Longterm experience in the use of polymeric coagulants at Umgeni Water

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Abstract Umgeni Water, the bulk treatment authority for the cities of Durban and Pietermaritzburg changed from inorganic coagulants to synthetic polymeric coagulants at its various works in the mid 1980s. The advantages and disadvantages experienced with the new chemicals are discussed in detail in the paper and the changes to test procedures necessary are highlighted. The polymeric coagulants were found to produce good quality water in line with international norms but their unsuitability for enhanced coagulation may preclude their use on some of the works where organic enrichment is becoming a problem.
Keywords Coagulation, enhanced coagulation, polyelectrolytes, polymeric coagulants.

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Introduction

Umgeni Water (UW) is a statutory water board or bulk water treatment authority established in 1974 and situated in KwaZulu Natal on the Eastern Seaboard of South Africa. UW was originally established to supply potable water to the major cities of Pietermaritzburg and Durban. The original areas of supply have however subsequently been extended several times and the supply area is now greater than 21 000 km^2 with a supply population in excess of 7 million. Durban and Pietermaritzburg together now use nearly 1000 Ml/d of water, the bulk of which originates from 3 large dams situated on the Mgeni River which is the central catchment of the treatment authority area. Supplies to the Durban/ Pietermaritzburg region are catered for by 3 large works and a number of smaller ones. A number of smaller rural schemes and works exist for various country towns within the supply area and a certain amount of inter-catchment transfer takes place to augment the supply to the main catchment. Most of the 14 works operated by UW were changed over to polymeric coagulants in the mid 1980s and operating data is available for more than 10 years.

Motivation for change over to polymeric coagulants

The original motivation for changing over to polyelectrolytes was an economic one. Tests carried out at the time of introduction of the synthetic coagulants to the market demonstrated that the cost of coagulation using the polymeric coagulants could be significantly lower than when using inorganic coagulants such as aluminium sulphate or ferric chloride.

Initially there was concern as to the safety of polymeric coagulants and detailed health information was requested and obtained from the initial supplier. Based on the EPA approval presented it was decided to go ahead with the use of polymeric coagulants on a trial basis at one works. This was successful and in time was extended to other plants.

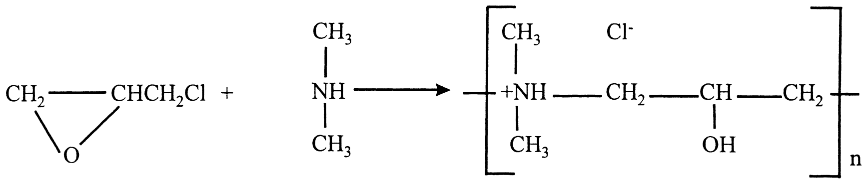
Polyelectrolytes and polymeric coagulants

The term polymeric coagulants has been used to distinguish the cationic polyelectrolytes which behave as primary coagulants from the polyacrylamides which act as floc builders. The polymeric coagulants under consideration in this paper consist primarily of blended or unblended cationic polyamines and polyDADMACS which are described below.

Polyamines

Epichlorhydrin-dimethylamine (epi-DMA) is the common name of a polyamine-type polymer formed by the step-reaction synthesis of 2-hydroxi-3-dimethylaminopropyl, a monomer formed by the reaction of epichlorhydrin and dimethylamine. The process tends to produce a linear rather than a branch chain or cross-linked quaternary ammonium polymer of low to moderate molecular weight.

Epichlorhydrin + Dimethylamine → Polyamine

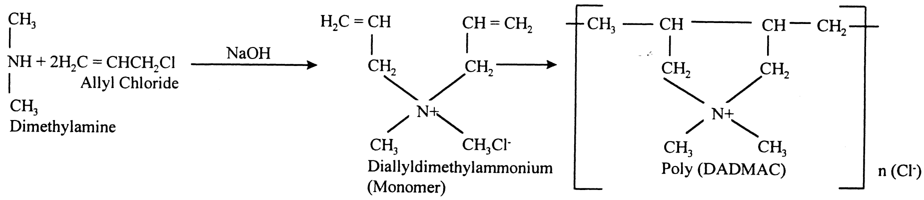


The molecular weight per monomeric unit is 102 and products of this type tend to have molecular weights of approximately 750 000.

PolyDADMAC

The other coagulant used in drinking water treatment is polydimethylamine diallyldimethylammonium chloride (poly-DADMAC) (also referred to as poly-DMDAAC). The manufacture of polyDADMAC involves two sequential steps; the formation of the monomer and its polymerisation. The monomer is usually formed by a reaction of a stoichiometric mixture of allyl chloride with dimethylamine in an aqueous solution.

Dimethylamine + Allyl Chloride $\xrightarrow{NaOH}$ Diallyldimethylammonium Chloride (Monomer) → Polymerisation Poly (DADMAC)



The molecular weight per monomeric unit is 161.5 and a typical molecular weight of a polyDADMAC is 2-3 million.

Suitability of polymeric coagulants for water treatment

The modified jar test

The suitability of a coagulant for treatment of water is generally established by means of the laboratory stirrer or Jar test. Using this on turbid waters it is relatively easy to establish the required dosages of the coagulant under consideration. However, UW's major waterworks are generally supplied by dams and tend to have low raw water turbidities for much of the year. When evaluating polymeric coagulants on these low turbidity waters it was quite often not possible to establish a suitable dosage as no visible floc formation took place. As a result of this a number of plant trials were carried out based on a certain amount of intuition as to whether a product was suitable or not. It was realised that the standard jar test required some modification if it was to predict successfully the ability of a polyelectrolyte to treat low turbidity water. The jar test now used by UW therefore demonstrates a number of additions to the procedure. At the low coagulant dosages employed on a clean water (less than 1mg/l) it is often not possible to see whether floc formation has taken place successfully or not. The procedure now employed therefore is to carry out a standard jar test with the usual rapid mix and slow mix periods, and, if there is a floc, its size and settling characteristics are noted. In all cases however, at the end of the test, the treated water is filtered through a Whatman No 1 equivalent paper and the turbidity of the filtered water measured as an indication of the effectiveness of coagulation. There are many occasions when no floc is visible but effective destabilisation of the colloids and turbidity removal takes place. Tables 1 and 2 show results of tests carried out on Albert Falls Dam water using aluminium sulphate and LP526 (a polymeric coagulant) where the former produces a visible floc and the latter does not although both produce turbidity removal.

Table 1 Albert Falls Dam raw water after treatment with alum at varying doses

Alum (mg/l)	5	10	15	20	25	30
pH	7.87	7.68	7.48	–	–	–
Turbidity (NTU)	0.28	0.08	0.03	0.00	0.00	0.00
Floc size	A	A	A	A	AB	AB
Settling rate	S	S	S	S	M	M

Table 2 Albert Falls Dam raw water after treatment with LP 526 at varying doses

LP 526 (mg/l)	1.0	1.5	2.0	2.5	3.0	3.5
pH	8.11	8.15	8.16	8.15	8.17	8.14
Turbidity (NTU)	1.17	0.38	0.21	0.20	1.41	2.35
Floc size	NV	NV	NV	NV	NV	NV
Settling rate	–	–	–	–	–	–

NV indicates not visible

Restabilisation

The UW treatment standard for turbidity is 0.5 NTU and, when evaluating a chemical, tests are carried out to establish the range of coagulant dosages at which the turbidity is lower than the limit. Generally with aluminium sulphate the turbidity decreases with increasing dosage and stabilises below 0.1 NTU. However with polyelectrolytes excessive dosage may result in the overall surface charge of each particle being converted to positive and this phenomenon is known as restabilisation. The result of this is that turbidity starts to increase again and if a graph is produced of turbidity versus dosage with a polymeric coagulant a U-shaped curve is obtained with a minimum being the dosage most suited to use on the plant. If this minimum is below 0.5 NTU the polyelectrolyte is regarded as suitable, if not then it is not considered unless no other suitable coagulants are available. Fig. 1 below shows typical curves for aluminium sulphate and LP526 based on the data in Tables 1 & 2.

Application to full scale plants

The procedure within UW has been to award contracts for the supply of treatment chemicals of two or longer year's duration and this is preceded by a tender period where products are evaluated in the laboratory followed by plant trials. With the refinement in evaluation techniques it has been possible to reasonably accurately assess in the laboratory the potential for treatment of a particular polymeric coagulant on a particular plant. However laboratory tests can never be a perfect predictor and on occasions plant trials have shown success on products that were marginal in the jar tests. However the laboratory tests have essentially fulfilled their function of screening out unsuitable products.

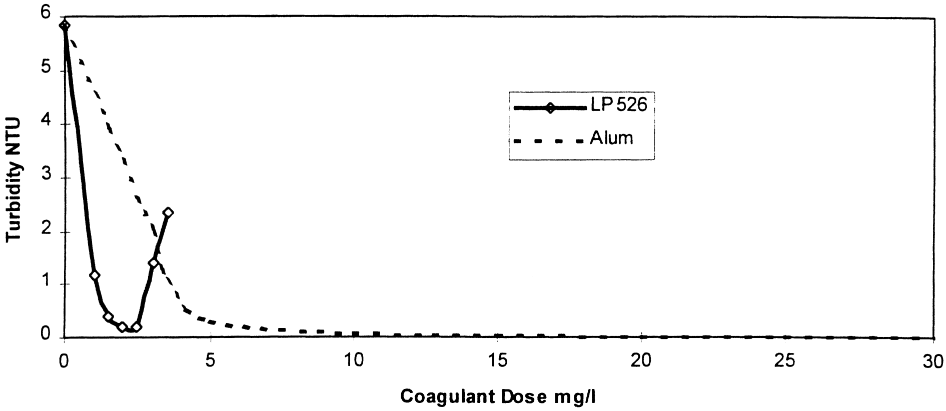


Figure 1

Several of the waterworks operated by Umgeni were switched over the polyamine type coagulants in the mid 1980s and at present nearly all the UW plants are operating on polyelectrolytes rather than on inorganic coagulants. During the 1980s the polyDADMAC compounds also came onto the market and it was found that in a number of cases these produced somewhat better results than the polyamine type. The polyDADMAC with a higher molecular weight appeared to be better suited to some of the types of water being treated.

One of the further developments in recent years has been the use of blended polymeric coagulants where the polyamine or polyDADMAC is blended with polyaluminium chloride or polyaluminium sulphate. This has resulted in improved performance at reduced cost on a number of the works and also has led to the situation where products can be tailored to suit specific raw water characteristics.

Advantages of polymeric coagulants

Ease of control of discharge ph

With aluminium sulphate pH adjustment is often needed at two points in the treatment process. pH correction may be necessary at the heads of works for optimum floc formation and subsequent pH adjustment after filtration is required for reduction of corrosion potential in the water. This is not the case with polymeric coagulants which are generally not sensitive to pH within a fairly wide range of application. In practice this means that pH correction can be carried out at the head of the process prior to coagulation and that no post pH correction is necessary. The fact that coagulants do not significantly affect the pH of the water is also beneficial as variation in dosage of the polymeric coagulants has virtually no effect on the pH of the treated water.

Lower sludge production

Inorganic coagulants because of their larger dosages tend to produce larger quantities of sludge than polymeric coagulants which tend to be used at dosages of as little as one tenth of that of the inorganic coagulant. The amount of sludge produced through addition of coagulant is therefore significantly less when using a polymeric coagulant and this reflects in lower sludge production on the plant which in turns means that desludging of clarifiers can be significantly reduced and that the sludge dewatering process can be reduced in size.

Improved sludge dewatering

Metal hydroxide sludges from aluminium sulphate or ferric salts tend to be hydrated and difficult to dewater. This is not the case with sludges from polymeric coagulants which dewater readily producing sludge with higher solids contents. The sludges also display improved characteristics with regards to handling.

Reduction of potential aluminium content in potable water

There has been reaction against the use of aluminium sulphate for coagulation in a number of western countries due to the perceived linkage between aluminium content in the water and the occurrence of Alzheimer's disease. As far as we are aware this link has not been proven despite the Water Research Centre in the UK having carried out considerable work in this regard. Nevertheless there is sensitivity amongst the public to the use of aluminium in potable water treatment and the use of polymeric coagulants eliminates a possible cause for concern in this regard. Although some of the polymeric coagulants are blended with polyaluminium chloride the amounts of aluminium added are significantly less (below 10%) than when using aluminium sulphate as a coagulant.

Reduced chemical costs

Table 3 shows the treatment costs for the Durban Heights Waterworks which changed from alum to a polymeric coagulant in the financial year March 1998 to February 1989.

Table 3 Treatment costs for Durban Heights Waterworks

Chemical	Unit costs c/kl		
	1987/88	1988/89	1989/90
Chlorine	0.48	0.43	0.53
Hydrated Lime	0.13	0.09	0.16
Sodium Hydroxide	0.52	0.15	–
Calcium Hypochlorite	0.01	0.01	–
Aluminium Sulphate	0.89	0.11	–
Polyelectrolyte	0.68	1.05	1.11
Activated Carbon	0.14	0.38	0.15
Copper Sulphate	–	0.01	0.01
Total Cost	**2.85**	**2.23**	**1.99**
Total Water Treated (Ml)	101 583	108 994	125 081
Average Raw Water Turbidity (NTU)	50.1	42.5	24

This shows a 30% decrease in the unit cost over the 3 year period despite an annual inflation rate over the period of approximately 10% p.a. In the 10 years following the treatment, cost has been kept to below the inflation rate for the period. There is also a minor reduction in power and maintenance costs. Polyelectrolyte dosages are typically 1/5 to 1/10th those of aluminium sulphate which allows the use of smaller dosing pumps which consume less power. Synthetic coagulants are also less aggressive than aluminium sulphate or ferric chloride resulting in reduced pump maintenance costs.

Automatic control of coagulant dosage

Most of the raw water treated by UW is abstracted from dams where the turbidity tends to be relatively low. This allows coagulation in the charge neutralisation zone indicated by streaming current detectors as opposed to the sweep flocculation. Operation in the charge neutralisation zone allows the use of streaming current detectors for automatic dosage control by means of a feedback control loop. This form of control has been found to be effective over nearly two orders of magnitude of incoming turbidity.

Disadvantages of synthetic coagulants

As might be expected there are a number of disadvantages to the use of synthetic coagulants and although in our experience these have been outweighed by the advantages there are situations where these might become overriding.

Sensitivity of treated water turbidity to incorrect dosage

With the use of an inorganic coagulant such as aluminium sulphate the dosage can vary widely without significantly affecting the turbidity of the treated water. However as mentioned previously with synthetic coagulants excessive dosage leads to restabilisation. The control range for polymeric coagulants is therefore narrower than for inorganic coagulants and there is a greater sensitivity to incorrect dosages being applied.

Turbidity removal

The turbidity standard for treated water at UW is 0.5 NTU. Polymeric coagulants on UW plants have generally produced turbidities in the range from 0.2–0.3 NTU. When using inorganic coagulants, such as aluminium sulphate it has been demonstrated that turbidities below 0.1 NTU can be achieved under optimum conditions. This does not appear to be possible when using organic coagulants. Should it ever be necessary to reduce the turbidity standard to (say) 0.1 NTU, it is likely that the plants would have to switch back to inorganic coagulants. Alternatively work would have to be carried out on developing polymeric blend formulations to produce lower turbidity results.

Enhanced coagulation

Enhanced coagulation is defined as the process where coagulant dosage is optimised for organics removal rather than for turbidity reduction. Based on a large number of tests carried out in our Research and Development laboratory the dosage for enhanced coagulation is generally of the order of three to seven times that required for optimum turbidity removal. Because of the occurrence of restabilisation when using polymeric coagulants, it can be appreciated that these would generally not be suitable for enhanced coagulation. Should organics removal be required it might be necessary to go back to using inorganic coagulants.

Chlorine resistance

At a number of our works, prechlorination is carried out for assistance with algal removal or for oxidation of iron and manganese. Use of polymeric coagulants has shown that certain types are susceptible to degradation in the presence of chlorine. Chlorine resistance testing has been incorporated into our jar test procedures where a standard addition of chlorine is carried out on samples to establish whether coagulation is affected. This has shown that many of the later products have improved chlorine resistance and that this is not as much of a problem as it was with earlier products.

Desludging

Due to the higher viscosity of the sludge produced, problems are sometimes experienced in removal of sludge from clarifier hoppers. This is especially noticeable in some of the older clarifier hoppers which were designed for handling aluminium sulphate sludge. These hoppers tend to have side walls angled at 40–50°. Polyelectrolyte sludge has a higher viscosity than aluminium sulphate and tends to stick to the side walls and is also prone to rat-holing.

Filter mudballing

Over dosage of polyelectrolytes can lead to mudballing of filters, especially where simultaneous air/water backwashing is not practised. It is thus imperative that incidents of over or under dosage be minimised and that the condition of the sand be closely monitored.

Reuglations and health aspects

At present no regulatory mechanism exists in South Africa for the control of drinking water treatment chemicals. Between 1986 and 1994 the then Department of National Health and Population Development started evaluating and approving chemicals used in the drinking water treatment process on an ad hoc basis. Their evaluation procedure was based on whether the chemicals met USA Environmental Protection Agency or other international standards. This ad hoc evaluation and approval system had no legal standing and was abruptly stopped in 1994. However the present National Department of Health has realised the importance of the establishment of a legally binding registration system for drinking water treatment chemicals and an initiative has been launched to obtain the opinions of all interested and affected parties and to produce a guideline for the establishment of a registration system. UW originally requested approval of products under the US EPA system and this was used as a guideline for setting maximum dosages in the initial stages. When the South African Department of Health began issuing certificates suppliers were required to obtain these for any products under consideration for use by UW. At present the situation is uncertain: some of the products are supplied using previous approval certificates and the largest suppliers are now in the process of obtaining NSF registration. It is possible that we will require NSF registration for future use of chemicals.

As far as the polyamines are concerned very little published information is available on their toxicity. It has been assumed that the polymer is not absorbed in the gastrointestinal tract and therefore has negligible toxicity. On the other hand a significant amount of data is available on epichlorhydrin one of the raw materials used in the manufacture. Epichlorhydrin has been shown to be both mutagenic and carcinogenic in animals. It has also been shown to cause sterility in male rats and mice. The oral LD50 for epichlorhydrin in rats and mice is of the order of 230 to 260 mg/kg of body weight.

With regard to the polyDADMACs the ammonium chloride can irritate eyes, skin and respiratory tracts and its ingestion can be harmful. However toxicological information on polyDADMACS and the DADMAC monomer does not appear to be available at present.

Future use

At this stage there is no intention of changing back from synthetic polymeric coagulants to inorganics as the synthetics have a number of advantages as discussed previously. However should organic enrichment of the catchments continue to increase to the extent that eutrophication and total organic carbon becomes a problem it may be necessary to use enhanced coagulation on many of the works where ozonation or other advanced treatment is not feasible. In such a case the works would have to switch over to an inorganic coagulant. This would not be undertaken lightly as in many cases major revisions to the design of waterworks might be necessary including upgrading of the chemical dosing sludge handling and dewatering facilities and modifications to the pH control systems.

Cost estimates carried out in our Process Services Department have shown that enhanced coagulation is not necessarily the most cost effective means of dealing with organics on large water works and that in such cases ozonation and GAC may be the preferred course.

This could apply to the three major work is operated by UW which supply the cities of Durban and Pietermaritzburg. These would presumably continue to use polymeric coagulants.

Conclusions

UW has been using polymeric coagulants for coagulation of its water supplies for in excess of 10 years. Operation using these products has generally been trouble free and has shown a number of advantages compared to the inorganic coagulants. The treated water has met all applicable standards. UW therefore intends to continue with their use unless through changes in the water supply or regulations this is no longer possible.

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