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INVESTIGATION INTO REQUIREMENTS FOR RESEARCH IN SURFACE WATER TREATMENT IN SOUTH AFRICA

Report to the
WATER RESEARCH COMMISSION
by the
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UNIVERSITY OF CAPE TOWN

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INTRODUCTION

The Water Research Commission requested the University of Cape Town to survey problems associated with treatment of potable water as regards water quality, design operation and control of water treatment works.

From discussion with the Water Research Commission it was decided that the survey should be focussed primarily on the larger water supply authorities. It was also agreed that the survey should be carried out by way of discussions with officials of these authorities and by visits to a number of the larger treatment works. Although the orientation of the survey was towards the larger authorities, the problems of smaller authorities are briefly addressed.

The principal water treatment authorities in South Africa were visited. The visits included discussions with senior officials of the authorities and site inspections of their major water treatment works. Authorities visited included Cape Town City Council; Department of Water Affairs, Pretoria; OFS Goldfields Water Board, Bothaville; Port Elizabeth Municipality; Rand Water Board, Johannesburg; Umgeni Water Board, Pietermaritzburg and Western Transvaal Water Treatment Company, Stilfontein.

To initiate an exchange of views discussions were conducted regarding treatment problems experienced, control and management difficulties, problems envisaged in the furture and research needs envisaged by the authorities. Initial response in discussions was generally one of (1) treatment works are operating satisfactorily with minimum problems, and (2) there are no basic research needs - this has already been carried out in Europe and the USA; what is required is simply local implementation of these findings.

On detailed discussion it emerged that all the authorities were in fact experiencing treatment problems and were carrying out pilot scale investigations in an effort to resolve these. Typically,

1. Removal of dissolved organics using activated carbon.
2. Sludge dewatering using membrane filtration.
3. Algae removal by dissolved air flotation prior to filtration.
4. Chemical methods for algae control, both pre- and post-treatment.

Discussions also indicated a divergence of attitudes between the various authorities. On the one hand there were those that expressed a prejudice to implementing new technology on the basis that this was unproven in the local scenario - particularly with regard to removal of suspended solids and colour. On the other hand there were those that expressed the philosophy of applying well established (but very expensive) European technology which has been developed for treatment of highly polluted waters in a relatively sophisticated society.

Site visits to major water treatment plants indicated a number of problem areas, as seen by the investigators, including:

1. Instances of misapplication of existing technology to coagulation and flocculation.
2. Instances of a lack of flexibility in treatment plant design to deal with both seasonal algal blooms and taste and odour problems occasionally arising from these.
3. Instances of application of extremely expensive and sophisticated European technology where a more appropriate technology possibly could suffice.
4. A general over-conservatism in design, probably as a result of insufficient preliminary laboratory and pilot scale investigations.
5. Very few treatment plants employed effective stabilization. This arose from two sources. Firstly, for some of the older treatment works effective stablization to a positive calcium carbonate precipitation potential was not possible without major extensions to the works. Secondly, with many of the authorities there was a lack of awareness of the economic consequences of distributing an unstabilized water.

These findings are dealt with in more detail below. The presentation will be broken down broadly into problems and research needs associated with

- treatment of waters for municipal supplies, and
- control and management of treatment works and water catchment areas.

TREATMENT OF WATERS FOR MUNICIPAL SUPPLIES

(Ranked in order of importance as perceived by the investigators)

1. Algae removal

Both coastal and inland waters in South Africa are receiving an increasing nutrient load from municipal and industrial waste discharges and agricultural run off. Algae was present in the influents to a number of treatment works; most treatment works visited showed evidence of algal growth within the treatment units; often there was visual evidence of algae in the filtered water. The causes for algal growth in the treatment units probably are due to the following factors:

(i) The presence of nutrients in the raw water, persisting even in the final stages of treatment, albeit in minute concentrations. Where steps are taken to eradicate algae from the influent to the works, via say prechlorination or preozonation, death and lyses releases nutrients for further algal growth back into solution.

(ii) The countrywide high incidence of solar radiation and high seasonal temperatures.

Present methods for *controlling* algal growth are:

- Covering the units to reduce the light intensity: This has been found to reduce the problem but not to eliminate it as some algae require very low light intensity for growth particularly if the water temperatures are relatively high.
- Chlorination/ozonation of the raw water. Chlorination presents a problem in formation of THM, tastes and odours. Two authorities have changed to ozonation, instead of chlorination, and there are others that contemplate using chlorine dioxide. However it seems that there is little quantitative information on the effectiveness of these procedures in controlling algae in the system in conditions of high solar radiation and high temperatures.

Current processes used in South Africa for algae removal are direct filtration for low turbidity waters (<15NTU) and a two stage process of dissolved air flotation (DAF) with deep bed filtration for medium turbidity waters (15 < NTU < 50 to 100). Where algae are associated with high turbidity waters (NTU > 50 to 100) colloidal turbidity removal is insufficient using DAF process, in these instances flocculation/sedimentation/filtration or flocculation/sedimentation/DAF/filtration are employed.

American research experience indicates that a feasible alternative to DAF is coagulation followed by deep bed filtration. However, algae removal by filtration may result in unacceptably short filter runs.

Requirements:

From the observations above it would seem that research is required into:

- Removal of algae in the raw water itself.
- Factors controlling algal growth in the treatment system, and
- development of measures chemical, physical and operational that may counter such growth.

- The use of coagulation with deep bed filtration, for algae removal, both alone or as an alternative to DAF in the flocculation/sedimentation/DAF/filtration system.

- The use of ultra-filtration, micro-screening and cross flow microfiltration for algae removal.

2. Inorganic sludge dewatering and disposal

The conventional water treatment process produces a sludge waste stream in the range 1 to 3 % of the water production. The sludge varies in concentration from 0,5 % to 1,5 % dry solids. Present methods of inorganic sludge dewatering in South Africa include lagooning, sludge drying beds, vacuum assisted sludge drying beds (RSDS), centrifuges, filter presses, cross flow microfiltration and others. In areas where land is plentiful lagooning appears to be the method favoured. Disposal of the dewatered sludge is usually to landfill. However all authorities expressed concern that as sludge quantities increase and shortage of land becomes critical there will be an urgent need to reduce the volume of sludge produced and to find alternative methods of disposal.

Requirements:

- Various water treatment authorities and research organizations are investigating the problem of sludge dewatering and disposal. Central coordination of their investigations and orderly dissemination of the findings in terms of sludge characteristics would be to the benefit of the whole water industry.

- Methods of inorganic sludge characterisation.

- Characterisation of inorganic sludge in terms of raw water quality, coagulant used.

- Specific investigations are necessary into economic dewatering processes in terms of the sludge characteristics.

- Specific investigations appear necessary into alternatives for sludge disposal, recovery of metal coagulants, brick production and their commercial uses.

3. Conservative aspects of design

The area of design most affected by over-conservatism is in removal of suspended solids and/or colour, that is, in the (i) design of the unit processes to effect coagulation, flocculation, sedimentation and filtration, and (ii) selection of a system to effect these processes.

Usually the system adopted to effect coagulation, flocculation, sedimentation and filtration comprises four separate process units. The units are often designed on a rule of thumb basis. Sedimentation units, of the horizontal or radial flow type, usually are designed for a loading of between 0,8 and 1,5 $m^3/m^2/h$. Filters are commonly of the shallow sand bed type with a design loading of about 5 $m^3/m^2/h$. However, it would appear from the literature that technological advances have taken place such that loadings of 2 to 10 times greater can be applied in each of these processes. Some authorities voiced an interest in the application of these high rate units - particularly in (i) the possible financial benefits, and (ii) their application to uprating existing treatment works.

With regard to selection of a system to effect the four processes involved in suspended solids/colour removal, current technology indicates that the four unit system above can be replaced by either three or two unit systems. The three unit system includes upflow sludge blanket clarification in place of separate flocculation and sedimentation units. Comparatively few of these have been installed in South Africa. However, practical experience has shown that relatively high loading rates, from 2 to 15 $m^3/m^2/h$, can be attained.

A current advancement in this area involves the recent development at Iowa University of a two unit (coagulation and direct filtration) system. The system comprises *deep* bed filters replacing the flocculation, sedimentation and filtration units. It has been operated successfully (for low turbidity waters) at high loading rates varying from 8 to 30 $m^3/m^2/h$ with substantial reduction in coagulant chemical dosage requirements. Although the system has been successfully used for turbidity, colour, algae and organism removal in America, its feasibility in South Africa, with highly turbid inland waters and highly coloured coastal waters, is unknown.

<u>Requirements</u>:

Selection of the processes and system to be used in a treatment works has long lasting implications regarding capital and running costs. However, there is a definite lack of guidance in South Africa regarding the use of high rate processes and systems under local conditions, particularly with regard to :

- The characteristics of raw waters most suitable for high rate processes.
- Rapid mix and flocculation requirements related to raw water type and coagulants.
- Types of coagulants and their effects on subsequent units in the process chain.
- Selection of high rate systems most suitable for particular waters.
- Flexibility of the systems and comparative costs.

4. Tastes and odours originating from algae or bacterial growth

Over the past year, two of the treatment authorities visited have experienced odour in the treated water. The odour was traced to the chlorination of certain algal species. In both cases the problem was of relatively short duration but can be expected to recur sporadically. Other water supply authorities have experienced taste and odour problems as a result of bacterial growths in the reticulation system. One authority traced the problem to the use of a particular flocculant. Virtually every authority expects that these problems will increase in the future.

Requirements:

Information on the causes that lead to odour development in the treated water is meagre particularly of a kind applicable to South African conditions. There appears to be justification for research into

- Causes, and methods of control, of odour development in the treatment process and the reticulation system under South African conditions.
- Treatment strategies to economically deal with these short term problems, and
- identification of treatment systems which also remove precursors to taste and odour problems.

5. Inadequacies in treatment works design

In general the larger plants visited appear to be well designed but conservative. The conservative aspects are dealt with in (3) above. Difficulties that have arisen, as a result of design features, are more commonly found in smaller installations. Shortcomings observed were:

- Inadequate provision for the number of dosing chemicals and associated rapid mix requirements.
- Inadequate provision for flocculation to suit the type of sedimentation tank installed.
- In the smaller water works the majority of designs make no provision for stabilization of the water before discharge to the distribution system.
- Inadequate provision in the design to cope with variations in raw water quality either seasonally or over the design period.

These situations appear to arise from the following:

- Inadequate appreciation of the function of the different unit processes and of the parameters controlling their performance.
- Inadequate information on the raw water quality, its seasonal variation and future trends. This situation may be exacerbated where there is an urgent need to complete the project.

Requirements:

Although there is extensive literature on all aspects of water treatment and unit process design, the information is not readily accessible to designers and its relevance to South African conditions is not clear:

- There is an urgent need for manuals of practice setting out the design considerations, process requirements, applicability of each type of unit process, preliminary testing requirements and design techniques all within the South African context; such manuals would help to avoid many of the pitfalls now commonly encountered.

6. **Organic colour removal**

Humic acids are the usual cause of organic colour in waters from the Table Mountain sandstone region. The quantities of humic acid can vary significantly between locations and also vary seasonably at a location. Usually removal is achieved by addition of alum at a low pH, sometimes with polyelectrolyte addition. Traditionally horizontal flow sedimentation tanks are installed. One authority has installed an upflow (sludge blanket) system for the removal of organic colour in association with turbidity. Operational experience with this system using a cationic polyelectrolyte as coagulant aid has indicated that the mean alum dosage can be reduced and need only be applied intermittently.

It would appear that knowledge of the treatment of organic coloured waters is still empirically based, there is very little real understanding of the chemistry of these waters, the possible influence, for example, of the colourless fulvic acids on the chemical response of these waters to coagulants. Only one authority traces the removal of the fulvic acid in addition to the humic acids.

Requirements:

Research is required into:

- Mechanism of humic and fulvic acid removal by means of metallic salts (e.g. alum) with and without polyelectrolyte addition.

- Application of alternative colour removal systems to the traditional alum-polyelectrolyte addition/flocculation/sedimentation/filtration processes. In particular, *upflow sludge bed clarification and deep bed filtration.*

- Optimization of liquids solids separation unit(s), i.e. flocculation and either sedimentation or cross flow microfiltration or dissolved air flotation, upflow sludge blanket clarification and deep bed filtration.

7. Manganese and iron in association with organic colour

Organic colour is removed with aluminium salts at a pH below 7; in contrast manganese and iron removal require the oxidation of the divalent metal Mn^{2+} to Mn^{4+} and Fe^{2+} to Fe^{3+} and their precipitation at a pH 8,0. Furthermore, manganese precipitation is autocatalytic so that the process is most effectively carried out in fixed bed processes such as filters. Consequently the removal of colour, manganese and iron in a single sedimentation unit is not possible. This problem has been found with certain dams when the water level is low or where water is drawn off from the hypolimnion, so that after disinfection (using chlorine) and stabilization (to a pH $\sim$ 9,0) precipitation of manganese and iron minerals has caused pipe narrowing of trunk water mains.

Although the problem has not been generally observed in South Africa, it is troublesome and merits study.

Requirements:

A research need is indicated into:

- Efficacy of manganese and iron removal from stabilized, chlorinated waters using various oxidants (eg. chlorinated compounds, peroxide etc) and sand filtration.

8. Appropriate technology

In the past the surface waters in South Africa have been relatively unpolluted and a conventional five stage (coagulation, flocculation, sedimentation, filtration and disinfection) water treatment process has been employed generally. Some treatment authorities however are experiencing problems arising from the presence of algae and have noted an increase in dissolved organics in the raw and treated water. This problem is likely to increase and become more widespread in the future.

Requirements:

Overseas experience indicates that a seven stage (ozenation, activated carbon filtration, coagulation, flocculation, sedimentation, filtration, disinfection) treatment process may be appropriate; this would have financial and operational implications; there appears to be room for development of technologies appropriate to the South African milieu.

9. **Stabilization - Corrosion and Aggression and Scaling in small systems**

The majority of small water works do not stabilize their treated water before distribution. There appears to be a lack of appreciation of the phenomena of corrosion and aggression. Also because the effects often take a number of years to become apparent, the connection between the stability of the water and its corrosive and aggressive effects are lost.

Pipe narrowing due to calcium carbonate scaling is a problem in many areas particularly where underground waters are distributed. Information to the Authors on this aspect is principally circumstantial, from requests for assistance from Commercial housing firms and "provincial" agencies. From discussion there is a general lack of understanding of the reasons for the pipe narrowing.

Requirements:

Technology for the control of aggression, corrosion and pipe narrowing is sufficiently developed that most of those problems can be controlled, however,

- there appears to be a need for improved technology transfer. Such transfer, to be of national benefit, should be pitched at different levels of users, engineers, chemists and commercial firms etc. in the water supply field.

10. **Stabilization - effectiveness in control of corrosion and aggression**

Some of the bigger municipalities are addressing the problem of corrosion and aggression in one or two ways:

- Stabilizing the water, and/or
- modification of pipe material or component materials.

Where stabilization has been implemented there is still inadequate attention given to assessing its effectiveness. There is no information available at present to provide guidelines as to whether stabilization only or stabilization plus material modification is required. In large reticulation systems invariably the alkalinity and pH will change as the water moves through the system. Usually alkalinity and pH will increase in cement pipes and alkalinity and pH decrease in ferrous pipes. Little attention appears to have been given to these phenomena and their effects on corrosion and aggression in different parts of the system. For example, in large systems there may be justification for secondary points of restabilization, and so on.

Requirements:

- There is a need to investigate existing reticulation systems transporting stabilized water to assess quality changes in the water with distance from treatment works.

11. Aggression of soft "brown" waters

Conveyance of these waters in concrete conduits has a history of apparently random attack - some systems show marked attack, others very little. An hypothesis that explains the reason for this is at present being tested: Briefly the humic acids cause the apparent $CaCO_3$ solubility product to be high but,contradictorily, if carbonation *has taken place*, dissolution does not readily occur, i.e. the response is as if the apparent $CaCO_3$ solubility product is low.

It is hypothesized that once carbonation of the pipe walls has taken place (accelerated by high CO_2 partial pressure) then the acid humic waters will not attack the walls because the solubility product of $CaCO_3$ apparently is small due to the effect of the humic acids. Conversely if the pipe is not carbonated, $H_2CO_3^*$ combines with the free lime in the mortar to form $CO_3^=$ and Ca^{++} which does not precipitate because the solubility product is high due to the effect of the humic acids.

In view of the current importance in South Africa of transporting soft (humic) waters through cement lined tunnels between catchments, this aspect warrants investigation.

Requirements:

- an investigation into the rate of dissolution of cement mortars (with and without carbonation) in humic waters.

CONTROL AND MANAGEMENT PROBLEMS

1. Control of the total water environments

Operation of sewage treatment works normally is vested in the local authority in whose area the effluent originates. These authorities are required to comply with legislation governing the qualifications of staff in control of the sewage works and the standard of effluent discharged to rivers. River water quality monitoring and policing of the regulations is done by the Department of Water Affairs. Water treatment works situated downstream from effluent discharge points frequently are under the control of different authorities.

A number of the authorities visited considered that it would be advantageous if the treatment of sewage and water, and control of discharge to the river as well as the task of river quality monitoring for each river system or catchment were vested in a single authority. One authority envisaged a system of total water management of a catchment similar to that employed in the United Kingdom.

2. **Guidance standards on maximum allowable THM in treated water**

Some overseas countries have formulated standards regarding the concentration of THM in potable water. In South Africa no such standards or guidance exist. Some of the treatment authorities drawing water from the Vaal River voiced a desire for guidance in this regard.

3. **Periodic changes in raw water quality**

Some treatment works experience control problems when sudden changes in raw water quality occur. This problem most commonly occurs on treatment works which draw raw water from rivers that receive a high level of treated effluent or during storm periods. Often the first intimation the treatment works operators have, that the influent quality has deteriorated, is several hours later, when the quality of the treated water itself deteriorates. To overcome this time delay, where waters are subject to rapid change, some treatment works have devised schemes where the floc quality is examined at regular intervals, in one instance, every twenty minutes. Some treatment authorities believe that there is a need for some formal type of testing procedure to forecast the occurrence of this type of problem.

4. **Measurement of algal concentrations**

One authority stated that current methods of determining algal concentrations and identifying the types of algae are cumbersome and time consuming and suggested that attention should be given to developing simplified practical techniques.

5. **Laboratory analysis of low pH, low alkalinity waters**

In the coloured, low alkalinity and low pH waters of the eastern and south eastern seaboard regions of South Africa measurement of alkalinity (both before and after colour removal) by conventional means is subject to gross errors. Alternative methods of chemical characterization of these waters have been formulated but are not in general use. Current practice gives rise to gross errors in chemical dosage estimation and difficulties in process control.

A gap in technology transfer is indicated.

CLOSURE

In summary the problems arising in the water supply industry in South Africa can be categorized as follows:

1. Technology is available but often is not disseminated adequately and there are

questions of its appropriateness to South African conditions.

2. There is a need for effective evaluation of existing technology and transfer of such technology per design, operation and controls by means of manuals of practice oriented to designers, chemists, operators etc. respectively.

3. There is a need for enquiry into comprehensive environmental control of individual catchment areas.

4. A number of specific research areas and tasks have been identified in 1 to 11 above which merit attention.

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