruments for testing the chlorine content and the alkalinity and clarity of water.

13. The foregoing paragraphs deal with the purification of water, but the prevention of unnecessary pollution entering the water greatly assists the operation of the purification plant. The following points require special attention.

14. It is essential to provide an adequate number of shower baths and foot-baths, placed at convenient points. These should be provided with soap and with both hot and cold water and an adjustable mixing apparatus. Before entering the pool, all bathers should take a shower bath as well as a foot bath.

15. Ample and convenient lavatory accommodation is also required. Separate accommodation for each sex should be provided at a pool which may be used for mixed bathing.

16. All side-walks surrounding the pool should be of sufficient width and should slope gently away from the pool to properly placed drains. The best material for such side-walks, which ought to be impervious, durable, easily cleaned, and not slippery for wet feet, has not yet been determined, and the subject deserves careful investigation. Slippery side-walks are the cause of many accidents.

17. Much avoidable dirt which finds its way into the water is carried to and from the surrounding side-walks by the shoes of bathers entering and leaving their dressing boxes and by the shoes of spectators. If possible, therefore, the dressing box arrangements should be such as to preclude the use of the side-walks by bathers previous to undressing, while other standing places or galleries should be provided for spectators.

Dressing boxes should be commodious, well lighted and ventilated, and their design and material should be such as to make cleaning and disinfection an easy matter. The bath hall should be well ventilated and lighted, and a plentiful supply of fresh air and direct sunlight should have access into it.

18. Removable steps which can be taken out of the water for cleaning are an advantage.

19. Costumes are the source of considerable dirt and discoloration in the pool. They should be washed, therefore, as well as towels, with hot water and soap, and sterilized after use. Costumes and towels should be provided in ample numbers so that there is a sufficient margin, even in times of rush attendance during a heat wave, to enable the laundry to wash, sterilize and dry every article. Merely to dry towels and costumes before re-use is a very bad practice which is likely to transmit infection.

20. Where filter plants have been installed, figures kept have shown large savings on working costs after all charges, including loan charges, have been met. This desirable financial position has usually been accompanied by increased popularity of the baths, no doubt partly due to the improved clarity and attractiveness of the water. Every day should be a clean water day.

21. It is suggested that byelaws based on the Ministry of Health Model Series VIIIA should be adopted and put into practice by Local Authorities in areas where privately-owned bathing pools are open to the public. The byelaws prescribe (i) the standard of purity of the water ; (ii) the provision of adequate and clean accommodation ; (iii) precautions to prevent accidents ; and (iv) the regulation of the conduct of persons using the baths.

22. In the description of filtration plants in Section IV, emphasis has been placed on the desirability of giving full consideration when a specification for plant is being drawn up, not only to the first cost, but to the questions of efficiency and the cost of running.

The design of these installations has not attained finality, of course, and further progress can be made only if makers are encouraged to produce plant which will show low running costs and will require as few repairs and renewals as possible. Progress will be slow, however, unless proper attention is given to the question, and the first need is the keeping of adequate records of running expenses and repairs.

Useful records are generally found in the Bath Superintendent's Office as to the number of bathers etc., but there is also the need for a detailed record of the performance of the filtration plant. In this connection, the great value must be emphasized of automatic recorders of the operations of the plant. It is suggested that "log books" should be kept, in which figures and facts relating exclusively to such installations should be entered daily. From these figures, a useful abstract can be prepared at the end of each year or bathing season.

A daily log might record, among other items :—

- (1) The hours during which the plant is working.
- (2) The washing of each filter unit and the time required.
- (3) The power consumed during each 24 hours, for the filters only.
- (4) The weight of each chemical used, including the liquid chlorine gas.
- (5) The amount of make-up water taken from the mains.
- (6) Notes on the alkalinity, clarity, and chlorine content, of the bath water.
- (7) Notes on any unusual condition observed in the water in the bath, and of any defects or difficulties experienced with the filter plant.

From such logs, it should be possible to calculate the cost of water, power, chemicals, chlorination, and maintenance per million gallons of water filtered, in addition to collecting valuable data relating to the process of bath water filtration.

The Baths Superintendents' Association take a great interest in all problems connected with bathing, and if the Association could take the lead in devising a satisfactory model log sheet, this might add greatly to the usefulness of the work of the Association.

The Chairman and other members of the Committee wish to express their appreciation of the research and enquiry carried out by Dr. A. Key, the Senior Chemical Inspector of the Ministry of Health, by which the inclusion of the most recent ideas regarding the treatment of water has been made possible.

We also wish to record our thanks to the Secretaries, firstly Mr. F. P. Gregory and later Mr. P. A. Cooke, for all the care they have bestowed on the work of the Committee.

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