WRC **WATER RESEARCH CENTRE**



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# DISINFECTION BY CHLORINATION IN CONTACT TANKS

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# 1. INTRODUCTION

This report summarises the findings of a literature survey by the WRC and a subsequent desk study carried out by the British Hydromechanics Research Association (BHRA) under contract to WRC on the hydraulic performance of chlorine contact tanks. The studies by WRC and BHRA (1) identify the important factors which promote equal distribution of the chlorine dose and which prevent rapid passage of the influent water through the contact tank, such as short-circuiting.

Observations from WRC studies on the inter-relationship of chlorine dose and contact time and on the potential problems resulting from long term post-chlorination contact are presented in Appendix A.

# 2. HYDRAULIC PERFORMANCE STUDIES

Four major problem areas in contact tank design have been identified:

a) initial injection of the concentrated chlorinated water into the treated water flow;
b) introduction of treated and chlorinated water into the contact tank;
c) design of the contact tank to minimise dispersion of the influent water;
d) difficulties in providing a measure of the dispersion of the influent water that can be related to the kinetics of disinfection by chlorine.

## 2.1. INJECTION OF CONCENTRATED CHLORINATED WATER DOSE

It is important that the dosed water is rapidly distributed over the total cross-section of the main treated water channel. Slow distribution is particularly ineffective where a channel feeding parallel tanks distributes water through a simple tee-branch, since the hydraulic flow pattern can determine that very little of the chlorine passes to one of the tanks.

The BHRA study criticises injection from a small pipe introduced at right angles to the flow as far as the centre line of the main channel. Improvement in the speed of distribution can be achieved by taking the small pipe about two thirds of the distance to the centre line, or by making use of a wake effect provided by bluff bodies downstream, or by the injection pipe itself. The study shows that there is a general lack of information on the subject of effective dosage into channels and pipes.

## 2.2. INTRODUCTION OF THE CHLORINATED TREATED WATER INTO THE CONTACT TANK

The major problem at this stage of treated water flow is the need to produce a more uniform flow across the channel in as short a distance as possible. This is usually achieved by rapid reduction of the excess energy in the incoming flow to small scale turbulence.

An example of poor inlet design is that of a pipe aligned along the longitudinal axis of the first bay in a contact tank. With this arrangement, the minimum retention time in the bay can be reduced to one twentieth of the theoretical residence time. This has been attributed to the persistence of the jet flow induced by the pipe inlet for some five tank widths or depths, whichever is the greater (2, 3).

Studies reported in the literature (4, 5) favour an inlet design incorporating a baffle to break up the jet and a further perforated baffle to smooth the flow. It is important to balance the hydraulic losses through baffle action with the smoothing effect on the flow pattern and to consider the relative efficiency of perforated and impact baffles in forming small eddies. In the UK, one way of achieving this baffle effect is to introduce the inlet pipe at right angles into the bay. The literature studies (3) commented on above favour narrow bays in this case to give better performance in flow distribution. However, it often appears that little thought is given to design at this stage, although considerable benefit could be obtained if a more rapid attainment of small-scale turbulence resulted in a reduced site area for the contact tank.

## 2.3. LAYOUT OF THE CONTACT TANK

A rectangular tank is preferred because the circular type will cause greater dispersion and more short-circuiting (6, 7). Maintenance of a uniform flow pattern and best use of the water volume in the tank is provided by a long narrow channel (Figure 1). Although this shape is hydraulically efficient, it is not the most economic for construction, nor a convenient unit in the plant layout. Although the least cost structure is square in plan area, channel length can be achieved by using baffles to give a serpentine flow pattern. These baffles need not be part of the load-bearing structure.

A recommendation is given (6) for a total channel length-to-width ratio of 40:1 to prevent increased dispersion in flow. BHRA deduced from known flow patterns round $180^{\circ}$ short radius bends that a bay length-to-width ratio of 10:1 would be acceptable but still provide near uniform flow in half the length of each bay. Flow separation at the port between bays (area B in Figure 1) can be prevented by incorporating vanes to guide the flow round the direction change (8). This modification reduces headloss through the tank and brings the minimum residence time closer to the theoretical retention time. Studies of the dispersion of tracer in flow round $90^{\circ}$ bends (9) indicated increased rates of dispersion and therefore reductions in the minimum residence time with wide channel widths, short bay lengths and shallow depths of water in the bays.

Considerable evidence is presented in previously quoted references and in the report (1) which qualitatively supports long narrow serpentine channels, but a practical assessment of the best serpentine layout was not achieved because of non-comparable inlet effects in the investigations. There is also the question of whether the problems in the design of serpentine channels are any less difficult to solve than those involved in distributing fractions of the total flow through shorter, straight channels from a manifold. The fitting of a contact tank design into the total treatment plant layout still requires much thought if effective use of the tank volume is to be achieved along with linear flow rates sufficient to prevent deposition of sediment. Versatility in use to cope with peak and minimum demands from supply and to allow for cleansing should also be considered. The design of the outlet, which can reduce the effective tank volume, has not received due recognition.

## 2.4. RESIDENCE TIME DISTRIBUTIONS

One goal of the study was to relate a measure of the distribution of residence times to the dimensions and the operational flow rate of the contact tank. Lack of sufficient detail in reported investigations and the influence of varied inlet devices made the achievement of that goal impossible.

The viewpoint is stressed in the BHRA study that complete characterisation of the distribution of residence times is necessary. When this information is combined with kinetic data on disinfectant action, the cumulative disinfectant that has reacted during its passage through the contact tank will reflect the potential for bacterial kill within a volume of dosed water. The BHRA report examines the variance of the distribution of residence times and its related parameter, the 'chemical engineering dispersion index', as methods of characterisation (10). Some test results in the report, however, indicate that the usefulness of this dispersion index may be restricted to well-designed tanks in which the volume used for flow-through approximates closely to the total tank volume.

This viewpoint emphasises the importance of knowing the variation of residence times about the mean. Knowledge is also required of the relation of the mean and/or minimum residence time to the theoretical contact time calculated as the occupied tank volume divided by the volumetric flow rate.

In practice, it is also important to know the minimum residence time to assess the risk of bacterial passage, and the maximum residence times in order to assess the potential for the reaction of chlorine with other contaminants in the water. Characterisation in terms of a minimum residence time and a measure of the spread of residence times may be sufficient if the techniques used give sufficient reproducibility. These residence times must be related to a batch test of the disinfectant efficiency of a particular dosage chlorine against contact time.

# 3. CONCLUSIONS

There is a considerable lack of detailed knowledge on the design of baffled contact tanks. Existing knowledge of the design of dose injection devices and of inlets to the tanks is not always implemented. Prediction of the minimum residence time and of the spread of residence times in a given contact tank design is not yet possible. Therefore the disinfection efficiency of a contact tank cannot at present be predicted at the design stage.

Model studies to provide a more satisfactory basis for design could be carried out, but the impetus must come from studies of the possible cost/benefits from the provision of a smaller hydraulically efficient contact tank with improved disinfection efficiency and from the realisation that poor design incurs risks of bacteria and viruses surviving beyond the contact tank or impairment of water quality when excessive chlorine doses are used.

Further design studies and experimental work will be necessary before firm recommendations can be made for improving the design and performance of chlorination contact tanks. As indicated in the Appendix, chemical aspects will impose limits on the maximum and minimum sizes of contact tanks.

The control of any potentially harmful chlorinated organic substances produced during chlorination could become an important factor in the operation and design of chlorination contact storage equipment as outlined in Appendix A.

## APPENDIX A - CHEMICAL ASPECTS OF DISINFECTION

### A.1. DISINFECTION IN THE CONTACT TANK

The WRC has been investigating the disinfection process and the influence of various contaminants in treated water on its effectiveness against bacteria and viruses. For chlorine as a disinfectant, several recommendations are found in the literature. Morris (11) recommends a level of 1 to 2 mg/l free chlorine residual with a contact time of 10 to 30 minutes as an overall treatment. British writings suggest a chlorine residual of 0.1 to 0.2 mg/l free chlorine after a contact time of 30 minutes (12). The Swedish Medical Commission has recommended that the product of free chlorine residual (mg/l) and contact time (minutes) should be greater than 6 at pH values below 8.0 or greater than 12 at higher pH values (13).

Hall (14) presents a discussion of the complex chemical kinetics of disinfection and an assessment of the necessary corrections to the kinetics for different temperatures, pH and impurities that react with the disinfectant. Achievement of disinfection is equated to the inactivation of bacteria resulting from exposure to a cumulative amount of disinfectant, which is expressed as the integrated product of time and concentration of disinfectant species. It would seem that, in principle, the economics of bacterial and viral inactivation can be presented as a balance between cost of chemical dosage and cost of time for reaction.

In practice the consequences from excessive reaction with other impurities, such as the conversion of ammonia to nitrogen tri-chloride, can impose limitations on disinfectant concentration and operating pH which restrict the optimal choice. Another practical requirement for prevention of corrosion and/or plumbosolvency poses a problem of where to adjust the pH by, say, lime addition. Addition before the contact tank imposes another restraint on the optimal choice of time and concentration. There are certain pH values at which chlorine disinfection should not be contemplated, for example >pH 8.5. An advantage therefore exists in dosing chlorine prior to an alkaline adjustment in pH before entry to the distribution system. However, alkaline addition after disinfection allows the criticism of contamination being allowed to enter into a less effective disinfectant regime. An accurate assessment of the required range of contact times for treated water cannot readily be provided when the source water contamination is variable. Automatic chlorine dosing based on chlorine residual control will largely cater for this.

Over the last few years there has been considerable concern about the production of chlorinated organic substances during disinfection of water with chlorine and the health risks involved (15). In brief, the situation is that chlorinated organic substances such as haloforms, and in particular chloroform, are produced in a side-reaction during the disinfection of water by chlorine at the treatment works. There is further evidence that chlorine reacts with humic acid to produce such compounds. Although some of these by-products are carcinogenic to animals, the precise health risks involved, if any, are not clear. However, it is likely that some control over their formation during disinfection will become desirable; indeed, in the United States a standard for chloroform has been proposed already.

Research is under way in several organisations aimed at reducing the formation of these undesirable substances while maintaining the very great benefits of chlorination. It is possible, therefore, that the production of undesirable by-products will become a factor to be considered in the operation and design of chlorination and contact storage equipment.

## A.2. POST-CONTACT DISINFECTANT EFFECTS

Reaction with chlorine continues beyond the confines of the contact tank. Although normally used residual concentrations and the demand exercised by the distribution system ensure slow rates of reaction, excessive post-contact exposure of supply water to chlorine can cause quality problems. Reduction of the contact time by operation of the tanks with a shallow depth can lead to ineffective disinfection in the contact tank and deposition of material capable of protecting bacteria and viruses from further disinfection in the supply tanks. Contamination of the supply is then possible.

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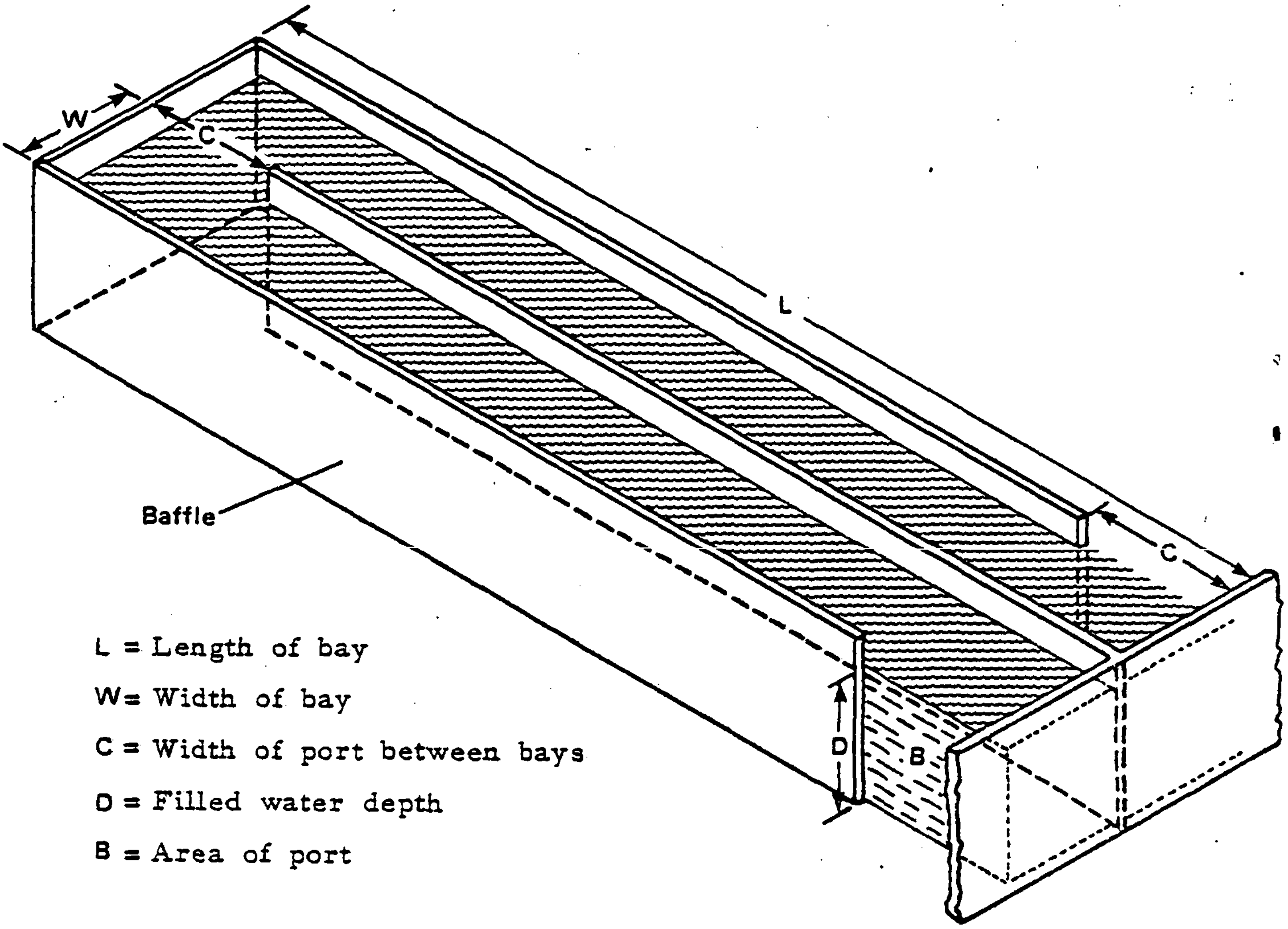


Figure 1. Diagram of a baffle arrangement in a serpentine channel