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MARKET ANALYSIS & MATERIAL EVALUATION
OF
COAGULANTS FOR REVERSE OSMOSIS
WATER PURIFICATION UNITS

FINAL TECHNICAL REPORT

OCT 03 1990

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28 SEPTEMBER 1990

PREPARED FOR THE

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CONTRACT NUMBER DAAK70-88-D-0014
TASK NUMBER 0015

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DISTRIBUTION STATEMENT A

Approved for public release
Distribution Unlimited

90 09 27 043

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188 Exp. Date: Jun 30, 1986	
1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS None		
2a. SECURITY CLASSIFICATION AUTHORITY N/A			3. DISTRIBUTION / AVAILABILITY OF REPORT To be assigned.		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE N/A					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) SAIC-90/1321			5. MONITORING ORGANIZATION REPORT NUMBER(S) To be assigned.		
6a. NAME OF PERFORMING ORGANIZATION Science Applications International Corporation		6b. OFFICE SYMBOL (If applicable) N/A	7a. NAME OF MONITORING ORGANIZATION US Army Belvoir Research, Development and Engineering Center		
6c. ADDRESS (City, State, and ZIP Code) 1710 Goodridge Drive, T1-7-2 McLean, Virginia 22102			7b. ADDRESS (City, State, and ZIP Code) Commander, Attn: STRBE-FSE Fort Belvoir, Virginia 22060-5606		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION US Army Belvoir Res., Dev. & Eng. Center		8b. OFFICE SYMBOL (If applicable) STRBE-ZTR	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAK70-88-D-0014		
8c. ADDRESS (City, State, and ZIP Code) Fort Belvoir, Virginia 22060-5606			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
					WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Market Analysis & Material Evaluation of Coagulants for ROWPUS					
12. PERSONAL AUTHOR(S) Dana L. Sheil, Bruce Halstead, Pat Potter					
13a. TYPE OF REPORT Technical		13b. TIME COVERED FROM 3/90 TO 9/90		14. DATE OF REPORT (Year, Month, Day) 31 August 1990	
				15. PAGE COUNT 101	
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Logistics Equipment Directorate, Reverse Osmosis Water Purification Unit, Coagulant, Reverse Osmosis (RO). (ROWPU)		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) The Logistics Equipment Directorate is responsible for development and engineering support of the family of water supply equipment, including the Reverse Osmosis Water Purification Units (ROWPU). The Army is using a cationic polyelectrolyte to coagulate suspended particles thereby increasing the effectiveness of the ROWPU's multi-media filter. They need to determine if other coagulants or materials are available in the commercial marketplace to increase particulate capture in the filter.					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL Dina Brown			22b. TELEPHONE (Include Area Code) (703) 664-5472		22c. OFFICE SYMBOL STRBE-FSE

FOREWARD AND ACKNOWLEDGEMENTS

The technical report for the Market Analysis and Material Evaluation of Coagulants for the Reverse Osmosis Water Purification Units was prepared by Science Applications International Corporation (SAIC) under Task Order 0015 of contract DAAK70-88-D-0014 sponsored by the US Army Belvoir Research, Development and Engineering Center (BELVOIR). Mr. Pat Potter and Mr. Bruce Halstead served as the Principal Investigator. Extensive assistance was provided by Ms. Dina Brown as the Technical Point of Contact. Mr. Domingo Caro assisted this effort as the Contract Officer's Representative for BELVOIR.

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Availability Codes	
Dist	Availability Codes Special
A-1	

STATEMENT "A" per Dina Brown
 US Army Belvoir RD&E Center/FSE
 Ft. Belvoir, VA 22060-5606
 TELECON 10/2/90 VG

**MARKET ANALYSIS & MATERIAL EVALUATION
OF COAGULANTS FOR REVERSE OSMOSIS
WATER PURIFICATION UNITS (ROWPU)
STUDY GIST**

PRINCIPAL FINDINGS

The water purification industry is making advances to create "custom-made" coagulants for use in individual locations and applications. The US Army is attempting to locate a "universal" coagulant for all locations and applications. The opposing goals of industry and the Army made it difficult to locate many strong candidates for Army requirements. Of the five available candidate coagulants studied in this market investigation, three received strong scores. The Army should test all three identified primary coagulants. Electrocoagulation, an emerging technology, was also discovered as being a relatively new area of research with great potential and should be investigated as a possible alternative to chemical coagulation.

MAIN ASSUMPTION

None.

PRINCIPAL LIMITATIONS

The weak response of coagulant manufacturers, resulting in a small number of available candidate coagulants.

SCOPE OF EFFORT

The scope of this effort was to conduct a comprehensive market analysis of commercially available coagulants that may be used in the pre-treatment section of the ROWPU and provide recommendations regarding the results of the findings.

OBJECTIVES

1. Development of a market survey questionnaire for plant operators as well as manufacturers.
2. Distribution of the questionnaire and collection of data.
3. Analysis of the data.

BASIC APPROACH

The basic approach used in this effort consisted of reviewing Government provided literature to gather sufficient data for development of the manufacturers' and users' survey questionnaires, based on established evaluation criteria. The questionnaires were distributed to manufacturers and coagulant users identified by materials such as trade periodicals, industry registers, reference publications, and American Water Works Association publications, etc., and various points of contact.

REASONS FOR PERFORMING THE STUDY

The reason for performing this study was to conduct a comprehensive market analysis of commercially available coagulants that may prove to be more effective and cost beneficial for use in the Army ROWPU.

IMPACT OF THE STUDY

The results of this study will determine if there are commercially available coagulants which would perform more effectively than the current coagulant in the ROWPU, thus increasing the effectiveness of the multi-media filter.

SPONSOR

US Army Belvoir Research, Development and Engineering Center

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DTIC/DLSIE ACCESSION NUMBER OF FINAL REPORT

To be assigned at a later date.

**MARKET ANALYSIS & MATERIAL EVALUATION
OF COAGULANTS FOR REVERSE OSMOSIS
WATER PURIFICATION UNITS**

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**MARKET ANALYSIS & MATERIAL EVALUATION
OF COAGULANTS FOR REVERSE OSMOSIS
WATER PURIFICATION UNITS**

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MARKET ANALYSIS & MATERIAL EVALUATION OF COAGULANTS FOR REVERSE OSMOSIS WATER PURIFICATION UNITS

SECTION 1 INTRODUCTION

1.1 BACKGROUND

The Logistics Equipment Directorate is responsible for development and engineering support of the family of water supply equipment, which includes the 600 gallons per hour (GPH), 3,000 GPH, and 150K GPH Reverse Osmosis Water Purification Units (ROWPU). The Army is using a cationic polyelectrolyte to coagulate suspended colloidal particles thereby increasing the effectiveness of the ROWPU's multi-media filter. A more effective media filter will extend the operational life of both the cartridge filters and the reverse osmosis (RO) elements.

The surface of each RO element carries an electrical charge which differs from manufacturer to manufacturer. Depending on the coagulants' charge, there may be an electrical attraction and a tendency for the coagulant to adhere to the RO membrane surface. This process can foul the membrane surface, decrease the amount of water flowing through the membrane, and shorten the operational life of the element. The Army's goal is to further increase the effectiveness of the multi-media filter. They need to determine if other coagulants or materials are available to increase particulate capture in the filter.

1.2 OBJECTIVE

The objective was to conduct a comprehensive market analysis and material evaluation of commercially available coagulants that may be used in the pre-treatment section of the ROWPU. The ultimate goal is to determine if there are commercially available coagulants which are more effective than those currently being used by the Army.

1.3 STUDY APPROACH

A market analysis and materiel evaluation of the coagulants available for the ROWPU was conducted. To initiate the study, the contractor developed two questionnaires; one for coagulant manufacturers, the other for plant operators/coagulant users. Questions were based upon Government input, pertinent articles, and technical studies. Manufacturers and users were surveyed with the questionnaire and responses were collected, organized, and categorized. The contractor reviewed the responses to the market investigation and other relevant sources to analyze the results. The Statement of Work (SOW) (Appendix A) for this effort has the following main tasks:

Task I. Literature Search and Concept Review.

The Government technical representative conducted a comprehensive review of available literature and previous related studies. This preliminary assessment of literature on coagulants used in the pretreatment section of ROWPUs provided the basis for the development of a market analysis questionnaire. The US Belvoir Research, Development and Engineering Center (BELVOIR) Foreign Information Office was also asked to provide information on pertinent foreign coagulants. The resulting information was provided to the contractor at the post award conference. The contractor was also briefed by the technical representative on the coagulant currently used, operation of the ROWPU, and other pertinent information on Army field water supply. Also, the 600 GPH ROWPU operator's manual was provided as reference material.

Task II. Development of a Market Survey Questionnaire.

The contractor developed, in conjunction with Government technical representative, a market survey questionnaire. The questionnaire was distributed to commercial users of coagulants, such as water treatment plant operators, as well as manufacturers of the various products.

Task III. Distribution of the Questionnaire and Collection of Data.

The contractor developed a distribution list for the market analysis questionnaire with assistance from the Government. The resulting distribution list was based upon information gathered during the Government's literature search and as a result of a Government *Commerce Business Daily (CBD)* announcement, developed by the contractor. The contractor distributed the questionnaires and coordinated the collection of required information on the coagulants. The data received in response to the questionnaire was organized and categorized by the contractor in a logical and easy to use manner.

Task IV. Analysis of Data.

The contractor analyzed the responses to the questionnaire, and when necessary, contacted non-respondes and respondes with incomplete questionnaires for follow-up information to permit complete evaluation of their products. The contractor evaluated all the responses based on requirements and criteria developed in conjunction with the Government. Coagulants most promising for use in the pre-treatment section of the ROWPUs in the Family of Water Supply Equipment were determined. A detailed review of literature provided by the Government was also performed. This analysis examined and evaluated the following coagulant characteristics; toxicity, shelf-life, estimated dosage, cost, type, corrosiveness, effectiveness, and system compatibility. Results of the analysis are in Section 4.

Task V. Technical Report and Study Gist.

The contractor documented results of the above tasks in a Technical Report Study Gist. This report is the result of this task.

The following sections of the report discuss each of these tasks in detail.

SECTION 2

LITERATURE SEARCH

2.1 IDENTIFICATION OF MANUFACTURERS/USERS

An extensive literature search was performed by the Government technical representative to identify companies which were involved in coagulant manufacturing or distributing. This literature was reviewed, (synopses at Appendix B) and analyzed by the contractor, and an initial list of manufacturers was drafted. Materials, such as trade periodicals, industry registers, casebook directories, reference publications, and American Water Works Association publications provided an excellent cross reference of information. Using these reference materials, together with phone conversations of subject matter experts, the study team generated a list of manufacturers.

Identifying coagulant users was a more difficult task. Phone conversations were conducted, starting with Melvin Leu, formerly of the Office of Water Research and Technology, Department of the Interior. Appendix C is the guide to all persons contacted, and information or leads that resulted from the conversations. The three lists which were eventually used to draft the roster of plant users were the plants identified by the International Desalinization Association (IDA) user-members provided by Mr. Jack Jorgenson, Executive Director of the National Water Supply Improvement Association (NWSIA), the customer list provided by Harmsco, and a mailing list of Florida Water Treatment Plant Operators provided by Bill Harlow, Membership Chairman of NWSIA.

2.2 DESCRIPTION OF THE ARMY'S REVERSE OSMOSIS WATER PURIFICATION UNIT AND PROCESSES

2.2.1 Introduction

The field Army, in order to perform its mission, must maintain a certain level of subsistence to maximize troop effectiveness. Among the list of necessities for life is potable water. This water is used in a variety of applications, such as drinking, washing, culinary, bathing, laundering, and dehydrated food reconstitution. Soldiers in the field must find a raw water source wherever available and must purify this water to a level commensurate with that of civilian practice, even though the raw water could be highly polluted, turbid, colored, salinated, or have high or low pH. Furthermore, the problem may be compounded with nuclear, biological, or chemical warfare (NBC) agents. A complete line of water purification equipment was developed for use in the field. In June, 1972 the kick-off of a new unit, the ROWPU, better equipped for desalination, occurred. The ROWPU has been successful and must remain capable of world-wide use for the purification of any water type.

2.2.2 Treatment Processes

The process flow diagram for the US Army 600 Gallon ROWPU is illustrated in Figure 1. The process shown is similar to the Army's 3,000 gallon per hour equipment. The first action to take place occurs in the intake step, which includes a strainer to provide rough filtering capabilities. Next, low pressure filtration (100 psi) takes place, beginning with the injection of a coagulant and sodium hexametaphosphate, with the water passing through the multi-media filter and finally, after injection of citric acid, the cartridge filter. The last step in the treatment process is high pressure separation (up to 1000 psi for sea water) by the reverse osmosis elements. The process ends with post-chlorination to five parts per minute (ppm) free residual chlorine, storage and distribution.

In order to lower operation and maintenance costs, the water source must be as clean and clear as possible prior to filtration. Currently the Army is using a cationic polyelectrolyte, dimethyldiallyl ammonium chloride (DMDAAC), in pre-treatment to destabilize particulates in the water, changing their charge and consequently forming larger particulates that are removed in the multi-media filter. The goal of the current Army effort is to determine whether other coagulants or alternate materials are available that can increase the effectiveness of particle capture by the multi-media filter.

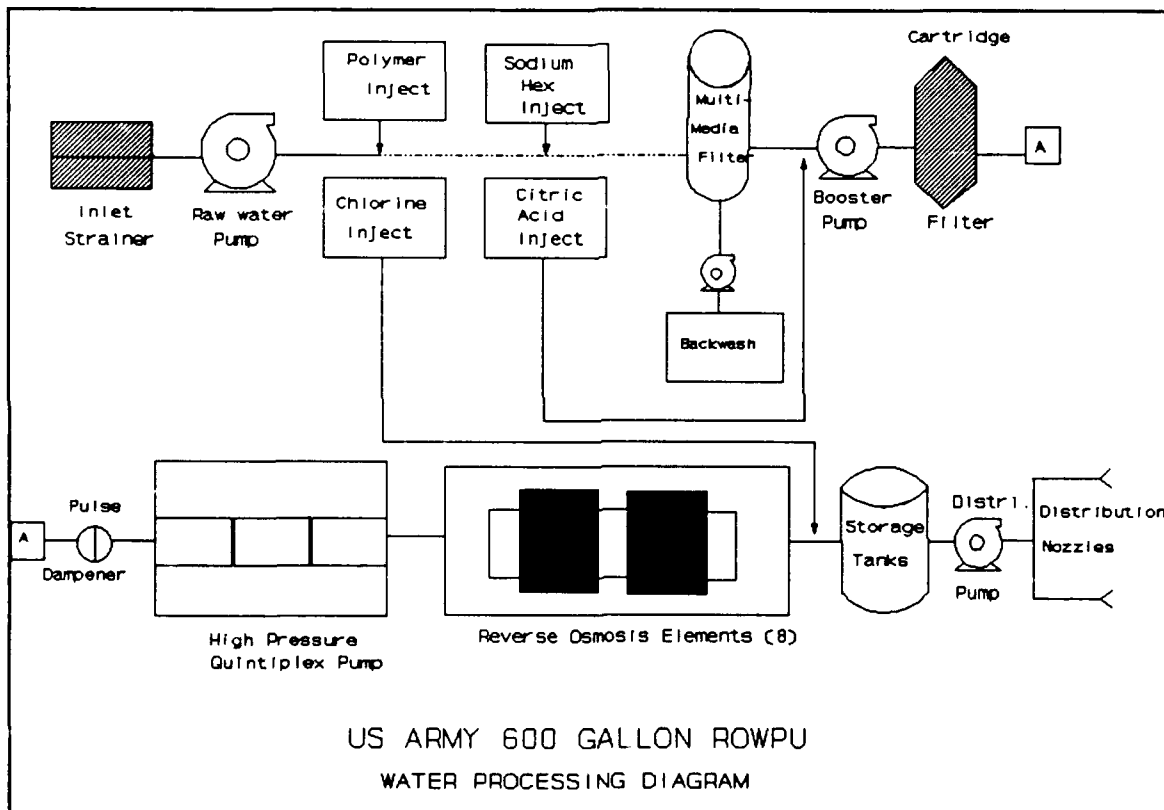


FIGURE 1 - ROWPU FLOW DIAGRAM

SECTION 3

DESIGN, DISTRIBUTION, AND COLLECTION OF QUESTIONNAIRES

3.1 COMPILATION OF QUESTIONNAIRE DISTRIBUTION LISTS

Once the identification of manufacturers and users involved in coagulants was completed, distribution lists for the manufacturer questionnaire and the coagulant user questionnaire were developed (reference Appendix D). The manufacturer list contained 79 companies and the users list contained 49 plants. The users list was primarily comprised of plants in Florida and California due to the fact that these two regions are the primary areas for reverse osmosis applications, specifically in desalinization.

3.2 DESIGN, APPROVAL, AND DISSEMINATION OF THE QUESTIONNAIRES

A questionnaire was designed that would solicit a manufacturer's product applicability toward fulfilling the ROWPU requirements for pre-treatment and gain information on any emerging technologies they may be developing. The cover letter familiarized the recipient companies with the specific project requirements, the field environment, and solicited completion of the questionnaire. Representative samples of both the cover letter and the survey appear in Appendix E. The sections on the survey were matched with the evaluation criteria established by the contractor in conjunction with the Government technical representative. This assisted in simplifying the analysis of data. The questionnaire was mailed out on 8 June 1990. Follow-up surveys were mailed out on 27 July 1990.

Another questionnaire was developed to ensure an accurate portrayal of the specific usage and applications of coagulants in various water treatment environments. This questionnaire solicited information from reverse osmosis plant operators that used coagulants as part of their pretreatment process. It was mailed out on 2 July 1990. Samples appear in Appendix E.

3.3 DATA OBTAINED FROM QUESTIONNAIRES

Of the 79 manufacturer questionnaires sent out, 18 companies responded. This corresponded to a 24% response rate. Follow-up calls were made and several companies had been sold or had gone bankrupt. Others expressed no interest in participating in the survey generally because they did not anticipate future business with the Government or they considered the information requested as proprietary. Although disappointing, the 24% response rate was consistent with rates obtained from other BELVOIR market surveys and, thus, should not be considered abnormal.

Of 49 user questionnaires sent out, 9 responded, corresponding to a 18% response rate. Follow-up calls were not possible for these surveys, as no phone numbers or points of contact were available. Since there were no incentives to complete this survey, the response rate is understandable.

SECTION 4

ANALYSIS OF QUESTIONNAIRE RESPONSES

4.1 CANDIDATE COAGULANT ANALYSIS

Only six of 18 candidates responding were determined to be worthy of further analysis and two of them were questionable, since the associated product is only used as a coagulant aid; one of the six candidates was considered an emerging technology, leaving five viable candidates for analysis. Ten of the remaining responding manufacturers did not distribute or manufacture coagulants; one submitted information on phosphates to be used in corrosion and scale control; and the last manufacturer elected not to submit information on their product, as National Sanitation Foundation (NSF) approval had not been obtained.

Initially, a list of evaluation criteria and their corresponding weights was developed. The qualitative analysis of the five candidate products was conducted, based on a weighted point system developed from the evaluation criteria.

To measure the utility or military worth of the alternatives, functions were assigned to describe coagulants. An extensive literature review assimilated as much information as possible about what characterized an efficient coagulant. The outcome resulted in six unique functions used to categorize a coagulant. The six functions are listed in Figure 2. A detailed definition of each function is at Appendix F.



FIGURE 2 - FUNCTIONS

An attribute provides a more detailed description of a function and helps define a function's effectiveness. Figure 3 illustrates all the attributes with respect to their specific functions and corresponding weights. These attributes were derived from the research mentioned earlier.

Each function was assigned a point value (out of 100 possible points), based on its perceived relative utility. Effectiveness, compatibility and cost were the three highest ranking functions. In like manner, attributes for each function were assigned a value based on the perceived contributions of the attribute to the overall effectiveness of the function. Product literature and surveys were then analyzed to determine an appropriate point value the coagulants should receive under each one of the functions and attributes. Certain rules were followed for evaluation of each line item. These rules were determined by the contractor's knowledge of Government requirements. Each one of the attributes are defined and discussed in Appendix F.

<u>EFFECTIVENESS</u>		33%
Dosage/Concentration	12%	
Sedimentation/Flocculation Time	10%	
Ability as Primary Coagulant	25%	
Human Interface (MANPRINT)	6%	
Headloss	20%	
Water Characteristics	<u>27%</u>	
	100%	
<u>COMPATIBILITY</u>		28%
Effect on Water pH	12%	
Solids/Residues Created by Coagulant	8%	
Reactivity with Multi-Media Filter	25%	
Reactivity with R.O. Membranes	32%	
Reactivity with Materials of Construction	5%	
Reactivity with Antiscalants	8%	
Reactivity with R.O. Clean. Agents/Acids	5%	
Reactivity with Water Disinfectants	<u>5%</u>	
	100%	
<u>LOGISTICS</u>		10%
Shelf-life	40%	
Packaging Flexibility	20%	
Freeze/Thaw Characteristics	<u>40%</u>	
	100%	
<u>SAFETY CONSIDERATIONS</u>		9%
Biodegradable	10%	
Toxicity	30%	
Corrosiveness	10%	
Flammability	10%	
NSF Approved	<u>40%</u>	
	100%	
<u>AVAILABILITY</u>		5%
Years in Production	10%	
Production Rate per Year	50%	
Solution/Dry	<u>40%</u>	
	100%	
<u>COST</u>		15%
Cost per Gallon/Pound	80%	
Quantity Discount Available	<u>20%</u>	
	100%	
		100%

FIGURE 3 - EVALUATION CRITERIA AND CORRESPONDING WEIGHTS

Some attributes were listed as "N/R" as the manufacturers did not include any data for them. The total points for these functions were normalized by subtracting out the possible points for the N/R attribute. For instance, if no information was available for Headloss, 20 points were removed from the total and the "Normal" score was calculated on a base of 80 points instead of 100. The "Percent" score was calculated by multiplying the normal score by the "Percent of Total," (i.e., .33, .28, etc.). The resulting percent scores were added together to achieve the product's final score (listed at Figure 4).

The first candidate coagulant analyzed is Clarifloc C-308P, manufactured by Polypure, Inc., located in Parsippany, New Jersey. This product is dimethyldiallyl ammonium chloride (DMDAAC), the same as the coagulant currently being used by the Government. It is a cationic polyelectrolyte, with a molecular weight of 50,000-100,000 g/mole and it can be used in any pH level, any color level and works best at high turbidity. Its ability to be used as a primary coagulant and it having no need for sedimentation time resulted in a high **Effectiveness** score of 27 out of 33 possible points. **Compatibility** function was allotted 28 points. Clarifloc scored 27 points in this function because it did not adversely alter the water pH and the performance of the R.O. elements. It also proved to be non-reactive to all materials; with the exception of construction materials, specifically, mild steel, copper, brass, galvanized steel, and aluminum. Clarifloc literature did not include information regarding shelf-life, so the points for **Logistics** were normalized to 60 points instead of 100. It has sufficient packaging flexibility, scoring 15 of 20 points. The freezing point is 25° F; however, it is freeze recoverable. The coagulant scored over half the possible 10 points in this function. In **Safety Considerations**, Clarifloc is non-biodegradable, so it lost a few points from its otherwise perfect score. Even though there were no recorded data on production rate per year (proprietary), the coagulant scored perfect in **Availability**. The cost was average and quantity discounts were available, so Clarifloc scored high in **Cost** as well. Overall the coagulant scored a **86.21**.

COAGULANT RATING SHEET
31 AUGUST 1990

PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC C-308P	NORMAL SCORE	PERCENT SCORE	KLAR AID	NORMAL SCORE	PERCENT SCORE	ACCOFLOC SCORE	NORMAL PERCENT SCORE	SODIUM SILICATE	NORMAL PERCENT SCORE
EFFECTIVENESS	33										
Dosage/Concentration	12	7	10		10			2		9	
Sediment./Floc. Time	10	10	8		7			4		4	
Ability as Primary Coag.	25	25	25		25			0		0	
Human Interface (MANPRINT)	6	3	6		3			2		2	
Headloss	20	N/R	N/R		N/R			N/R		N/R	
Water Characteristics	27	20	25		12			12		12	
	100	65 81.25 26.81	74 92.5 30.53		57 71.25 23.51			20 25 8.25		27 33.75 11.14	
COMPATIBILITY	28										
Effect on Water pH	12	11	12		12			12		6	
Solids/Residues created	8	8	6		8			N/R		0	
Reactivity w/ M.-Media Filter	25	24	25		25			25		25	
Reactivity w/ R.O. Membranes	32	32	32		32			32		19	
Reactivity w/ Constr. Matls.	5	2	5		2			5		5	
Reactivity w/ Antiscalants	8	8	8		8			8		5	
Reactivity w/ Clean. Agents	5	5	5		5			5		0	
Reactivity w/ disinfectants	5	5	0		5			5		0	
	100	95 95 26.6	93 93 26.04		97 97 27.16			92 100 28		60 60 16.8	

FIGURE 4 - BASELINE RATING SHEET

COAGULANT RATING SHEET
31 AUGUST 1990

	PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC C-308P	NORMAL SCORE	PERCENT SCORE	ULTRION SCORE	NORMAL SCORE	KLAR A1D	PERCENT SCORE	ACCOFLOC SCORE	NORMAL SCORE	PERCENT SCORE	SODIUM SILICATE	NORMAL SCORE	PERCENT SCORE
LOGISTICS	10	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Shelf-life	:	40	N/R	:	30	:	20	:	40	:	:	:	20	:	:
Packaging Flexibility	:	20	15	:	15	:	20	:	20	:	:	:	10	:	:
Freeze/Thaw Cnars.	:	40	20	:	40	:	20	:	40	:	:	:	5	:	:
	:	:	35	58.33	5.83	85.00	85.00	8.50	:	60	60	6.00	:	35	35
	:	100	:	:	:	:	:	:	:	100	100	10	:	35	3.50
SAFETY CONSIDERATIONS	9	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Biodegradable	:	10	4	:	0	:	10	:	N/R	:	:	:	0	:	:
Toxicity	:	30	30	:	30	:	30	:	30	:	:	:	30	:	:
Corrosiveness	:	10	10	:	N/R	:	3	:	10	:	:	:	10	:	:
Flammability	:	10	10	:	10	:	10	:	10	:	:	:	10	:	:
MSF Approved	:	40	40	:	40	:	40	:	0	:	:	:	40	:	:
	:	:	94	94	8.46	80	88.89	8	93	8.37	50	55.56	5	90	8.1
AVAILABILITY	5	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Years in Production	:	10	10	:	10	:	10	:	10	:	:	:	10	:	:
Production Rate/Yr	:	50	N/R	:	N/R	:	N/R	:	N/R	:	:	:	N/R	:	:
Solution/Dry	:	40	40	:	40	:	40	:	40	:	:	:	40	:	:
	:	100	50	100	5	50	100	5	50	100	5	10	20	1	50
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FIGURE 4 - BASELINE RATING SHEET (CONTINUED)

[illegible]

The second candidate was Ultrion by Nalco Chemical Company in Naperville, Illinois. It is a polymeric aluminum chloride and coagulant blend. Much of the other chemical data is proprietary to the company. It can be used over a broad range of pH, alkalinity, temperature, color, and turbidity. With an **Effectiveness** score of 31 of 33 points, this was a strong candidate. It scored high in the following attributes; low dosages (per the Lab Data from Nalco), no sedimentation time required, ability to act as a primary coagulant, ease of use, and effectiveness in many types of water. Being compatible with all aspects of the ROWPU, a score of 26 of 28 possible points was achieved under **Compatibility**, only scoring low in solids/residues created and reactivity with water disinfectants. A shelf-life of 9 to 12 months was considered average. The manufacturer also offered a variety of packaging, making the **Logistics** function a stronger score. The strongest attribute of Ultrion is its low freeze point (-12° F) and its complete recoverability from freeze. The function score was 8.5 of 10. Ultrion is non-biodegradable, resulting in a score of eight of nine in **Safety Considerations**. The product has been in production for over 10 years and is a liquid polymer, so it scored a perfect 5 in **Availability**. The **Cost** was well within average of the candidate products so a score of 12 of 15 was received. Ultrion's overall score was **90.07**.

Klar Aid, a cationic polyelectrolyte was the third candidate. Manufactured by W.R. Grace & Company's Dearborn division, it has a molecular weight of 10,000 g/mole or less, and is effective in any turbidity water up to 300 nephelometric turbidity units (ntu), low total suspended solids (TSS) in water, but is limited to pH level of 6-9. Its primary use is as a sole coagulant but it can be used as a coagulant aid as well. It scored a total of 24 in **Effectiveness**, specifically weak in the limited types of water it treats effectively. Reactivity with materials of construction was the only attribute not scored perfectly in **Compatibility**. Klar Aid received a score of 27 of 28 in this function. Having a shelf-life of only six months and a high freezing point of -4° F resulted in the score of six out of 10 points for **Logistics**. Corrosiveness of the product lowered the score in **Safety Considerations** to eight from a perfect score of nine. Klar Aid scored a perfect five in **Availability**, and 10.5 out of 15 in **Cost** because the product was priced considerably higher than the other candidate products. The overall score of Klar Aid was **80.54**.

The remaining two candidates are coagulant aids and are capable of working effectively alone, but only to increase the rate and efficiency of flocculation. They were rated with the primary coagulants, and the differences were accounted for in the sensitivity analysis.

Accofloc, or sodium bentonite was the fourth candidate, manufactured by American Colloid Company of Arlington Heights, Illinois. It is most effective under low turbidity and neutral to high pH source water. Its maximum dosage of 200 ppm was considered high and consequently scored low. Low points were also given for sedimentation time, as 20 to 30 minutes were listed; a non-acceptable amount. Also receiving low scores were its ability as primary and its performance in differing water characteristics. The score for **Effectiveness** was 8 out of 33. **Compatibility** was a high scoring function with 28 out of 28 possible points. There was no record of solid or residue creation, and the score was normalized to exclude this attribute. **Logistics** was another function in which Accofloc scored the maximum of 10 points. Biodegradability was not discussed and NSF Approval is pending, so a low score of five out of nine was given in **Safety Considerations**. Being a dry polymer, this resulted in only one of five points being assigned to **Availability**. **Cost** was competitive, even though quantity discount was not discussed, so Accofloc scored 12 of 15 points. The overall score of Accofloc was **64.25**.

The final candidate was a product manufactured by PQ Corporation called sodium silicate. It is a solution of water soluble glasses manufactured from varied proportions of Na_2CO_3 and SiO_2 . It acts as a coagulant aid and is most effective in water with a pH level between five and 6.5, in varying degrees of turbidity. Its overall **Effectiveness** score was very low; only 11 out of 33 because it received minimal points in sedimentation time, MANPRINT, and water characteristics. Sodium silicate was below average in **Compatibility**, with a score of 17 out of 28. It has adverse effects on the water pH, generates solids, reacts slightly with R.O. membranes, reacts with cleaning agents and water disinfectants as well. Shelf-life of one year is considered average, along with packaging flexibility. But the product must be kept above 32° F, with no mention of recoverability, so the score for **Logistics** was 3.5 out of 10 total. Sodium silicate is not biodegradable, resulting in a little less than perfect score of eight of nine in **Safety Considerations**. **Availability** of the product was strong and received a perfect score of 5. No

information was available in the Cost function, so the final score was normalized to a new total of 85. A low overall score of 52.4 was achieved.

A parametric analysis was conducted by changing the weights of functions or attributes to determine the sensitivity of the results to different weighting parameters. The first sensitivity analysis (Version 2), shown at Figure 5, involved increasing the compatibility function to 40% and lowering the effectiveness function to 21%. The resulting ranking did not change from the original analysis. Ultrion remained the strongest alternative. The second sensitivity analysis, (Version 3), shown at Figure 6, involved decreasing two attributes within the Effectiveness function, specifically, Ability as Primary Coagulant and Headloss. These two attributes were selected because they appeared to make a significant impact on the final score of the candidates. Twenty points were removed from Ability as Primary and ten points from Headloss and redistributed evenly among the remaining attributes. Once again, this resulted in the same ranking of the alternatives. The sensitivity analysis validates the ranking of the five alternatives, thus giving evidence to the statistical soundness of the analytical results.

The two coagulant aids, Accofloc and Sodium Silicate, were "normalized" for comparison with the primary coagulants, by decreasing the importance of the attribute "Ability as Primary." This ensured fair comparison was provided between the coagulant aids and the primary coagulants.

COAGULANT RATINGS SHEET-VERSION 2
31 AUGUST 1990

	PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC C-308P	NORMAL PERCENT		ULTRION		NORMAL PERCENT		KLAR AID		NORMAL PERCENT		ACCOFLOC		NORMAL PERCENT		SODIUM SILICATE		NORMAL PERCENT	
				SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE	SCORE
EFFECTIVENESS	21																				
Dosage/Concentration		12	7			10				10				2						9	
Sediment./Floc. Time		10	10			8				7				4						4	
Ability as Primary Coag.		25	25			25				25				0						0	
Human Interface (MANPRINT)		6	3			6				3				2						2	
Headloss		20	N/R			N/R				N/R				N/R						N/R	
Water Characteristics		27	20			25				12				12						12	
		100	65	81.25	17.06	74	92.5	19.43		57	71.25	14.96		20	25	5.25			27	33.75	7.09
COMPATIBILITY	40																				
Effect on Water pH		12	11			12				12				12						6	
Solids/Residues created		8	8			6				8				N/R						0	
Reactivity w/ M.-Media Filter		25	24			25				25				25						25	
Reactivity w/ R.O. Membranes		32	32			32				32				32						19	
Reactivity w/ Constr. Matls.		5	2			5				2				5						5	
Reactivity w Antiscalants		8	8			8				8				8						5	
Reactivity w. Clean. Agents		5	5			5				5				5						0	
Reactivity w/ disinfectants		5	5			0				5				5						0	
		100	95	95	38	93	93	37.2		97	97	38.8		92	100	40			60	60	24

FIGURE 5 - VERSION 2 RATINGS SHEET

COAGULANT RATING SHEET-VERSION 2
31 AUGUST 1990

LOGISTICS	PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC C-308P	NORMAL SCORE	PERCENT SCORE	ULTRION	NORMAL SCORE	KLAR AID	NORMAL SCORE	PERCENT SCORE	ACCOFLOC	NORMAL SCORE	PERCENT SCORE	SODIUM SILICATE	NORMAL SCORE	PERCENT SCORE
Shelf-life	10	40	N/R	30	20	40	20	20	40	20	35	35	3.5			
Packaging Flexibility		20	15	15	20	20	20	20	40	40	5					
Freeze/Thaw Chars.		40	20	40	20	40	20	20	40	40	5					
		100	35	58.33	5.83	85	85	60	60	6	100	100	10	35	35	3.5
SAFETY CONSIDERATIONS	9															
Biodegradable		10	4	0	10	N/R	0	10	N/R	0						
Toxicity		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Corrosiveness		10	10	N/R	3	10	3	10	10	10	10	10	10	10	10	10
Flammability		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
NSF Approved		40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
		100	94	94	8.46	80	88.89	8	93	8.37	50	55.56	5	90	90	8.1
AVAILABILITY	5															
Years in Production		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Production Rate/Yr		50	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R	N/R
Solution/Dry		40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
		100	50	100	5	50	100	5	50	100	5	10	20	1	50	100

FIGURE 5 - VERSION 2 RATING SHEET (CONTINUED)

COAGULANT RATING SHEET-VERSION 2
31 AUGUST 1990

	PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC C-308P	NORMAL SCORE	PERCENT SCORE	ULTRION SCORE	NORMAL SCORE	KLAR AID SCORE	NORMAL SCORE	PERCENT SCORE	ACCOFLOC SCORE	NORMAL SCORE	PERCENT SCORE	SODIUM SILICATE SCORE	NORMAL SCORE	PERCENT SCORE
COST	15	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Cost per gallon/pound	:	80	70	:	:	75	:	50	:	:	70	:	:	N/R	:	:
Qty. Disc. Available	:	20	20	:	:	5	:	20	:	:	10	:	:	N/R	:	:
TOTAL	100	:	90	90	13.5	80	80	12	70	10.5	80	80	12	0	0	0
FUNCTION TOTAL	100	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
FINAL SCORE	:	:	:	:	87.86	:	:	90.13	:	83.63	:	73.25	:	:	47.69	:
															NORMAL	56.11

FIGURE 5 - VERSION 2 RATING SHEET (CONTINUED)

COAGULANT RATING SHEET-VERSION 3
31 AUGUST 1990

PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC		NORMAL PERCENT		NORMAL PERCENT		NORMAL PERCENT		NORMAL PERCENT		NORMAL PERCENT		NORMAL PERCENT		NORMAL PERCENT	
		C-308P	SCORE	SCORE	SCORE	ULTRION	SCORE	KLAR AID	SCORE	SCORE	ACCOFLOC	SCORE	SCORE	SILICATE	SCORE	SCORE	SCORE
EFFECTIVENESS	33																
Dosage/Concentration		20	12			17		17			3					15	
Sediment./Floc. Time		18	18			16		13			7					7	
Ability as Primary Coag.		5	5			5		5			0					0	
Human Interface (HANDPRINT)		13	7			13		7			4					4	
Headloss		10	N/R			N/R		N/R			N/R					N/R	
Water Characteristics		34	25			32		15			15					15	
		100	67	74.44	24.57	83	92.22	30.43	57.00	63.33	20.90	29	32.22	10.63	41	45.56	8.91
CUMPATIBILITY	28																
Effect on Water pH		12	11			12		12			12					6	
Solids/Residues created		8	8			6		8			N/R					0	
Reactivity w/ M.-Media Filter		25	24			25		25			25					25	
Reactivity w/ R.O. Membranes		32	32			32		32			32					19	
Reactivity w/ Constr. Matls.		5	2			5		2			5					5	
Reactivity w/ Antiscalants		8	8			8		8			8					5	
Reactivity w/ Clean. Agents		5	5			5		5			5					0	
Reactivity w/ disinfectants		5	5			0		5			5					0	
		100	95	95	26.6	93	93	26.04	97	97	27.16	92	100	28	60	60	24

FIGURE 6 - VERSION 3 RATING SHEET

COAGULANT RATING SHEET-VERSION 3
31 AUGUST 1990

LOGISTICS	PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC C-308P	NORMAL PERCENT SCORE	NORMAL PERCENT		ULTRION SCORE	NORMAL PERCENT		KLAR AID SCORE	NORMAL PERCENT		ACCOFLOC SCORE	NORMAL PERCENT		SODIUM SILICATE	NORMAL PERCENT	
					SCORE	SCORE		SCORE	SCORE		SCORE	SCORE		SCORE	SCORE		SCORE	SCORE
10 :	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Shelf-life	:	40 :	N/R	:	30	:	:	20	:	:	40	:	:	20	:	:	:	:
Packaging Flexibility	:	20 :	15	:	15	:	:	20	:	:	20	:	:	10	:	:	:	:
Freeze/Thaw Chars.	:	40 :	20	:	40	:	:	20	:	:	40	:	:	5	:	:	:	:
:	:	100 :	35	58.33	5.83	:	85	85	8.50	:	60	60	:	35	35	:	3.5	:
=====																		
SAFETY CONSIDERATIONS	9 :	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Biodegradable	:	10 :	4	:	0	:	:	10	:	:	N/R	:	:	0	:	:	:	:
Toxicity	:	30 :	30	:	30	:	:	30	:	:	30	:	:	30	:	:	:	:
Corrosiveness	:	10 :	10	:	N/R	:	:	3	:	:	10	:	:	10	:	:	:	:
Flammability	:	10 :	10	:	10	:	:	10	:	:	10	:	:	10	:	:	:	:
NSF Approved	:	40 :	40	:	40	:	:	40	:	:	0	:	:	40	:	:	:	:
:	:	100 :	94	94	8.46	:	80	88.89	8	:	93	93	:	50	55.56	:	90	8.1
=====																		
AVAILABILITY	5 :	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Years in Production	:	10 :	10	:	10	:	:	10	:	:	10	:	:	10	:	:	:	:
Production Rate/Yr	:	50 :	N/R	:	N/R	:	:	N/R	:	:	N/R	:	:	N/R	:	:	:	:
Solution/Dry	:	40 :	40	:	40	:	:	40	:	:	0	:	:	40	:	:	:	:
:	:	100 :	50	100	5	:	50	100	5	:	50	100	:	10	20	:	50	5
=====																		

FIGURE 6 - VERSION 3 RATING SHEET (CONTINUED)

COAGULANT RATING SHEET-VERSION 3
31 AUGUST 1990

	PERCENT OF TOTAL	MAX. POINTS	CLARIFLOC C-308P	NORMAL SCORE	PERCENT SCORE	KLAR ATD	NORMAL SCORE	PERCENT SCORE	ACCOFLOC	NORMAL SCORE	PERCENT SCORE	SODIUM SILICATE	NORMAL SCORE	PERCENT SCORE
COST	15	:	:	:	:	:	:	:	:	:	:	:	:	:
Cost per gallon/pound	:	80	70	:	75	:	50	:	70	:	:	N/R	:	:
Qty. Disc. Available	:	20	20	:	5	:	20	:	10	:	:	N/R	:	:
TOTAL	100	:	90	90	13.5	:	80	80	12	:	70	70	10.5	:
FUNCTION TOTAL	100	:	:	:	:	:	:	:	:	:	:	:	:	:
FINAL SCORE	:	:	:	83.96	:	:	89.97	:	66.63	:	77.93	:	49.51	:
													NORMAL	58.25

FIGURE 6 - VERSION 3 RATING SHEET (CONTINUED)

4.2 COAGULANT USERS' RESPONSE ANALYSIS

Most wastewater treatment plants contacted either did not respond to the users' survey, or responded that they did not use coagulation in pretreatment. The two plants which did use coagulants use metallic oxides, and therefore experienced a drop in pH of their source water and had to add either lime or caustic soda to bring the pH level back up again. The two respondents are discussed below.

Of the 49 surveys sent, nine were received, only two of which use coagulants. The two plants which use coagulants are the San Diego Waste Water Treatment Plant and the Contra Costa Water District in Concord, CA.

San Diego uses ferric chloride as a primary coagulant. Their raw water source has turbidity ranging from 8-20 ntu's. The average pH is 7.2. They are satisfied with the 96-98% reduction in turbidity provided by the ferric chloride. The average dosage is 50 mg/L, but the dosage increases when turbidity increases and media begins to deteriorate in the filter. There is a ferric sludge generated in the clarifier section of the package plant. The only other negative effect on the process is that the coagulant lowers the pH from approximately 7.2 to 6.5.

Contra Costa Water District provided a copy of a study completed on a prototype water purification unit, along with product safety sheet for their coagulant, liquid alum and a coagulant aid, Magnifloc 985N. They are satisfied with the finished water turbidity level of less than .1 ntu's under most conditions. The average dosage is approximately 25 mg/L (range from 15-50 depending on turbidity, chlorides, algae, etc., in raw water). There is no sludge generation in their application of the coagulant. There is, however, a drop of .7 - 1.5 units in the pH of the source water.

4.3 EMERGING TECHNOLOGIES

4.3.1 Introduction

The Army requirements illustrate the importance of mobility, flexibility and increased performance. The water purification industry is moving in the opposite direction from the Army where coagulation is concerned. Individual reverse osmosis plants are looking for a "custom-made" coagulant to be used in their source water and water treatment plant. The method industry uses in determining the best coagulant for a specific application is to test samples of their source water at a given location and actually create the "perfect" coagulant for use at that location. Alternatively, the Army requires a "universal" coagulant to be used in any raw water source, under any conditions, at any location in the world. The next section discusses the conclusions and recommendations regarding chemical coagulation. However, there is yet another avenue the Army needs to explore -- electrocoagulation.

4.3.2 Electrocoagulation¹

Electrocoagulation processes utilize an electrical current to remove ionic and other charged particles from wastewater streams. Successful research of various applications in wastewater treatment indicate a great potential for the use of this expanding technology. Many materials have proven to be effectively removed from source water (see Figure 7).

A typical electrocoagulator consists of a combination of a treating chamber, which operates as an electrolytic cell, with a water-inlet and a water-outlet, an anode and cathode, and an electrical source connected to the anode and cathode for applying an electric current (alternating or direct). Electrocoagulation development was based on the colloidal theory that two particles in an aqueous solution can bond a molecule of water between them, and that electrical charges

¹Simmons, Brad F., "Continuous Flow Electrocoagulation, Waste Water Treatment & Recycling Applications," RMI Environmental Services, 2 April, 1990.

Contaminant Concentrations Before and After Electrocoagulation Treatment at WRI (1)				
Contaminant	Wastewater Source	Concentration, mg/L		% Removal
		Raw	After Treatment	
Dissolved Cations				
Aluminum	Can mfg	317	53	83
	Can mfg	224	0.693	99.6
	Syn fuel	0.20	<0.05	75+
Barium	River	0.17	<0.01	94+
Calcium	Cooling tower	1,321	21.4	98
	Canal	202	63.4	67
	River	42.8	21.9	49
Cadmium	Syn fuel	6.41	1.96	69
	Electroplating	31.0	0.338	99
	Electroplating	12.0	0.057	99+
	Electroplating	3.0	<0.005	99.8+
Chromium, total	Electroplating	0.3	0.006	98
	Electroplating	169	<0.05	99.9+
	Electroplating	5.0	<0.050	99+
Copper	Can mfg	1.02	<0.02	98+
	Electroplating	287	0.484	99.8
	Electroplating	17.6	0.25	98.5
Iron	Electroplating	7.6	0.22	97
	Acid drainage	151	0.57	99+
Lead	Syn fuel	1.15	<0.05	95+
	Foundry	0.74	<0.01	98+
Magnesium	Acid drainage	0.258	<0.06	76+
	Canal	92.2	23.6	74
	River	12.0	8.3	31
Manganese	Syn fuel	4.85	1.28	74
	Syn fuel	1.68	0.28	83
	Can plant	3.37	0.56	83
	Can plant	2.40	0.39	84
Nickel	Syn fuel	0.035	<0.01	71+
	Electroplating	128	0.678	99.5
Radium, pCi/L	Electroplating	34.9	0.117	99.7
	Leaching operation	1,093	19	98
Silicon	Syn fuel	38	0.8	98
	Acid drainage	21.7	<0.1	99+
	Syn fuel	12.6	0.38	97
Strontium	River	3.98	0.63	84
	Canal	2.74	1.40	49
Vanadium	Syn fuel	0.034	<0.01	70+
Uranium	Leaching operation	16.2	0.6	96
Zinc	Electroplating	221	0.069	99.9+
	Foundry	13.8	0.030	99
	Can mfg	1.12	<0.02	98+
	Acid drainage	0.298	<0.01	96+
Dissolved Anions				
Arsenic	Acid drainage	0.159	<0.10	37+
Cyanide, total	Electroplating	28.1	0.98	96.1
Nitrate, as N	Plating R.O. brine	190	94	50
	Standard solution	15.1	0.4	97
Fluoride	Can mfg	64.0	28.0	56
Sulfate	Oil brine	1,100	740	33
Phosphate, as P	City sewage	7.0	0.07	99
	Can plant	2.5	0.63	75
Selenium	Drainage	0.068	0.038	44
Other Dissolved and Suspended Material				
Biochemical Oxygen Demand (BOD)	Rendering	5,700	590	89
	Potato processing	1,740	330	81
	Brewery	960	650	32
	Fish processing	185	86	53
Oil and Grease	Rendering	19,350	1,340	93
	Syn fuel	1,100	<10	99+
Total Organic Carbon (TOC)	Syn fuel	6,400	250	96
	Syn fuel	2,253	30.1	96.6
Total Suspended Solids (TSS)	Food processing	88,900	1,420	98
	Syn fuel	16,270	10	99+
	Rendering	4,540	260	94
	Syn fuel	1,278	2.0	99.8
	Syn fuel (clay)	310	0.8	99+
	Carbon black	65	<10	85+

FIGURE 7 - Materials Dissolved and Undissolved Removed by Electrocoagulation

in both the water and the particles lead to a double-layer water bond. Electrical current passing through the water flow in the electrolytic cell neutralizes these electrical charges and helps to separate the water bond. This enables the natural forces of interparticle attraction to coagulate particles together as a mass within the water stream. The process is not instantaneous, but eventually extends throughout the water loop. There is, however, a feature that can be added to the electrocoagulator to overcome excessive residence times and reduce the voltages needed to oxidize trace quantities of dissolved impurities.

The advantages of electrocoagulation outlined below are the advantages applicable to the Army's requirements:

- No storage requirements - unit is attached to ROWPU
- No toxic hazards from chemicals
- No estimations of dosage required
- No transportation of chemicals
- Potential to treat more types of water without alteration of chemical type or dosage

Electrocoagulation offers a promising alternative to chemical coagulants for worldwide use of ROWPUs as envisioned by the Army.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The conclusions in this section are based on the study effort which analyzed and evaluated coagulants for raw water pretreatment in reverse osmosis environment.

The water purification industry is making advances to create "custom-made" coagulants for individual locations and applications. The Army is attempting to locate a "universal" coagulant for all locations and applications. The opposing goals of industry and the Army have made it difficult to locate many strong candidates.

Of the five available candidate coagulants, three received strong scores. The results of the analysis illustrated that Nalco Chemical Company's Ultrion product line was the superior candidate with a final score of 90.17. Polypure, Inc.'s Clarifloc C-308P came in close behind with 86.21. Klar Aid from Dearborn Chemical followed a close third with 80.54. Finally, Accofloc from American Colloid Company and Sodium Silicate from PQ Corporation, both coagulant aids, scored 64.25 and 52.40, respectively.

The ranking of the five coagulants specify which coagulants rated the highest with the evaluation criteria. The strongest candidate, Ultrion, is effective in a variety of water types, (i.e., high and low turbidity waters, any temperature range, and various pH levels). Ultrion is non-reactive with ROWPU materials, 100% recoverable from a freeze, and appears to be cost effective. Clarifloc C-308P is a version of what the Army is currently using. It scored three points under Ultrion and may not be statistically different. Lastly, Klar Aid scored approximately 10 points below the other two. Klar Aid's weakest point is its limited ability to perform in varying water types.

The remaining two coagulants did not score high enough to be considered, primarily due to the fact they are coagulant aids, and are not recommended to perform as a primary coagulant.

Metallic oxides would not be worthy of analysis, because:

- they have a small molecular size greatly limiting their effectiveness in flocculation;

- they require additional chemicals to counteract their effect on the pH level of the raw water;

- on the average, treatment costs are much higher than when using polymers;

- larger volumes of metallic oxides are needed, so chemical handling is more burdensome;

- metallic oxides form gelatinous sludges that are much bulkier and harder to dewater than polymer-formed sludges;

- metallic oxides are more sensitive to the pH of the water than polymers;

- metallic oxides can be corrosive.

Polymers appear to be superior overall to metallic oxides because they may have an extremely large molecular size, offering thousands of charged sites. The polymer chains are sufficiently large to attach to the surface on more than one particle, thus binding or bridging the particles together, to form a particle-polymer-particle bridge. This causes the formation of larger floc and possibly better filtration.

5.2 RECOMMENDATIONS

- The Army should test all three identified primary coagulants.
- Further efforts should be expended to investigate polymer coagulants manufactured by companies which did not respond to the survey.
- Electrocoagulation should be investigated as a possible alternative to chemical coagulation.

APPENDIX A
STATEMENT OF WORK

STATEMENT OF WORK AND SERVICES FOR
MARKET ANALYSIS AND MATERIEL EVALUATION OF COAGULANTS
FOR THE FAMILY OF WATER SUPPLY EQUIPMENT

1. The contractor shall perform the following work and services:

Background: The Logistics Equipment Directorate is responsible for development and engineering support of the Family of Water Supply Equipment, which includes the 600 GPH Reverse Osmosis Water Purification Unit (ROWPU) and the 3,000 GPH ROWPU. The Army is using a cationic polyelectrolyte to coagulate suspended colloidal particles thereby increasing the effectiveness of the ROWPUs' multi-media filter. A more effective media filter will extend the operational life of both the cartridge filters and the reverse osmosis (RO) elements.

The surface of each RO element carries an electrical charge which differs from manufacturer to manufacturer. Depending on the coagulants' charge, there may be an electrical attraction and a tendency for the coagulant to adhere to the RO membrane surface. This process can foul the membrane surface, decrease the amount of water flowing through the membrane and shorten the operational life of the element.

A market investigation is necessary to determine if there are commercially available coagulants which are more effective than what is being used. If so, the Army will realize a significant savings in cartridge filter and RO element replacement costs. In addition, the frequency of RO element cleanings will be reduced, thereby allowing more time for potable water production.

Objective: The objective of this task is to conduct a comprehensive market analysis of commercially available coagulants that may be used in the pre-treatment section of the ROWPU. The market analysis will concentrate solely on this item.

Program Approach: The contractor's expertise in system/hardware integration and the materiel acquisition process will be used to conduct the market analysis and materiel evaluation on the coagulants available for the ROWPU. This effort will develop an in-depth questionnaire, provide a comprehensive description of the coagulants available, and, in conjunction with government technical representatives, conduct an in-depth evaluation of these items resulting in a recommendation of the most promising coagulant.

Task I. Literature Search and Concept Review. The Government technical point of contact will conduct a comprehensive review of available literature and previous related studies. This preliminary assessment of literature on coagulants which can be used in the pretreatment section of ROWPUs, will provide the basis for the development of a market analysis questionnaire. The Belvoir Foreign Information Office shall also be queried to provide information on pertinent foreign coagulants. The resulting information will be provided to the contractor by the Government at the post award conference which shall occur within ten days of task order award. The contractor shall also be briefed by the technical point of contact on the coagulant currently used, operation of the ROWPU, and other pertinent information on Army Field Water Supply. In addition to the literature search information, one set of documentation consisting of previous ROWPU reports and 600 GPH ROWPU operator's manual will be provided as reference material for conduct of this effort. (C.4.2.b)

Task II. Development of a Market Survey Questionnaire. The contractor shall develop, in conjunction with government technical representatives, a market survey questionnaire. The purpose of the questionnaire will be to gather the technical information needed to determine whether the coagulants in question will satisfy the needs of the U.S. Army's water purification equipment. The questionnaire will be distributed to commercial users of coagulants such as water treatment plant operators as well as manufacturers of the various products. The contractor shall develop this questionnaire in draft form and submit it to the government for approval. (C.4.2b)

Task III. Distribution of the Questionnaire and Collection of Data. The contractor shall develop a distribution list for the market analysis questionnaire in conjunction with the government. The resulting distribution list will be based upon information gathered during the Government's literature search and as a result of a government Commerce Business Daily (CBD) announcement, which the contractor will develop in conjunction with government technical representatives. The government approved list will be used to distribute the questionnaire. The contractor shall distribute the questionnaires and coordinate the collection of required information on the coagulants. The data received in response to the questionnaire shall be organized and categorized by the contractor in a logical and easy to use manner. (C.4.2b)

Task IV. Analysis of Data. The contractor shall analyze the responses to the questionnaire and, when necessary, will contact the non-respondes and incomplete respondees for follow-up information to permit complete evaluation of their products. The contractor shall evaluate all the responses based on requirements and criteria developed in conjunction with the government, and determine which coagulants are most promising for use in the pre-treatment section of the ROWPUS in the Family of Water Supply Equipment. A detailed review of the government gathered literature shall also be performed. As a minimum, this analysis will examine and evaluate the following coagulant characteristics: toxicity; shelf-life; estimated dosage; cost; type (anionic, non-ionic or cationic); corrosiveness; effectiveness; and system compatibility. (C.4.2b)

Task V. Technical Report and Study Gist. The contractor shall document results of the above tasks in a Final Technical Report and Study Gist. (C.5)

2. The work shall be in accordance with Section C of the contract and CLIN 0003. Data, CLIN 0004 shall be delivered as set forth on Contract Data Requirements List, DD Form 1423, Sequence Numbers A001, A002, A007, A008 and A009, dated 25 January and 13 March 1990.
3. CLASSIFICATION: Work on this task order may be classified up to SECRET. If SECRET information is used in the report, it will be contained in a separate classified annex.
4. GOVERNMENT FURNISHED EQUIPMENT: None.
5. The completion date for this task order is 30 September 1990.
6. Deliverables will be shipped to Block 14, DD 1155, ATTN: Brad Spitznogle, STRBE-HP.

APPENDIX B
ARTICLE SYNOPSES

APPENDIX B

ARTICLE SYNOPSSES

Gross, Water Treatment Chemicals, Section VI, Coagulants, AUG '81.

Coagulation is the process whereby suspended solids and colloidal materials in the water are agglomerated into masses sufficiently large to settle. Coagulants neutralize the charge on particles allowing them to come together. Coagulation is an irreversible process and a chemical action which can be assisted by mechanical agitation.

Flocculation is the aggregation of suspended solid particles in water such that they form small tufts or clumps resembling wool. Flocculants may act by charge neutralization, but generally act by bridging among particles. Flocculation is a reversible process as cohesive forces are relatively weak. In this discussion, the terms coagulation and flocculation are regarded as roughly synonymous.

The most significant recent development is the combination of inorganic coagulants with organic ones for most effective action in chemical treatment of water and wastewater. Organic ones are effective in water clarification. The demand for organics will grow faster than inorganic coagulants.

Inorganic coagulants: Alum, Iron Salts (ferric chloride, ferric sulfate, others), aluminum compounds (recently developed), lime, clays (bentonite, kaolin), sodium aluminate and sodium silicate. Annual growth rate in '80: 5.4 % in quantity used, 9.7 % in dollar cost.

Organic Coagulants: Natural polymers: starches, gums, proteins. Synthetic polyelectrolytes: most are acrylamide-based and may be long- or short-chain. More information and cost data on p. 109.

Low molecular weight cationic polyelectrolytes for water clarification and filter aids.

High molecular weight anionic polyelectrolytes for water settling, sludge dewatering, and flocculation.

Nonionics are used as water conditioners and adsorbants.

MAGNAFLOC is an example of a flocculant used in direct filtration.

Organic coagulants reduce ecological problems since they are nontoxic to humans, small in volume, easy to incinerate, and have other advantages. Annual growth rate in '80s: 9.6 % in quantity, 13.5 % in dollar cost.

Kim, Robert P. (Calgon Corp), "Selecting Polymeric Flocculants for Water Treatment," Public Works for Sept. 1985.

The annual growth rate of polymeric flocculant production is several times that of alum and ferric salt for several reasons:

- o Because of polymer efficiency, treatment costs are often reduced.
- o Smaller volumes of polymer are needed so chemical handling is simplified.
- o Inorganic coagulants form gelatinous sludges that are much bulkier and harder to dewater than polymer-formed sludges.
- o As salts of strong acids and weak bases, aluminum sulfate and ferric chloride or sulfate make a system more acidic so that lime or caustic must be added, whereas polymers produce no acidity.
- o Polymers are less sensitive than alum or ferric salt to the pH of the water being treated.
- o Using polymers avoids metallic fouling of heat exchanger surfaces.
- o Polymers are not corrosive and do not present the handling problems that alum and ferric salts do.

Factors to consider when selecting the best polymer:

- Cost/performance
- The ability of the polymer treatment to withstand fluctuations in plant operations
- The reproducibility of the polymer product
- Feed equipment requirements
- Handling and storage
- Reliability of the supplier

Typical dosage ranges: Primary coagulant: 1 to 5 mg/L
 Coagulant aid (polymer): .25 to 1mg/L
 Coagulant aid (clay): 1 to 10 mg/L

Coagulant aids are necessary where turbulence is low and mixing is slow.

"Cationic Polyelectrolyte and TM 5-4610-215-10," U.S. Army 600 Gallons Per Hour ROWPU Technical Manual

Colloidal particles almost invariably negatively charged (this charge called the Zeta potential).

Cationic polyelectrolytes accomplish coagulation in two steps:

1. Charge neutralization - due to its position
2. Bridging - colloidal particles become clustered together and filtered away.

Steps for how and when to add the cation polyelectrolyte in the ROWPU, complete with control panel diagrams.

"Specifications for CAT-FLOC T-2," Calgon Corporation, 1984

This packet contains the chemical and technical information regarding the current polymer that Army is using as a coagulant.

"Chapter 6, Precipitation, Coagulation, Flocculation," Unknown source

Difference between coagulation and flocculation is that coagulation is the rapid, flash or initial mixing stage (less than 1 minute usually) and flocculation is less intense mixing to provide increased rate of particulate encounters.

Colloidal material upper size limit of approx 1 μm and lower limit of 5nm - any particles that are smaller than 5nm are in solution.

Hydrophobic particulates: well-defined interface between the water and solid phases and have a low affinity for water molecules. They are thermodynamically unstable and will aggregate irreversibly over time.

Hydrophilic particulates: characterized by the lack of a clear phase boundary and are generally solutions of macromolecular organic compounds, such as proteins or humic acids. They can be reconstituted after aggregation and are thus reversible.

Effective removal of the colloidal and suspended particulates from water depends on a reduction on particulate stability.

Methods of Destabilization

Double-layer compression: increase the ionic strength which compresses the double-layer. Critical coagulation concentration (CCC) is the amount of dissolved ions that produce rapid coagulation.

Electrostatic attraction: oppositely charged surfaces. This can be promoted by absorption of specific ions on the surface of particulates. Alteration of pH changes the charge, when charge is predictable.

Interparticle bridging: biocolloidal particles have hard to predict charges. So destabilization is difficult to predict. Long-chain polymers carrying negative charges can form bridges between particulates, thus destabilizing the suspension (tail that is hanging off the end of a polymer has a tendency to bridge with another introduced molecule in the water). This mechanism is used primarily for the aggregation of bacterial and algae suspensions.

Sweep floc: The destabilization of particulates using soluble cations (aluminum, iron, magnesium - they hydrolyze and form an insoluble precipitate, thereby minimizing the concentration of ions added to the water) Ph values need to be maintained between 6 and 8.

Two primary functions required of coagulant chemicals: a) particulate destabilization, 2) strengthening flocs to reduce floc breakdown.

Practical constraints of chemical coagulants:

1. low cost
2. ease of handling
3. availability
4. chemical stability in storage
5. must form highly insoluble compounds or be strongly absorbed on particulate surfaces (to minimize soluble residuals that might pass thru the treatment system)

Inorganic Coagulants:

Polymers - long-chain molecules consisting of repeated chemical units with a structure designed to provide distinctive physicochemical properties to the polymer. The chemical units usually have an ionic nature that imparts an electrical charge to the polymer chain, thus they get their name, polyelectrolytes.

Polymer use has been limited due to the high cost and uncertainties regarding chemical impurities associated with polymer synthesis.

Over 600 polymers have been approved in the US by the EPA for potable water treatment (1979)

Types of polymers: Broadly classified into natural and synthetic, the later type being predominant.

Polymer synthesis can be manipulated to produce polymers of varying size (molecular wt), charge groups, number of charge groups per polymer chain (charge density), and structure (linear or branched).

Monomer - single molecule of a chemical

Homopolymerize - the process of the same molecule linking in an indefinite number of molecules in a chain.

Polymer - chain of monomers.

Cationic polymers are usually achieved by copolymerization process.

Overdosing of particles will cause restabilization.

Examples of 3 cationic polymers:

1. DMDAAC, molecular wt range 10^4 - 10^6 , primary coagulant, chlorine resistant, charge density not pH sensitive; available in liquid form. Turbidity/color removal, sludge conditioning. May be used in conjunction with inorganic coagulants.
2. Quarternized polyamines, molecular weight range 10^4 - 10^5 , primary coagulant, color/turbidity removal (used primarily for color removal) (properties similar to DMDAAC).
3. Polyamines, molecular weight range 10^4 - 10^7 , primary coagulant, also used as coagulant aid (high MW). All types react with chlorine. Charge density depends on pH.

In general, anionic polymers make effective coagulant aids, while nonionic polymers are effective filter aids.

Edzwald, James K., "Organics, Polymers, and Performance in Direct Filtration"

Direct filtration is a treatment scheme where all of the particulates are removed in the filters; there is not a sedimentation tank. Two types of direct filtration; 1) in-line filtration (contact filtration), 2) direct filtration with a flocculation tank prior to the filters.

This paper compares the use of polymers and alum in direct filtration.

Three cationic polyelectrolytes were chosen for this study, Betz 1190 (mfg is Betz Laboratories) and Magnifloc 572C and 573C (mfg is American Cyanamid).

Magnifloc 573C was used primarily due to its high charge density and because of excellent direct filtration results obtained with its use.

The results of this study were that alum removed higher portions of total organic carbon (TOC) and trihalomethane (THM) than the cationic polymer. Although it was discovered that alum can be very effective in the treatment of colored water by direct filtration. The use of alum in direct filtration is not recommended, except for low turbidity, low TOC water.

Craig, Keith, "Direct Filtration: An Australian Study" Journal AWWA

Chichester Dam, New South Wales, Australia, run by Hunter District Water Board, standards for treated water are as follows: turbidity < 0.5 ntu, true color < 5 cu, iron < 0.2 mg/L, and manganese < 0.05 mg/L. The dam would be closed off if the water did not meet specs, and with increasing water shortage, they needed a treatment facility for the water.

Alum and polyelectrolyte were dosed into the raw water line using in-line static mixers. The chemical dosing system was common to all filters and enabled various sizes and types of media to be evaluated concurrently. Alum was the primary coagulant and the (nonionic polymer) polyelectrolytes were the coagulant aids.

(Nonionic polymers used were as follows: Magnafloc series LT20 (nonionic), LT24 (anionic), LT22 (cationic) (manufacturer, Allied Colloids (Australia) Pty. Lt, Sydney, N.S.W., Australia). Alfloc Series 8103 (cationic), 8020 (nonionic), 8035 (cationic), all liquids, (manufacturer, Catoleum Pty. Ltd., Sydney, N.S.W. Australia)

The optimum dose for raw water quality of 2.0-100 ntu varied from 10-35 mg as $Al_2(SO_4)_3 \cdot 18 H_2O/L$, producing an effluent with turbidity < 0.3 ntu and color < 5 cu. There was a lag time between the addition of the alum and the subsequent addition of the polymer. 6.5 seconds was the optimum. Varying water temperatures changes the lag times considerably.

Kim, Yong H., "The Importance of Polymer Activation in Flocculation." WEM Reference Handbook. Water/Engineering & Management, August 1988.

The use of synthetic polymers as flocculants, however, is of growing technological importance because flocculation by polymer produces flocs (large clumps of suspended particles) which can be much stronger or larger than those formed by inorganic salts.

Drawbacks of alum and ferric oxide as coagulants:

- o they have a small molecular size greatly limiting their effectiveness in flocculation
- o they are both positively charged (cationic) and thus will attract only negatively charged particles
- o they either depend upon or have a substantial effect on pH of the solution
- o sludge accumulation is increased because of the additional volume of salts required in treatment

Polymers may have an extremely large molecular size, offering thousands and thousands of charged sites. The polymer chains are sufficiently extensive to attach to the surface or adsorb on more than one particle, thus binding or bridging the particles together, thus forming a particle-polymer-particle bridge.

"Storage and Handling of Polymers," *ibid.*

HANDLING OF POLYMERS

Dry polymers: come in various types of powders, depending on manufacturer. Most claim to be 100% effective, but are truly only 94-96% active. Most package in 50 lb. bags. This is by far the most economical, but a fine dust is present when the powder is handled, causing a safety hazard.

Liquid polymers: two types, solution or emulsion/dispersion. Water or oil base solutions (respectively).

Solution polymers: range of 4-50% polymer. Some are extremely viscous and difficult to pump.

Emulsion/dispersion polymers: range between 25-50% polymer concentration. "Neat" or undiluted form they have a low viscosity and may be easily pumped, but when water is added, viscosity greatly increased. Therefore prevention of water contamination is necessary during storage of these polymers.

Packaged forms include 5 gallon pails, 55 gallon drums and "mini-bulk" tote bins of 300-700 gallons capacity.

- pails are often preferable to 5 gallon drums for small volume users of emulsion/dispersion polymers, since they are used fairly rapidly and separation of the oil from the polymer is not allowed to occur (called stratification). Pails weigh approx. 50 lbs. easily transported.

- drums are a good packaging option for medium consumers. As they weigh up to 500 lbs when full, a hand truck, drum cart or fork lift truck should be used. Stratification happens, so a drum mixer should be used before use on the emulsion/dispersion polymers.

- tote bins are for large consumers. Hold the equivalent of 12, 55 gallon drums. The empty tote bins are returned to the supplier. Bins are usually equipped with recirculation pumps for emulsion/dispersion polymers to avoid stratification.

STORAGE OF POLYMERS

The storage area should be covered and dry, with a temp range of 40° F, minimum to 100° F maximum. Temperature is especially important for liquids as they should never freeze or be exposed to extreme heat.

Dry polymers are moisture attracting (hydrophilic), no dampness should be around during storage. Properly stored, dry polymers have a long shelf-life.

Solution polymers should be stored in tightly sealed, original containers, and properly ventilated.

Emulsion/Dispersion polymers are basically the same as solution, however, the tendency to stratify means strict stock control program should be followed. Always mix contents before use.

SAFETY HAZARDS

Potential falls due to slippage and possible irritation to skin, eyes or lungs due to exposure to many coagulants.

Committee Report, American Water Works Assoc., "Survey of Polyelectrolyte Coagulant use in the United States," November, 1982, Journal AWWA.

300 Utilities answered questions about their use of polyelectrolyte coagulants.

73% (of 336 responses) indicated that their source of raw water was a surface source upland impoundment, (river or creek, natural lake) either as a sole source or in combination with well water.

The 50 percentile values for the minimum, average, and maximum turbidity are approximately 1, 5, and 32 tu, respectively. It is interesting to note that in an earlier survey of direct filtration practice in the US, a similar plot of percentage values for turbidity values yielded 50 percentile values of approx. 1, 3 and 28 tu, respectively.

Table 2, p. 601

Polyelectrolyte suppliers and product designations

Supplier	Product Designation
Allied Colloidal	LT-24
American Cyanamid	836-A, 847-A, 1849-A, 572-C,

Betz
Calgon

Craig
Culligan
Dow
E.A. Stanley
Ham & Hayes
Hercules
Nalco

573-C, 575-C, 577-C, 585-C,
588-C, 593-C, 985-N, 990-N,
1986-N
1100-P
CatFloc A, CatFloc B, CatFloc
T, 233N, 223
FK-110
F-86
NP-10
Hamaco 196
80-7 AP
HF-813, HF-863
110A, 345*, 607, 617, 8100,
8101, 8102, 8103, 8104, 8113,
8170, 8171, 8172, 8173, 8174,
8182, 8184, 8770, 8792
M295
ZF-67

PE-Stewart
Zimmite

*(Nalco 345 is not approved for potable water by EPA)

The single largest response to how polyelectrolytes are used is combined with alum. Only 17 out of 129 users indicated that they use polyelectrolytes as sole coagulants.

Randtke, Stephen J. "Organic Contaminant Removal by Coagulation and Related Process Combinations," Journal AWWA

Three types of organic contaminants in water, 1: Natural Organic Matter, (NOM) 2: Synthetic Organic Chemicals, (SOC) 3: Chemical by-products and additives formed during treatment.

Successful operation depends on maintaining a low loading of adequately destabilized particles to the filters, which is generally accomplished by relying on charge neutralization rather than enmeshment as the primary destabilization mechanism. Polymers, alone or in combination with low dosages of alum, are very commonly used in direct filtration to reduce solids production, improve solids capture, and lengthen filter runs. Direct filtration can effectively remove particles, including NOM and SOC's absorbed to particles.

Leu, Rong-Jin and Ghosh, Mriganka M., "Polyelectrolyte Characteristics and Flocculation," AWWA Journal, April 1988

Polyelectrolyte Standards Committee of the American Water Works Assoc. is working hard to establish a rational method for selecting chemicals.

The purpose of this study was to determine the interrelationships among M_w (molecular weight), CD (charge density), dosage, mixing intensity, and flocculated particle size distribution (PSD) for several commercially available cationic polyelectrolytes.

The charge density rather than the molecular weight of a polyelectrolyte is important in selecting the optimal dosage for flocculating particles with a primary charge opposite that of the polyelectrolyte.

Amy, Gary L. and Chadik, Paul A. "Cationic Polyelectrolytes as Primary Coagulants for Removing Trihalomethane Precursors," Journal AWWA

The research in this article attempts to provide insight into the use of cationic polyelectrolytes as sole coagulants for removing THM precursors from a broad spectrum of natural waters and to relate these results to coagulation of synthetic waters.

Cationic polyelectrolytes can affect TOC and THMFP concentration because they themselves are capable of forming THMs during chlorination if a residual of the polymer remains in solution after the treatment.

It was found that polymer coagulation works well for natural water with low turbidity, low pH levels, and high color. Direct filtration may be a potential strategy for THM control. Raw water characteristics influence polymer selection and performance.

Tate, Carol H. and Trussell, R. Rhodes, "Recent Developments in Direct Filtration," Journal AWWA, March 1980

Study in New South Wales, Australian on the water supplies of the Wyong River and Ourimbah Creek. They were found to be highly colored.

The polymer used in this study were CatFloc T (Calgon Corp.) and Alfloc 8101 (Catoleum Pty., Ltd., Botany, NSW, Australia)

Ozone pretreatment to direct filtration has been determined to make a difference in the removal of turbidity.

Letterman, Raymond D., "An Overview of Filtration," Journal AWWA, December 1987.

Effective operation of filtration systems may require pretreatment of the influent suspension. Processes used in pretreatment include coagulation, flocculation, and solid-liquid separation, such as sedimentation, flotation, and low-efficiency filtration.

Cationic polyelectrolyte coagulants destabilize suspensions by adsorption on the particle surfaces. If the particles are negatively charged, as most naturally occurring particles are, this charge is neutralized by the adsorbed positive sites on the polymer molecules. If too

much polyelectrolyte is added to the suspension, the particles become restabilized by the adsorbed positive charge. The positive charged particles then tend to deposit on the negatively charged filter surface, and removal efficiency may deteriorate.

The aggregates formed after destabilization with cationic polyelectrolytes usually have a higher density than those formed by the use of hydrolyzing metal coagulants. There is, as yet, no rational basis for predicting the required amount of coagulant. Therefore, operators use rules-of-thumb and batch testing, which is a weak point in plant operation.

Flocculation is a process in which mixing is used to promote the aggregation of particles in a destabilized, coagulant-treated suspension. It often produces very inefficient use of the interstitial space in the bed and therefore, an unacceptably high rate of head loss.

AWWA Coagulation Committee, "Coagulation as an Integrated Water Treatment Process," Journal AWWA, October 1989

Chemical coagulants serve a variety of purposes: 1) to destabilize solid particles, 2) to remove organic color and trihalomethane (THM) precursors from solution, 3) to aid flocculation through the use of coagulant aids, 4) to improve filtration, and 5) to pretreat water prior to use of granular activated carbon.

Alum is the most commonly used coagulant in the US.

The majority of research and observation indicates that the contaminants most easily removed by coagulation are those of high molecular weight and those that are hydrophobic but possess functional groups able to react with specific sites on the coagulant floc particles. As a result, coagulation is preferentially used to remove color. Coagulation is often unsuccessful for the removal of SOC's.

It is important to consider the dissolved organic carbon (DOC) concentration as well as turbidity in evaluating coagulants.

Unknown, "Coagulation Treats Water to Aid Settling, Removing Suspended Solids from Water, A Special Report."

Successful coagulation depends on both pH and the water analysis after addition of chemicals. Optimum dosage will vary with suspended particle size and concentration, detention time before coagulation, water temp, amount of mixing, etc.

Gross, Andrew C., "The Market for Water Management Chemicals," Environmental Science and Technology volume 13, number 9, Sept. 1979.

Types of companies that sell water treatment chemicals are classified under SIC codes 28 and 35.

This article contained a list of selected water treatment chemical companies.

End markets or users for water treatment chemicals include municipalities, industries, and even households and farms.

Newton, James J., "Chemicals for Wastewater Treatment," Pollution Engineering, November 1985, v17.

Not very useful, only deals with wastewater.

Keeper, Lynn P., "Successful R-O Operation Demands Careful Pretreatment," Dec. 1987

This was not very useful.

Wiesner, Mark R., O'Melia, Charles R., Cohon, Jared L., "Optimal Water Treatment Plant Design"

Cost reduction study of various types of water treatment, did not find this very useful.

Bratby, John R., "Optimizing Direct Filtration in Brasilia," Journal AWWA, July 1986"

Study to define the optimum conditions for direct filtration at the Brasilia, Brazil water treatment plant. The use of ferric chloride was found to offer definite advantages (longer filter runs and lower effluent turbidities) over the use of alum. For the raw waters studied, the use of cationic polyelectrolytes to reduce the metal coagulant dosage was not feasible.

If the coagulant dosage required to obtain satisfactory results is high, then the possibility of practicable treatment by direct filtration is doubtful. Problems arising from relatively high coagulant dosage can be tempered by designing a filter with more storage and thus a capacity for greater loads.

Treweek, Gordon P., "Optimization of Flocculation Time Prior to Direct Filtration," Journal AWWA, February 1979

Combination of alum and CatFloc T were used simultaneously as coagulants in this experiment. A time of seven minutes, minimum in flocculation time was required to produce

the aggregation of the singlets required for their removal in the filter media. Seven minutes or more resulted in sufficient growth of aggregates to cause their removal in the subsequent filtration step.

The elimination of the sedimentation step resulted in a significant cost savings, in the design and construction of the Utah Valley water purification plant in this case.

Glasgow, Larry A. and Kim, Y.H. "Characterization of Agitation Intensity in Flocculation Processes," unknown source

Not very useful.

Tanaka, Theodore S., Pirbazari, "Effects of Cationic Polyelectrolytes on the Removal of Suspended Particulates During Direct Filtration," Journal AWWA, December 1986

Recent studies on direct filtration have only addressed the treatment of source waters with moderately high turbidities (20-75 mg/L or higher). A large proportion of naturally occurring waters is low turbidity (less than 10 mg/L).

Six different cationic polyelectrolytes and three different colloidal suspension types were used in the bench-scale tests. The six polyelectrolytes were of two basic monomeric structures: PDADMAC (polydiallyldimethylammonium chloride) and polyethylenimine (PEI). The three different colloidal suspension types were silica, bentonite, and kaolin.

This test involved rapid mixing after addition of the coagulant.

Amirtharajah, Appiah, Trusler, Scott L., "Destabilization of Particles by Turbulent Rapid Mixing," unknown source

The intensity of rapid mixing required, which controls the rate of collisions, is dependent on the predominant mode of coagulation.

The process of coagulation transforms smaller particles into larger aggregates, such that they are amenable to sedimentation. The overall process of coagulation includes a particle destabilization step followed by flocculation, which is a transport step causing growth of aggregates. Flocculation is currently analyzed as being caused by collisions between particles in three mechanisms: 1) Brownian or perikinetic flocculation due to the thermal energy of the fluid, 2) velocity gradient or orthokinetic flocculation due to bulk fluid motion, 3) differential settling due to a larger particle overtaking and colliding with a slower settling particle.

Destabilization is due to two mechanisms, 1) charge neutralization/precipitation, in which metal-hydroxy polymers coat the raw water colloidal surfaces and 2) sweep coagulation,

where physical interaction occurs between the voluminous precipitates formed (iron or aluminum hydroxide) and the raw water colloids.

After this discussion, the study then moves on to turbulence, which is not useful for this study.

Cadotte & Peterson, "Mechanism and Prevention of RO Membrane Fouling"

MERADCOM company uses a pretreatment process involving addition of an organic polymer flocculating agent followed by sand filtration. The flocculant is a quaternary amine group. It was found that ferric chloride is somewhat better than alum for removing the organic colloids from river water. Also, the alum residues fouled the membrane whereas ferric chloride did not.

Yeh, Hsuan-Hsien, Ghosh, Mriganka M., "Selecting Polymers for Direct Filtration," Journal AWWA, April 1981

Cationic polymers with low to medium molecular weights and high charge densities are ideally suited for direct filtration. Rapid mixing at a velocity gradient of $300-650 \text{ sec}^{-1}$ for 3-6 min is necessary before filtration. In most cases slow flocculation may be avoided. Modified jar tests with high intensity mixing followed immediately by particle size distribution analysis should be the method of choice for selecting polymers for direct filtration.

Direct filtration differs from conventional methods of treatment in that all solids, those occurring naturally and those added in the course of treatment, must be removed in the filter. This process usually consists of the addition of destabilizing chemicals, followed by some flocculation with no settling, and finally, filtration. However, in some cases, depending on the raw water quality, an organic polyelectrolyte may be added by rapid mixing and the water filtered directly with no flocculation. The use of polyelectrolytes instead of metal coagulants such as alum, may substantially reduce the amount of sledge to be handled.

Most often polymer selection is made on a hit-or-miss basis. Polymers, pH, and ionic strength of natural waters are the three most important variables that can be used to improve the efficiency of direct filtration by modifying the surface characteristics of either the suspension, filter, or both. pH and ionic strength are usually not the variables routinely controlled.

Information supplied by manufacturers should include the type of polymer or copolymer, the concentration of action ingredient, the concentration of free monomer, the proportion of ionizable groups, and the molecular weight or intrinsic viscosity under specified conditions. Also information on the extent of mixing required to disperse polymers effectively in the water is needed in selecting polymers for direct filtration.

The essential function of polymeric flocculation is to produce aggregates that will be large enough to be captured and strong enough to withstand shear in the filter voids. However, shear may not be the mechanism of floc breakup, if any in filter. Conceivably, the flocs are held together by interfacial tension. It was suggested that the early conditions of floc formation are important and the function of rapid mixing is more than simply dispersing the flocculant. Cationic polyelectrolytes of low to medium molecular weight seem to be most effective in the direct filtration process, especially in dual or multi-media filters treating natural suspensions. It was observed that better filtration performance with increasing molecular weight occurred only when a reasonable flocculation period was provided.

Concentration of free polymers in solution was found by using the colloid titration technique. A jar test was used for determining optimum dosage of the 10 polymers to be tested. Rapid mixing at 85 rpm for 1 minute, slow mixing at 25 rpm for 20 minutes, and settling for 30 minutes, before turbidity was measured.

The optimum dosage was found to be in the range of .3 to .5 mg/L for polymer C (polyethylenimine).

The effect of mixing intensity and duration on polymer flocculation was determined to be a range of 3 to 8 minutes. Anything over 8 minutes caused breakup of floc, especially for large molecular weight polymers.

Conclusions: Polymers found to be good flocculants and filter aids are usually linear homopolymers. The effect of mixing on polymer dosage and filter performance is significant.

Habibian, Mohammad, O'Melia, Charles, "Particles, Polymers and Performance in Filtration," Journal of the Environmental Engineering Division, August 1975

This study involves the use of polymers as coagulant aids. Primarily, to evaluate the influence of molecular weight on the effectiveness of polymers as filter aids.

Coagulation, unknown author

Water quality and health problems associated with high concentrations of aluminum in finished drinking water have raised questions about the wisdom of using aluminum salts as coagulants and have led to discussions of ways in which residual aluminum concentrations could be limited.

Two other drawbacks of alum are its lack of cost-effectiveness compared with other coagulants and its loss of turbidity removal efficiency at low temperatures. Ferric chloride removes turbidity more effectively than does alum. However, alum causes slower head loss development.

Brink, Deborah, Choi, Suing-Il, Al-Ani, Mohammed, & Hendricks, David, "Bench Scale Evaluation of Coagulants in Low Turbidity Water," April 1988, AWWA Journal

Conventional jar testing is ineffective for determining optimal coagulant dosages for low turbidity waters. Utilities employing rapid-rate filtration of such waters may fail to maximize treatment efficiency for lack of a simple bench-scale test for determining coagulant dosage. This study involved waters with turbidity of levels 1 ntu or less. The test is like a jar test except the use of bench-scale filters is added and the slow mix and settling steps are omitted.

It was found that jar-filtration tests can have utility in determining coagulant dosages in filtration of low turbidity waters. A visible floc is not readily formed during coagulation of low turbidity waters, making the conventional jar test not applicable.

Suzuki, Akira, Kashiki, Isamu, "Flocculation of Suspension by Binary (Polycation-Polyanion) Flocculant," Ind. Engr. Chem Res., Vol. 26, No. 7, 1987

PEI (polyethylenimine hydrochloride) and PVSK (potassium polyvinyl sulfate) were mixed together to test their combined flocculation power. It was found that not only are their powers increased, the concentration region where the polyelectrolytes work was greatly increased.

The power of this combined flocculant was good for two reasons: 1) a small dosage of only about 22 ppm was enough to flocculate the suspension, 2) the restabilization phenomenon caused by an overdose of the flocculant was not observed.

Kashiki, Isamu and Suzuki, Akira "On a New Type of Flocculant," Ind. Engr Chem. Fundamentals, 1986, 120-125

Associated Colloidal Flocculant (ACF) was generalized to the case of a colloid formed from a precipitation or coacervation reaction. Based on this idea, various colloids were prepared by making use of the reactions between cations and anions. To test the colloids aggregating powers, water clarification experiments on suspensions were carried out by using the colloids as ACFs. The results showed that aggregating power can be greatly improved by changing the state of the corresponding ions from soluble to nearly insoluble. With increasing molecular weight, the solubility of a polymer generally tends to decrease, causing the technological difficulty involved in the synthesis of water-soluble high polymers to increase. An ACF can be defined as a flocculant that is hardly soluble in water, so that it is dispersed in the state of relatively large colloidal particles through molecular association, and thereby shows an ability to flocculate suspended solids.

Hong-Xiao, Tang, Stumm, Werner, "The Coagulating Behaviors of Fe(III) Polymeric Species-I and II, Performed Polymers by Base Addition," Water Resources, Vol. 2, No. 1, pp. 115-121, 1987.

Part I - Of no use to this study.

Part II - Two main types of interaction occur in coagulation, 1) the binding (specific adsorption) of coagulant species to the material to be coagulated (particles, colloids, polymers and solutes) and 2) the enmeshment of the material to be coagulated by hydroxide precipitates of the coagulant metals (sweep coagulation). In the second method, the percentage of coagulant needed is not primarily related to the concentration of colloids present.

Dentel, Steven, Resta, John, Shetty, Prasanna, Bober, Todd, "Selecting Coagulant, Filtration, and Sludge Conditioning Aids, Journal AWWA, January 1988"

This study developed the manual we plan to order from the AWWA. The US EPA has listed more than 1,300 coagulant aid products approved for treatment of drinking water. Errors caused by nonuniform testing procedures could be minimized by the use of a standardized set of evaluation methods. A clear need exists for an established set of evaluation procedures that could be used to select the most promising polymers and dosages for use in water treatment plants.

Traditional testing procedures for coagulants, filtrates, and sludge conditioning was discussed. The jar test has widespread use due to its ability to simulate rapid mix, flocculation, and sedimentation in one vessel. However, there is a great deal of variation in how the test is performed. Because the polymer may be sensitive to these performance variables, many variables were assessed while developing this study procedure. Means to compare jar test results include visible inspection, turbidimetry and particle size analysis. Bench-scale filtration downfall that results may somehow be scaled up to predict filtration phenomena with increasing media depth.

Dewaterability of sludge is tested by using specific resistance to filtration (SRF) and capillary suction time (CST). No standardized procedure exists for the SRF test because of disagreement on a number of factors that may influence the results. CST measures the time required for liquid extraction caused by capillary action from a sludge into a sheet of chromatography paper. It is rapid and simple and can be performed using only a 2-L jar test. However, a specialized CST instrument is required.

Preparing, diluting, and dosing the working solutions of polymers was difficult because of: adding the polymer to water too rapidly or too slowly; inconsistent aging of the solution; exposing the polymer to high turbulence, such as in centrifugal pumps; excessive exposure to light, heat, or cold; and biodegradation caused by improper storage.

This was an experiment to test polymers as coagulant aids, not as a primary coagulant. In testing the polymers in turbidity removal, optimal turbidity removal occurred at lower dosages of polymers.

Pizzi, Nick, DeCola, Tony, "Primary Coagulant Aid Outperforms Alum, Slashes Operating Costs," Journal AWWA

This study involves the use of water with the following characteristics: average turbidity of 25 ntu's, pH ranges from 7.5 to 8.3. The goal was to make the water turbidity 0.1 ntu or less with a pH of 8.1 to 8.3, chlorine residuals 2.2 to 2.5 mg/L, no taste and odor problems, and no algae breakthrough in its mixed-media filters.

This plant has two 5,000 gallon rapid mix tanks for the addition of coagulant aid, caustic or chlorine. It also has six 105,000 gallon settling basins and two 60,000 gallon sludge thickeners.

The mixed media filters contain anthracite coal, sand and gravel. Filter beds are periodically cleaned by a standard backwash. Powdered activated carbon, fluoride, chlorine or a filtration aid can be added to the water prior to filtration.

Alum was the primary coagulant aid used with a dose of 18 mg/L. Several inefficiencies and cost concerns arose with alum: 1) High sludge generation with a low 6.8 percent sludge solids content. 2) An unacceptably high filterability index of 1.4 on settled water - which meant more frequent filter washing and more wash water had to be recycled and retreated; and 3) A 16 to 20 water corrosivity index range.

Then the plant switched to use of a specially formulated liquid cationic polymer. Polymer used was Cat-Floc K-5.

Benefits:

- o Plant producing one third as much sludge.
- o Increased filter runs from 48 hours to 80 hours.
- o Less filter backwashing is necessary and more finished water is sent to distribution.
- o Less caustic was necessary to reduce the pH of the water.

The polymer neutralized the negative charges on suspended particles, and quickly forms a dense, rapid settling floc. The polymer is chlorine-resistant and is effective over a broad pH range. Initial dosage has been 6-7 mg/L.

McCormick, Richard and King, Paul, "Factors that Affect Use of Direct Filtration in Treating Surface Waters," Journal AWWA, May 1982

This is an evaluation of direct filtration as a treatment method for water from five sources in Virginia. The most effective filter scheme consisted of a three minute rapid mix with alum and a cationic polymer used in combination as primary coagulants. The rapid mix was followed by filtration at 3.5 mm/s through 51 cm of 1.3-mm effective size anthracite coal and 25 cm silica sand.

The definition of ntu is nephelometric turbidity unit.

Coagulation by aluminum salts is affected by salt concentration, pH, temperature, nature of solids, size of turbidity particles, mixing, and coagulant concentration. One problem with the use of aluminum sulfates as a coagulant in direct filtration is early breakthrough of turbidity with increasing coagulant dosage. It was reported that the advantages of using polymers as primary coagulants include reduced sludge volumes, reduced coagulant dosages, improved sludge dewatering, lowered chemical residuals in the filtered water and diminished problems with pH and alkalinity adjustments; polymers are also non-toxic. There may be some problem using cationic polymers as primary coagulants in direct filtration from an efficiency standpoint. Low turbidity water is difficult to coagulate with polymers because the particle-polymer complex may fail to bridge to another particle because of particle scarcity. The subsequent result is that the polymer becomes entwined around the first particle, causing restabilization.

Alum coagulated trials accumulated head loss at approximately twice the rate of polymer coagulated trials for raw water of similar quality.

The advantages of using alum and polymer together include fewer added solids to be stored in the filter compared with alum coagulated runs, the color removal achieved with alum, the breakthrough prevention ability of polymer, and the .10 ntu filtered water turbidity that seems to be necessary to guarantee removal of algae and coliform bacteria.

Monsevizt, J.T., Rexing, D.J., Williams, R.G., Heckler, J. "Some Practical Experience in Direct Filtration," Journal AWWA October 1978

This plant used aluminum sulfate at two flash mixers (150 and 56 kW), along with other chemicals, such as powdered activated carbon. Provisions were made for the addition of a polyelectrolyte at this location and at the inlet of each filter, but improvement of the floc was left to contact within the filter media. Analysis showed an excess of aluminum in the finished water.

Turbidity is not the only parameter used as a criterion for water quality. Direct filtration methods, while effective for turbidity removal, may be inadequate for plankton and taste and odor removal. In general, the amount of coagulant required with sedimentation was 25 to

40 percent greater than for treatment without sedimentation. Alum dosages were determined by comparing total system performance. A combination of alum and a cationic polymer at a ratio of 10 to 1 resulted in the best overall pilot plant performance. Minimum coagulant use was obtained by 20 to 30 min of flocculation, as determined by zeta potential adjustment and process performance measured by effluent turbidity, filter run duration, and headloss profiles. Specific coagulant amounts were dependent upon raw water quality. Filtration with flocculation resulted in longer filter runs in all modes of treatment. Less coagulant was required when flocculation was incorporated as a pretreatment unit process, and more consistent plankton removal was achieved.

McKeon, William, Muldowney, John, "Evaluating Alternative Coagulants to Determine Efficiency and Cost Effectiveness," November 1987, Journal AWWA

Ferrous sulfate was studied as an alternative coagulant to ferric chloride. Coagulants were evaluated for iron content, heavy metal contaminants, acidity, chlorine demand, and settleable solids.

The cost of ferric chloride had been spiraling at a rate over and above cost increases for other water treatment chemicals. This plant was located in Philadelphia, PA on the Delaware River. This river is subject to tidal variations that affect raw water quality. Turbidities range from 3 to 100 ntu and alkalinities range from 20 to 60 mg/L. Chemicals fed routinely include chlorine, ferric chloride, lime, fluoride, and ammonia. Powdered activated carbon is added periodically to control taste and odor. Trihalomethane control is accomplished with the addition of chlorine dioxide.

Ferric Chloride advantages: broad range of pH for performance, formation of a heavier floc than that of alum, and low aluminum residuals in the finished water. The other coagulants were compared with known qualities of ferric chloride.

Polyaluminum chloride (PAC) is popular in Japan and Europe. The benefits of PAC relative to alum have been investigated as a function of pH, raw water composition, and mixing conditions. Advantages are good floc formulation, reduced need for neutralizing agents, activity over a broad range of pH, and reduced sludge generation. Very high cost compared to ferric chloride, so it was removed from consideration.

Use of aluminum sulfate was discontinued because of economics and the need to cease the use of lime at posttreatment. The lime in posttreatment caused increased turbidity and deposition of solids in the clearwell.

Performance and cost criteria were consistently better for ferric chloride than for alum over the years of testing at this plant.

Ferrous iron use was discontinued because of a nationwide shortage of chlorine. A ferrous form of iron was evaluated once again and ferrous sulfate was located and evaluated

according to the criteria previously discussed. After initial evaluation it appeared to be competitive in both price and performance to the currently used ferric chloride. Further tests were performed. The ferrous sulfate required 20 percent less lime than the ferric chloride to adjust pH. The ferrous sulfate consistently outperformed the ferric chloride.

Eisenberg, Talbert, Middlebrooks, E. Joe, "A Survey of Problems with Reverse Osmosis Water Treatment," AWWA Journal, August 1984.

The authors surveyed operators of 28 reverse osmosis water treatment plants to obtain information on the types and causes of problems.

Survey was sent to 117 plants, only 24% responded, which is typical of mail surveys.

Some 95% of the plants reported using pretreatment with chemicals added to the feedwater. To control calcium carbonate scale, sulfuric acid was used at 95% of the sites and hydrochloric acid was used at 5 percent. Sodium hexametaphosphate (SHMP) was used at 93% as a scale inhibitor.

Coagulation, flocculation, and sedimentation was used at 5 sites only. Lime softening was used at 10% of the plants. Coagulant aids were ferric sulfate, alum, and polymers.

Eisenberg, Talbert N. and Middlebrooks, E. Joe, "Reverse Osmosis Treatment of Drinking Water," post 1983

Sodium hexametaphosphate is widely used to keep calcium, magnesium, and metallic salts in solution.

Pretreatment is an integral part of the total reverse osmosis system. While pretreatment adds to the capital cost of the plant, the extra cost is soon saved in reduced maintenance costs.

Himmelstein, Walter and Amjad, Zahid, "The Role of Water Analysis, Scale Control, and Cleaning Agents in Reverse Osmosis," Ultrapure Water, March/April 1985.

Methods of diagnosing, removing, and preventing fouling of R.O. membranes are discussed.

Periodic water analysis is often required for maintaining membrane performance guarantees.

Slovak, Jack and Robert, "Developments in Membrane Technology," Coster Engineering, August 1987.

No pertinent information regarding coagulants in this article.

APPENDIX C
POINTS OF CONTACT

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FOR
COAGULANT DATA

1. Melvin Leu, TEL 648-6811, Geological Survey Research Office (formerly with the Office of Water Research and Technology, Dept of the Interior).

A. Indicated that information on nationwide water desalting plants (a book-size report) can be obtained from the National Water Supply Improvement Association, Ms. Patricia Burke, TEL (617)887-8101. Some of these plants use coagulants. See # 2 below.

B. Also recommended contacting the Bureau of Reclamation R&D Center in Yuma, AZ, TEL (602) 343-8155. Spoke with Ed Lohman, Ops and Maint Manager. He said the R&D pertains strictly to very dirty agricultural water. He reinforced the fact that use of coagulants is a "black art" in that it is highly dependent on the quality of the raw water. Manufacturers usually have the best idea of the type of chemicals to be used for a certain type of water. The manufacturers that are used most by BR are: Ciba-Geigy, Flocon, Calgon, and Betz. BR normally uses either solids contact reactor (lime addition to soften the water) or gravel and anthracite filters used in conjunction with coagulant as pre-treatment. Mr. Lohman provided excerpts of polymer testing that has been completed on RO feed water on 6/11/90 (copy given to Dina). Provides good information on several polymer products.

C. Mr. Leu also recommended talking with the Naval Civil Engineering Lab (NCEL), Port Huaneme, CA. See # 3 below.

2. The International Desalinization Association (IDA) is located in Topsfield, MA, TEL (508) 356-2727. Spoke with Patricia Burke who provides the plant inventory for either \$160. or \$210. (member vs nonmember). The Biennial meeting is scheduled for August 1991 in Washington, DC. The National Water Supply Improvement Association (NWSIA) is an affiliate of IDA and the POC is Mr. Jack Jorgenson (301) 855-1173. Mr. Jorgenson provided a list of user-members (about 25-30 water purification plants in FL and CA, both public and private) on 5/21/90. He also provided another POC, Mr. Bill Harlow at (813) 966-4878.

A discussion with Mr. Harlow on 5/23/90 revealed that he has a list of about 200 plants in FL, of which the first 85 are RO. The list was compiled for a water treatment conference (to be held in Orlando in August). He will provide the list, but first needs a letter of request sent to him at: 469 Laurencin, Nokomis, FL 34275-3529. Make reference to the phone conversation with Mr. Jorgenson of NWSIA. He will denote the most promising RO plants on the list. He also said that many membrane softening plants are being used in Florida. This process uses RO and almost potable quality water, and removes ion causing

hardness. It differs somewhat from lime softening and causes less sludge accumulation. List was provided about 6/8/90.

Mr. Tom Sheil, Blue Plains Water Treatment facility, WASH, DC (202) 563-3494, tried to get access to the directory to obtain the names of a few important facilities. He was unable to access the directory.

3. Mark Silvernagle of NCEL, TEL (805) 982-1631, has extensive experience with ROWPUs including use of media filters. They have investigated use of coagulants including polymers for use in drinking water.

A. Many polymers are not approved for potable water. Of those that are, liquids are easiest to use or batch, as opposed to those that are packaged as solids or emulsions. The liquids do not require a mixer or high mixing energy, just a paddle will do.

B. Agrees that cationic polymers are likely to be best. The types that form a pinpoint type floc (higher charge densities) will most likely preclude plugging or clogging. On the other hand, NCEL is currently doing a project to determine the feasibility using polymer to create larger, denser floc in conjunction with ROWPU settling or clarification tanks that are portable.

C. Indicated that recent articles in the Journal of Environmental Engineering tested Calgon CAT FLOC products in various waters including those high in algae. Higher charge densities worked best.

D. Often, ferrous sulfate (which is fairly cheap) is used as the coagulant in high turbidity water to create a positive charge. Then an ionic polymer is used in small quantities (higher cost) to neutralize the particles.

4. David H. Paul, Inc, is headed by Mr. Paul, TEL (505) 326-3431, who was contacted to determine if a list of RO and coagulant users was available. He said that the majority of utilities don't use RO, and most of those don't use coagulants (most utilities of interest are in Florida). He indicated that as a result of his market research he could identify the RO and coagulant user. He was only able to identify 2: R D Nixon Power Plant, Colorado Springs, CO, Mr. Bob Doyle (719) 636-5686; San Diego Wastewater Treatment facility, CA, Mr. Able Hernandez (619) 280-4107. Dana made calls on 5/16 - see her notes at 8.-10. below.

5. American Water Works Association (AWWA), Standards Engineer for the Filtration Committee is Ed Baruch, TEL (303) 794-7711. He indicated that surveys of water utilities were conducted in 1984-85 and 1989-90. These are not of value as they did not request the type of purification process used; however, RO is not common in large utilities. He relayed me to:

A. AWWA Research Foundation, Joel Catlin, who indicates that work is underway in the areas of pre- and post-filtration for RO. They have an RFP out for research in these areas. He agrees that there are few commercial RO plants, especially that use coagulants. He provided a copy of the RFP and the annual report, and a catalog (copies provided to Bobby Shalewicz and Dina Brown at BELVOIR) which includes the study "Potable Water Membrane Applications". The study is said to include a list of about 100 plants that were surveyed. We may want to order the study in addition to another one that Dina said looked useful, "Procedures Manual for Polymer Selection in Water Treatment Plants." Several other studies that may be of use are to be published soon.

B. Prof. Ray Letterman (Syracuse University) is chairman of the AWWA Filtration Committee (and the Polyelectrolytes Standards Committee) TEL (315) 443-3307. He can provide good information on polyelectrolytes and chemicals.

Talked w/ Prof. Letterman on 5/16 - he has not seen a list of RO plants that use coagulants. The best place to look is the Journal of the AWWA (December issue contains the yearly table of contents). The Journal has included several articles on RO in the last 5 years. He says matching polymers with water types or applications is usually done by manufacturers with lots of smoke and mirrors. The manufacturer normally analyzes the water and specifies the best product by product name or blend (lots of products are just different dilutions of same basic formulation). There are generally no handbooks to match the polymer with the type water. There are three main types of polyelectrolytes:

1. cationic - the Cat Flocc product line by Calgon of Pittsburgh)
2. FEDMA - a general alternative to the Cat Floccs
3. Anionics - a large number of high molecular weight acrylamides polymerized with various polymers. Used to dewater sludge.

There are a few other polyamides and things like DADMAC (diallyldimethyl ammonium chloride), (similar to DMDAAC) as well. The latter two are quaternary amides where the nitrogen carries the positive charge and holds 4 carbons. The charge is not affected by the pH values. Lots of polyelectrolytes (thousands - many are dilutions) have been approved by the Environmental Protection Agency (EPA) (formerly by the Public Health Service). The National Sanitation Foundation, (NSF) Ann Arbor, MI (313) 769-8010 (Mr. Dave Gregorka) can give information on the standards and testing of polymers that has been conducted under NSF Standard #60 for Drinking Water Treatment. Time constraints precluded contact.

6. Water Pollution Control Federation, Alexandria, VA, TEL (703) 684-2400. Also affiliated with the Federal Water Quality Association, Washington, DC, TEL (202) 447-4925. Time precluded contact.

7. American Water Research Association, Bethesda, MD, TEL (301) 493-8600, Time precluded contact. Also National Water Resources Association, Washington, DC, (202) 488-0610. Time precluded contact.

8. R.D. Nixon Water Plant, Route 2, Ray Nixon Rd, Fountain, CO 80817. (719) 636-5885 ext. 12. Spoke to Ron Petrovich (since Bob Doyle, the plant superintendent was out) to qualify the lead as whether this plant uses coagulants in pretreatment. They do and specified to me that previously they had been using ferric chloride and a polymer, but the alkalinity in their feed water dropped, so they had to change to a new coagulant. Now they are using bentonite clay and a flocculant, which they buy from Nalco. Did not know of any other users, but suggested we talk to David Paul, which we had already.

9. Environmental Technology, 223 Hickman Drive, Sanford, FL, (407) 321-7910. This is a company that re-packages and blends chemicals. They buy their chemicals from American Cyanamid and Stockhausen. Gave me a contact of Mr. Rick Joy at Stockhausen (919) 378-9393 in the Greensboro, NC office of Stockhausen.

10. San Diego Waste Water Treatment Plant, 3250 Camino del Rio North, San Diego, CA 92108. Gave me the name of another waste water treatment plant in San Diego (see below). Currently they use ferric chloride alone. He said that the other plant uses ferric chloride with a polymer.

- a. Point Loma Waste Water Treatment Plant
1902 Gatchell Road
San Diego, CA 92106

APPENDIX D
QUESTIONNAIRE DISTRIBUTION LISTS

APPENDIX D

DISTRIBUTION LIST OF MANUFACTURERS

Airco
Gases Div. of B.O.C. Group
575 Mountain Ave
Murray Hill, NJ 07974
(201) 464-8100

Alken-Murray Corporation
417 Canal St.
New York, NY 10013

Allied Colloids, Inc.
Attn: June Garrison
2301 Wilroy Road
Suffolk, VA 23434
(804) 934-3700

Allied Corporation
(Same as Polypure - bought out)
Attn: Alex White
Water Treatment Chemicals
P.O. Box 1139R
Morristown, NJ 07960
(201) 455-3221

American Colloid Company
1500 West Shure Drive
Arlington Heights, IL 60004
(708) 392-4600

American Cyanamid Company
Chemical Group, Polymer Products Div.
1 Cyanamid Place
Wayne, NY 07470
(201) 831-2000

American Engineering Services, Inc.
Attn: Al Kalantar
816 West Foot Hill Blvd.
Monroevia, CA 91016

American Hospital Supply Company
American Dade Div.
P.O. Box 520672 (Lab)
Miami, FL 33131

BF Goodrich Company
Specialty Polymers & Chemicals Div.
Dept. 2264
9911 Brecksville Rd
Brecksville, OH 44141
800 331-1144 or 216 447-5580

J.T. Baker Chemical Company
222 Red School Lane
Phillipsburgh, NJ 08865
(201) 859-2151

Betz Laboratories, Inc.
Attn: Dan Lusardi
Research and Development
Somerton Road
Trevose, PA 19047
(215) 355-3300

Borden, Inc.
Chemical Division
180 E. Broad St.
Columbus, OH 43215
(614) 225-4000

By-Products Management of Ohio, Inc.
17879 St. Clair Avenue
Cleveland, OH 44110
(216) 486-9100

Calgon Vestel Laboratories
P.O. Box 147
St. Louis, MO 63166
(412) 777-8294

Carus Chemical Company
315 Fifth Street
Peru, IL 61354
(815) 223-1500

Catoleum Pty. Ltd.
(Subsidiary of Nalco)
Anderson Street
Botany, New South Wales
2019 Australia

DuBois Chemicals, Inc.
1200 DuBois Tower
Cincinnati, OH 45202-3178
(513) 762-6900

Chemtrust Industries
Chrysler Corporation
Indianapolis Foundry Plant
1100 S. Tibbs Avenue
Indianapolis, IN

Chesapeake Services
International (AKA RMI)
Attn: Marla Swanson
P.O. Box 96
Mount Vernon, VA 22121

Clow Corporation
6622 South Point Drive, South
Jacksonville, FL 32216
(904) 739-2900

Craig Chemical and Soap Products
P.O. Box 311
Eau Claire, WI 54702
(715) 835-6563

Crown Technology, Inc.
P.O. Box 50426
Indianapolis, IN 46250-0426
(317) 845-0045

Culligan
Industrial Water Systems
50 Belden Avenue
Sodus, NY 14551
(315) 483-9129

Grace Dearborn
Dearborn Division
300 Genesee Street
Lake Zurich, IL 60047

The Dexter Group
Water Treatment Division
1 Elm Street
Windsor Locks, CT 06096
(203) 623-9801

Diamond Shamrock Chemicals Company
351 Phelps Court
Irving, TX 75015
(214) 659-7000

Dionex Corporation
1228 Titan Way
P.O. Box 3603
Sunnyvale, CA 94088

Diversey Corporation
1532 Biddle Avenue
Wyandotte, MI 48192
(313) 281-0930

Dow Chemical USA
Water Purification Division
Michigan Division
2020 Willard H. Dow Center
Midland, MI 48667
(517) 636-1000

Drew Chemical Division
/Ashland Chemical
One Drew Plaza
Boonton, NJ 07005
1-800-526-7600

Dupont De Nemours,
E.I. & Company, Inc.
Barly Mill Plaza
Wilmington, DE 19880-0029
800-441-7515

Eagle-Picher Industries
Eagle-Picher Minerals
P.O. Box 12130
Reno, NV 89510
(702) 322-3331

Economics Laboratory, Inc.
Osborn Bldg
St Paul, MN 55102
(612) 293-2329

Ensotech, Inc.
7949 Ajay Street
Sun Valley, CA 91352
(818) 767-2222

Essex Chemical Corporation
1401 Broad Street
Clifton, NJ 07015
(201) 773-6300

Fairmount Chemical Company, Inc.
117 Blanchard Street
Newark, NJ 07005
(201) 344-5790

Fisher Scientific Company
711 Forbes Avenue
Pittsburgh, PA 15219
(412) 562-8300

Foseco Inc.
20200 Sheldon Rd
At Eastland
Brookpark, OH 44141

Garrett-Callahan Company
111 Rollins Road
Millbrae, CA 94030
(415) 697-5811

General Chemical Corporation
Water Chemicals Group
90 East Halsey Road
P.O. Box 394
Parsippany, NJ 07054-0394

General Refractories Company
225 City Avenue
Bala Cynwyd, PA 19004
(215) 667-7900

W.R. Grace & Company
55 Hayen Avenue
Lexington, MA 02173
(617) 861-6600

Hercules, Inc.
Attn: Marilyn Tate
Marketing Center
Hercules Plaza
Wilmington, DE 19894
(302) 594-6500

Illinois Water Treatment Company
4669 Shepard Trail
Rockford, IL 61105
(815) 877-3041

Ionics, Inc.
65 Grove Street
Watertown, MA 02172
(617) 926-2500

Lonza AG
Munchen Steinerstrasse 38,
CH-4002
Basel, Switzerland Tel 061 51 8111

Manville Filtration and Minerals
P.O. Box 519
Lompoc, CA 93438
1-800-654-3103

McGean-Rohco
1250 Terminal Tower
Cleveland, OH 44113-2251
(216) 621-6425

Merck/Calgon Corporation
P.O. Box 2000
Rahway, NJ 07065
(201) 574-4000

Millipore Corporation
80 Ashby Road
Bedford, MA 01730
1-800-225-1380

Mitco Water Laboratories Inc.
P.O. Box 1435M
Winter Haven, FL 33882-1435
(813) 967-4456

Mitsubishi Monsanto Chemical Co.
Marunouchi 2
Chome
Chiyoda-Ku
Tokyo, Japan

Monsanto Chemical Company
Detergents and Phosphates Div.
800 N. Lindbergh Blvd.
St. Louis, MO 63167
(314) 694-1000

Rheox, Inc.
Attn: John Doherty
P.O. Box 700
Hightstown, NJ 08520
(609) 443-2000

Nalco Chemical Company
Attn: Kersten Lampert
1 Nalco Center
Naperville, IL 60563
(708) 305-1173

NCH (National Chemsearch)
P.O. Box 152170
Irving, TX 75015
(214) 438-0211

Neutron Products, Inc.
22301 Mt. Ephraim Road
Dickerson, MD 20842
(301) 349-5001

Oakite Products, Inc.
Attn: Denny Bardoliwalla
50 Valley Road
Berkley Heights, NJ 07922
(201) 464-6900

Olin Corporation
Industrial Chemical Group
120 Long Ridge Rd
P.O. Box 1355
Stamford, CT 06904-1355
(203) 356-2000

PPG Industries, Inc.
Chemicals Group
1 PPG Place
Pittsburgh, PA 15272

Atochem, North America, Inc.
Inorganic Chemical Div.
3 Parkway
Philadelphia, PA 19102

Petrolite Corporation
Oil Field Chemicals Group
16010 Barker's Point Lane
Suite 600
Houston, TX 77079
(713) 558-5200

The PQ Corporation
P.O.Box 840
Valley Forge, PA 19482
(215) 293-7200

Polypure, Inc.
One Gatehall Drive
Parsippany, NJ 07054
(201) 292-2900

Rohm and Haas Company
195 Canal
Malden, MA 02148
(617) 321-6984

Stauffer Chemical Company
Basic Products Group
Nyala Farm Rd.
Westport, CT 06880

Stewart Chemical, Inc.
2859 20th St., South
Minneapolis, MN 55407
(612) 722-9541

Stockhausen, Inc.
Attn: Voyn Stanley
2408 Doyle Street
Greensboro, NC 27406
(919) 378-9393

Stranco, Inc.
Attn: Barbara Mill
Rt. 50 North
P.O. Box 389
Bradley, IL 60915
(815) 932-8154

Sybron Corporation
Medical Products Division
P.O. Box 23077
Rochester, NY 14692
(716) 475-4990

Tennessee Chemical Company
Attn: Fred Row
3400 Peachtree Rd, NE
Suite 401
Atlanta, GA 30326
(404) 233-6811

Union Carbide Corporation
Specialty Chemicals Division
Old Field Chemicals-
Water Soluble Chemicals
39 Old Ridgebury Rd.
Danbury, CT 06817-0001
1-800-822-7645

USG Industries, Inc.
101 S. Wacker Dr.
Dept. TR 86
Chicago, IL 60606
(312) 321-4000

Vinings Chemical Company
Dept R-H
2555 Cumberland Pkwy.
Atlanta, GA 30339
(404) 436-1542

Virginia Chemical Inc.
3340 W. Norfolk Rd.
Portsmouth, VA 23703
(804) 483-7000

Western Water Management Inc.
1345 Taney
P.O. Box 7469
North Kansas City, MO 64116
(816) 842-0560

Witco Corporation
520 Madison Avenue
Continental Illinois Bank Bldg.
New York, NY 10022-4236
(212) 605-3800

Zenon Corporation
13 Estates Drive
Sussex, NJ 07461
(201) 702-0174

Zimmite Corporation
810 Sharon Drive
Westlake, OH 44145

COAGULANT USERS DISTRIBUTION LIST

R.D. Nixon Water Plant
Route 2, Ray Nixon Road
Fountain, CO 80817
Attn: Ron Petrovich
Date Received:
Comments:

San Diego Wastewater Treatment Plant
3250 Camino del Rio North
San Diego, CA 92108
Date Received: 08/08/90
Comments: Uses ferric chloride as
primary coagulant.

Point Loma Wastewater Treatment Plant
1902 Gatchell Road
San Diego, CA 92106
Date Received: 07/12/90
Comments: Return to sender

Purification Sciences, Inc.
P.O. Box 311
Geneva, NY 14456
(315) 789-2543
Date Received:
Comments:

Water Services Corporation
111 E. North Street
Waukesha, WI 53188
(414) 547-1862
Date Received:
Comments:

Southern Water Conditioning
P.O. Box 4507
Macon, GA 31208
(912) 745-0466
Date Received:
Comments:

V.I. Water, Power Authority
Attn: Raymond L. George
P.O. Box 1450
St. Thomas, VI 00801
Date Received:
Comments:

U.S. Bureau of Reclamation
U.S. D.O.I.
Attn: John Anderson
18th & C St., NW
Washington, DC 20240
Date Received:
Comments:

City of Virginia Beach
Dept. of Public Utilities
Attn: Thomas M. Leahy, III
Virginia Beach, VA 23456-9002
Date Received: 07/10/90
Comments: They purchase water
from Norfolk - no treatment at all

Sarasota County Utilities
Attn: Loring Lovell
P.O. Box 2553
Sarasota, FL 34230
Date Received:
Comments:

Englewood Water District
Attn: Pedro Mora
P.O. Box 1399
Englewood, FL 34295-1399
Date Received:
Comments:

Red River Authority of Texas
302 Hamilton Bldg.
Wichita Falls, TX 76301
Date Received:
Comments:

Metro Water Dist. of So. CA
Attn: Richard Balcerzak
P.O. Box 54153
Los Angeles, CA 90054
Date Received:
Comments:

Chino Basin Municipal Water Dist.
Attn: Thomas J. Homan
P.O. Box 697
Cucamonga, CA 91730

Orange County Water Dist.
Attn: William R. Mills, Jr.
P.O. Box 8300
Fountain Valley, CA 92728-8300
Date Received:
Comments:

California Dept. of Water Resources
Attn: Lou Beck
3374 East Shields Avenue
Fresno, CA 93726
Date Received:
Comments:

Contra Costa Water Dist.
Attn: Ed Seegmiller
P.O. Box H20
Concord, CA 94524
Date Received:
Comments:

Hawaii Dept. of Land and
Natural Resources
Attn: Manabu Tagomori
P.O. Box 373
Honolulu, HI 96809
Date Received: 08/03/90
Comments: Point of contract:
Mr. Linford Chang
(808) 548-3944 Does not use coagulants.

Dare County-Reverse Osmosis
Water Treatment Plant
Attn: Bob Oreskovich
P.O. Box 1000
Manteo, NC 27954
Date Received: 07/23/90
Comments: Does not use coagulants in
pretreatment

Indian River County Utility Service
Attn: Brad O'Keefe
1550 S.W. 9th Street
Vero Beach, FL 32962
(407) 567-0224
Date Received: 07/17/90
Comments: Uses sequestrants

Southwest Florida Water Mgmt. Dist.
Attn: Richard S. Owen
2379 Broad Street
Brooksville, FL 34609
Date Received:
Comments:

Water Dir. City of Dunedin
Attn: Gerald Knippel
1401 County Road 1
Dunedin, FL 34698
Date Received:
Comments:

Polk County Utilities Div.
Donald Crawford
P.O. Box 2019
Bartow, FL 33830
Date Received:
Comments:

Beverly Beach Surfside
P.O. Box 1048
Flagler Beach, FL 32036
Date Received:
Comments:

Ocean City Utilities
Water Treatment Plant
Route 1, Box 211
Flagler Beach, FL 32036
Date Received:
Comments:

Marineland
RFD Rt. 1 Box 122
St. Augustine, FL 32084
Date Received:
Comments:

Parker Hannifin
3200 Parker Drive
St. Augustine, FL 32084
Date Received:
Comments:

The Cove at South Beaches
4320 South Highway A1A
Melbourne Beach, FL 32951
Date Received:
Comments:

Indian River County/North Beach
P.O. Box 1750
Vero Beach, FL 32961
Date Received:
Comments:

Acme Improvement District
Attn: Ed Wasielewski
14000 Greenbriar Blvd.
Wellington, FL 33414
Date Received:
Comments:

St. Lucie West Utilities
N. Prima Vista, W. Cashmere
West Port St. Lucie, FL 34986
Date Received: 07/12/90
Comments: Return to Sender

Island Water Association
P.O. Box 509
Sanibel, FL 33957
Date Received:
Comments:

Greater Pine Island Water Assn.
Attn: Larry Harrison
5281 Pine Island Road
Bokeelia, FL 33922
Date Received:
Comments:

City of Cape Coral R/O Plant
P.O. Box 150027
Cape Coral, FL 33915
Date Received: 07/09/90
Comments: Does not use coagulants

City of Sarasota Utilities
Attn: Douglas Taylor
P.O. Box 1058
Sarasota, FL 34236
Date Received:
Comments:

Venice Gardens Utility Corp.
1731 So. Tamiami Trail, Suite D
Venice, FL 34285
Date Received: 07/09/90
Comments: Return to Sender

City of Venice Water Dept.
Attn: John Lane
401 W. Venice Avenue
Venice, FL 34293
Date Received: 07/25/90
Comments: Does not use coagulants.

Southbay Utilities
4370 S. Tamiami Trail
Osprey, FL 34229
Date Received: 07/10/90
Comments: Return to Sender

Fort Myers Utility
Attn: Donald McKenna
P.O. Drawer 2217
Ft. Myers, FL 33902
Date Received:
Comments:

Vero Beach Utility
Attn: Russ Bradley
P.O. 1389
Vero Beach, FL 32961
Date Received:
Comments:

Charlotte Harbor Water Association
27147 Del Prado Parkway
620 Highlands Road
Harbor Heights, FL 33983
Date Received:
Comments:

Indian River Plantation
385 NE Plantation Road
Stuart (Hutchinson Island), FL 33494
Date Received:
Comments:

Sand Dollar Utilities Corp.
P.O. Box 2632
Stuart, FL 33494
Date Received: 07/16/90
Comments: Return to Sender

Fiveland Investments Utility
6515 Gasparilla Pines Blvd.
Englewood, FL 34223
Date Received:
Comments:

Burnt Store, Deep Creek Utility
15550 Burnt Store Road
Punta Gorda, FL 33955
Date Received:
Comments:

Palm Beach County Water Authority
6501 Belvedere Road
West Palm Beach, FL 33417
Date Received: 07/20/90
Comments:

Sarasota County Utility Dept.
Sorrento Utility
P.O. Box 2553
Sarasota, FL 34250
Attn: Chuck Wigley
Date Received: 07/19/90
Comments: Does not use coagulants

APPENDIX E
QUESTIONNAIRES AND COVER LETTERS

Airco
Gases Div. of B.O.C. Group
575 Mountain Avenue
Murray Hill, NJ 07974

June 8, 1990

Dear Sir/Madam:

Science Applications International Corporation is under contract to assist the Fuel and Water Supply Division of the US Army Belvoir Research, Development and Engineering Center (BELVOIR) in a survey and evaluation of coagulants offering improved performance over current products. BELVOIR seeks information on products that will more effectively coagulate suspended colloidal particles in the water supply. This will increase the effectiveness of the multi-media filter and reduce the amount of colloidal particles that pass through the pretreatment system and foul the Reverse Osmosis (RO) membranes. The Survey Sheet (Attachment 1), has background information on the Army requirement, and provides instructions on completing the Coagulant Questionnaire.

We have identified your firm as a potential manufacturer or source of coagulants or similar chemicals. You are invited to submit technical information about your products by completing a Coagulant Questionnaire (Attachment 2) for each applicable product. Please return the questionnaire along with any applicable commercial literature or test data to:

Science Applications International Corporation
ATTN: Mrs. Dana Sheil (T1-7-2)
1710 Goodridge Drive
McLean, VA 22102

Questions or comments may be directed to Dana Sheil or me at (703) 821-4397, or Dina Brown at BELVOIR at (703) 664-5472/5172. Information can only be accepted on a no cost or no obligation basis. Proprietary information will be appropriately protected. Please return Attachment 1 even if you do not manufacture coagulant products.

We appreciate your help in this effort. We expect that the information collected during this market survey will lead to better Army water treatment capabilities. Again, thank you.

Sincerely,

SCIENCE APPLICATIONS
INTERNATIONAL CORPORATION

Bruce B. Halstead
Principal Investigator
Attachments A/S

MANUFACTURER
SURVEY SHEET

ATTACHMENT 1

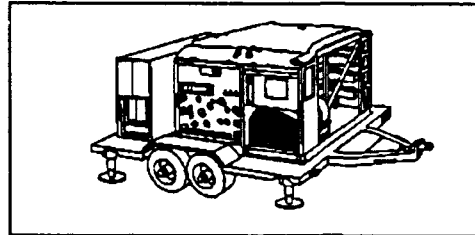


Figure 1 - ARMY 600 GPH ROWPU

Airco
Gases Div. of B.O.C. Group
575 Mountain Avenue
Murray Hill, NJ 07974

INSTRUCTIONS:

Make any necessary changes to your company address below:

Please provide the name and phone number for a point of contact:

Does your firm manufacture and/or distribute coagulants for use in water pretreatment?

Yes _____ No _____

If your answer was yes, please complete an attached Coagulant Questionnaire for each appropriate product.

If your company does not supply coagulants, please describe other products that may be useful for future Army water treatment efforts;

then return the Survey Sheet to the address following.

For each applicable coagulant manufactured or distributed by your firm, please complete a Coagulant Questionnaire (please make additional copies if necessary).

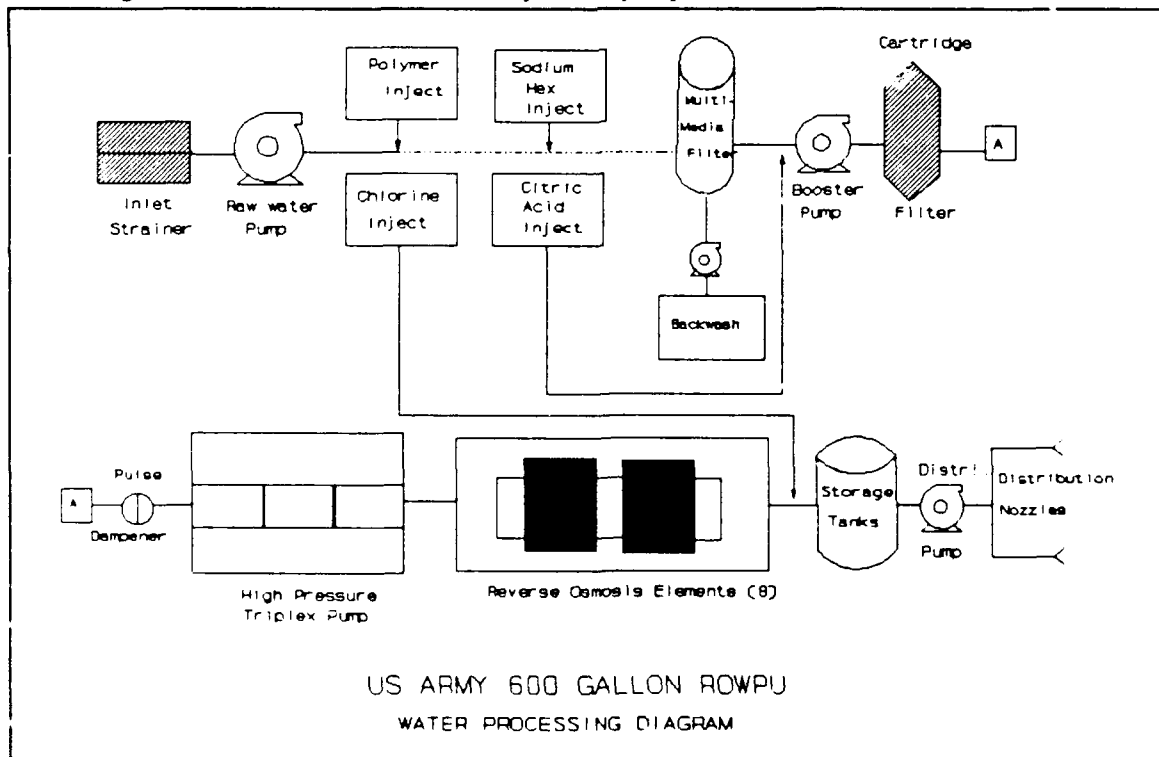
Please return survey by June 30, 1990 or as soon as possible thereafter to:

Science Applications International Corporation
ATTN: Mrs. Dana Sheil (MS T1-7-2)
1710 Goodridge Drive
McLean, Virginia 22102

BACKGROUND:

The US Army Reverse Osmosis Water Purification Unit (ROWPU) (Figure 1) provides potable water for drinking, washing, culinary, bathing, laundering, and dehydrated-food-reconstitution purposes. The ROWPU employs the process shown in Figure 2 to produce potable water. The Army ROWPU must be capable of world-wide use including the following types of raw water: fresh, brackish, and sea.

To increase the effectiveness of the ROWPU's multi-media filter, the Army uses a cationic polyelectrolyte to coagulate suspended colloidal particles in raw water. The main coagulant currently used is dimethyldiallyl ammonium chloride (DMAAC). This coagulant is used in the direct filtration pre-treatment mode to destabilize particulates (suspended colloidal particles) in the water, changing their charge and consequently forming larger particulates that are removed by the multi-media filter. The size of the piping for the 600 gallon ROWPU is 1 1/2 inch copper-nickel pipe measuring 78 inches and 2 inch copper-nickel pipe measuring approximately 65 inches. The average flow is 28-32 gallons per minute. The size of piping for the 3000 gallon ROWPU is 3 inch stainless steel pipe measuring 84 inches, with an average flow rate of 100 gallons per minute. These figures can be used to determine the approximate mixing time for the coagulant. Be advised that settling tanks cannot be used due to military mobility requirements.



The goal of the current Army effort is to determine whether coagulants or other materials are available that can increase the effectiveness of particulate capture by the multi-media filter. The coagulant must be capable of use with a wide range of water types, either alone or in conjunction with other substances (such as alum, other oxides or salts, etc). The coagulant must be easy to store and use; safe for ROWPU operators and water supply users; and economical. The coagulant must also be compatible with the following materials, which are an integral part in the performance of the ROWPU:

Table I - ROWPU Chemicals

ITEM	600 GALLON ROWPU	3000 GALLON ROWPU
Coagulant	DMDAAC	DMDAAC
Antiscalant	Sodium Hexametaphosphate	AC 1000
RO Cleaning	Citric Acid Triton-X-100	Citric Acid PA-111 (2) Aminotri(methylene phosphonic acid)
Water Disinfectant	Calcium Hypochlorite	Calcium Hypochlorite
RO Membrane	Polyamide Poly (ether-urea)	Polyamide Poly (ether-urea)
RO Membrane Preservative	Formaldehyde Glycerol	Sodium Metabisulfite

COAGULANT MANUFACTURER
QUESTIONNAIRE
ATTACHMENT 2

A. PRODUCT CHARACTERISTICS

1. Tradename: _____
2. Chemical name: _____
3. Physical type: Solid _____ Liquid _____ (Solution _____ Emulsion/Dispersion _____)
4. Chemical type (examples: cationic polyelectrolyte, polymer (anionic, non-ionic, cationic), iron salts, aluminum compounds, etc.): _____

5. Type of polymer or copolymer (if applicable) _____
6. Concentration of active ingredient: _____
7. Concentration of free monomer: _____
8. Proportion of ionizable groups: _____
9. Molecular weight range (or intrinsic viscosity) under most common conditions or use:

10. Charge density: _____

B. PERFORMANCE

11. Primary use (sole coagulant, coagulant aid, filter aid, other):

12. Raw water characteristics for which this coagulant is recommended (for example, turbidity (TSS or ntu):

13. Under what conditions (i.e., high/medium/low color, pH level, etc.) does the coagulant provide the highest effectiveness? lowest effectiveness? _____

14. What is the approximate headloss which results from use of the coagulant:

C. METHOD OF APPLICATION

15. Optimum recommended dosage (mg/L): _____

16. Do you recommend that this product be used in conjunction with a salt, metal oxide, or other substance (if yes, please specify): _____

17. Recommended injection method(s): _____

18. Mixing time (and speed if known) required to effectively disperse coagulant in the water: _____

19. Is flocculation required: _____ Amount of time or other requirements: _____

20. Describe any unique aspects of application of the coagulant: _____

D. COMPATIBILITY

21. Will the product react adversely with any of the ROWPU materials (reference background): _____

22. What solids or residues are created by the addition of the coagulant: _____

23. Are there concerns regarding the presence of unreacted polymer in the product water, or the formation of by-products should chlorine or other oxidants react with the polymer: _____

E. EFFECTIVENESS

(Please attach charts, graphs, or other indicators of effectiveness.)

24. Type of coagulation mechanism (charge neutralization, bridging flocculation, other): _____

25. Description of particle capture types and sizes and rate of deposition on multi-media/depth filter: _____

26. Effect of raw water pH on the coagulant (and vice versa; does coagulant affect the pH of the water):

F. SAFETY CONSIDERATIONS

27. What safety considerations and potential hazards are associated with the coagulant (such as burns, or irritation to skin, eyes or lungs due to exposure, slippery footing, etc):

28. Is the product toxic and, if so, what antidotes are recommended: _____

29. Is the product corrosive, and if so, what special procedures, if any, are recommended: _____

30. Are there noxious odors associated with the product (if so, please specify): _____

31. Is the product biodegradable (if not, what special disposal procedures are needed): _____

32. Has the product been approved for use in potable water by the EPA, National Sanitation Foundation, or other agencies (please specify): _____

G. STORAGE

33. What forms of packaging are available (please describe by size, packaging material, product type, etc.):

34. Storage requirements (consider temperature, humidity, stacking height, and transportability restrictions):

35. Product shelf-life: _____

36. What is the freezing point of the undiluted product, and is it able to withstand freeze/thaw cycles:

H. AVAILABILITY

37. Cost per gallon or pound: _____

38. Years in production: _____

39. Quantity currently produced per year: _____

I. ADDITIONAL NOTES/COMMENTS:

R.D. Nixon Water Plant
Attn: Ron Petrovich
Route 2, Ray Nixon Road
Fountain, CO 80817

2 July 1990

Dear Sir/Madam:

As fellow water purification specialists, the US Army Fuel and Water Supply Division of the Belvoir Research Development and Engineering Center (BELVOIR) needs your assistance in the search for the best possible pretreatment coagulant for use in a Reverse Osmosis (RO) environment. We believe that the research being performed by BELVOIR and Science Applications International Corporation (under contract) will have long-range effects on how water purification systems work throughout the world. Due to the variability of water types and the fluctuations in the characteristics, (i.e., pH, turbidity, TSS), the search for the most economical and effective "universal" coagulant would be a much needed discovery. Therefore, we request a small amount of your time to complete a survey and questionnaire regarding the types of coagulants you are using and have used in the past.

BELVOIR seeks any information on products that will more effectively coagulate suspended colloidal particles in any type of water. This will increase the effectiveness of the multi-media filter and reduce the amount of suspended particles that pass through the pretreatment system and foul the RO membranes. The Survey Sheet, (Attachment 1), has an overview of the Army requirement and provides instructions on completing the coagulant questionnaire, (Attachment 2).

We have identified you as a potential user of coagulants in water pretreatment. We request you take a few minutes to submit technical information about the products you use, how you use them, and the type of raw water undergoing treatment, by completing a questionnaire for the coagulant(s) used in your RO pretreatment. Please return to:

Science Applications International Corporation
Attn: Mrs. Dana Sheil (T1-7-2)
1710 Goodridge Drive
McLean, VA 22102

Questions or comments may be directed to Dana Sheil or myself at (703) 821-4397, or Dina Brown at BELVOIR at (703) 664-5472/5172. Information can only be accepted on a no cost and no obligation basis. Proprietary information will be appropriately protected. Please return Attachment 1 even if you do not use coagulants in water pretreatment. We appreciate your assistance in this effort. The information collected in this market survey is expected to lead to better water treatment capabilities. Again, thank you.

Sincerely,

SCIENCE APPLICATIONS
INTERNATIONAL CORPORATION

Bruce Halstead
Principal Investigator

Attachments A/S

COAGULANT USERS
SURVEY SHEET
ATTACHMENT 1

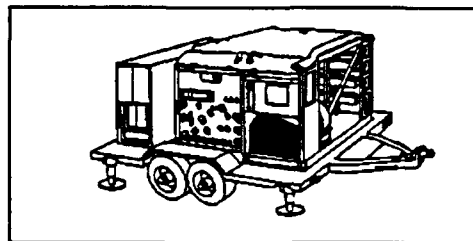


Figure 3 - ARMY 600 GPH ROWPU

R.D. Nixon Water Plant
Attn: Ron Petrovich
Fountain, CO 80817

INSTRUCTIONS:

Make any necessary changes to your address: _____

Please provide the name and phone number for a point of contact:

Do you use coagulants in water pretreatment?

Yes _____ No _____

If your answer was yes, please complete the attached Coagulant Questionnaire.

If you do not use coagulants, please describe other products that may be useful for future Army water treatment efforts;

then return the Survey Sheet by July 16 to:

Science Applications International Corporation
Attn: Mrs. Dana Sheil (T1-7-2)
1710 Goodridge Drive
McLean, VA 22102

Please provide a response to as many questions as possible. We appreciate any information you can provide.

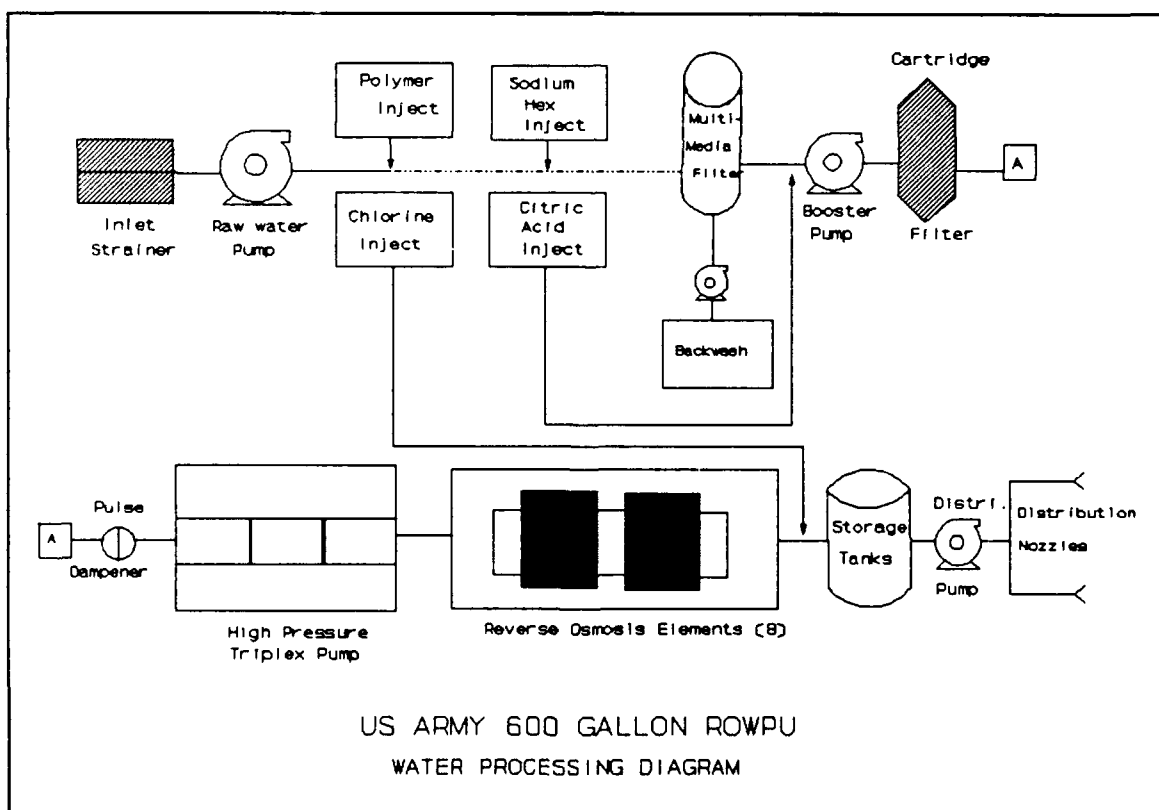
COAGULANT USERS
QUESTIONNAIRE
ATTACHMENT 2

OVERVIEW:

The US Army Reverse Osmosis Water Purification Unit (ROWPU), (Figure 1), provides potable water for drinking, washing, culinary, bathing, laundering, and dehydrated-food-reconstitution purposes. The ROWPU employs the process shown in Figure 2 to produce potable water and must be capable of world-wide use including fresh, brackish, and sea raw waters.

To increase the effectiveness of the ROWPU's multi-media filter, the Army uses a cationic polyelectrolyte to coagulate suspended colloidal particles in raw water. The main coagulant currently used is dimethyldiallyl ammonium chloride (DMDAAC). This coagulant is used in the direct filtration pre-treatment mode to destabilize particulates (suspended colloidal particles) in the water, changing their charge and consequently forming larger particulates that are removed by the multi-media filter. The mixing time is almost non-existent, (1 or 2 seconds), from the time the coagulant is injected until arriving at the media-filter.

The goal of the current Army effort is to determine whether coagulants or other materials are available that can increase the effectiveness of particulate capture by the multi-media filter. Therefore, we are collecting data regarding the uses of various coagulants in different raw water types to discover the best possible coagulant for the Army.



A. PRODUCT CHARACTERISTICS

1. Tradename and manufacturer of coagulant: _____
2. Physical Type: Solid ____ Liquid ____ (Solution ____ Emulsion/Dispersion ____)
3. Chemical Type (examples: cationic polyelectrolyte, polymer, iron salts, aluminum compounds, etc.):

4. Concentration of active ingredient: _____
5. Molecular weight range (or intrinsic viscosity) under most common conditions or use: _____
6. Charge density: _____

B. PERFORMANCE

7. Primary use (sole coagulant, coagulant aid, filter aid, other): _____
8. Raw water characteristics for which this coagulant is used (source water) (i.e., turbidity (TSS or ntu), pH, color, odor, etc.):

9. How would you rate the effectiveness of the coagulant for your use, (excellent, good, adequate, poor), and explain why: _____

10. Have you experienced any problems such as headloss, sludge generation, pH fluctuations, etc., since first using this coagulant? What were they? _____

11. Were other coagulants used before the current one (please, limit discussion to 3 most recent):
What problems caused the change to a new coagulant _____

C. METHOD OF APPLICATION

11. Dosage used under normal conditions (mg/L): _____
Have variations to this dosage been necessary? How much? Under what conditions?

12. Injection method(s): _____

13. Mixing time (and speed if known) required to effectively disperse coagulant in the water:

14. Is flocculation required: ____ Amount of time or other requirements: _____

15. Describe any unique aspects deemed necessary in the application of the coagulant: _____

D. COMPATIBILITY

16. Has the coagulant ever reacted adversely with any of the other water treatment materials (i.e., RO membranes, cleaning agents, chlorine, etc.) Specify: _____

17. What solids or residues are created by the addition of the coagulant, if any: _____

18. Are there concerns regarding the presence of unreacted polymer in the product water, or the formation of by-products should chlorine or other oxidants react with the polymer? _____

E. EFFECTIVENESS

19. Description of particle capture types and sizes and rate of deposition on multi-media/depth filter: _____

20. Effect of coagulant on the raw water pH level (and vice versa): _____

21. Measures to counteract any variation in raw water pH level, if any: _____

F. ADDITIONAL NOTES/COMMENTS

APPENDIX F

GLOSSARY

APPENDIX F

GLOSSARY

KEY TERMS

Anionic - negatively charged

Cationic - positively charged

Cationic polyelectrolyte - positively charged polymer when used as a coagulant can cause the formation of floc in solution.

Coagulation - the process whereby suspended solids and colloidal materials in water are agglomerated into masses sufficiently large to settle.

Coagulants - chemicals, either organic or inorganic which neutralize the charge on suspended particles allowing them to come together and form larger flocs.

Colloids - a suspension of finely divided particles in a continuous medium that do not settle out of the substance rapidly and are not readily filtered.

Direct filtration - a treatment scheme where all of the particulates are removed in the filters; no sedimentation time is used.

Flocculation - the aggregation of suspended solid particles in water such that they form small tufts or clumps resembling wool.

Nephelometric Turbidity Unit (NTU) - measurement of colloidal particles which are contained in raw water.

Polymers - long chain molecules consisting of repeated chemical units with a structure designed to provide distinctive physiochemical properties to the polymer. The chemical units usually have an ionic nature that imparts an electrical charge to the polymer chain, thus they get their name, polyelectrolytes.

Sodium Hexametaphosphate (SHMP) - a chemical additive widely used in water pretreatment to keep calcium, magnesium, and metallic salts in solution.

Total Suspended Solids (TSS) - suspended solids contained in raw water

Turbidity - term describing the amount of impurities in raw water

FUNCTIONS AND ATTRIBUTES

Effectiveness - how well the coagulant performs in the ROWPU environment. See attributes for specific measurements.

Dosage/Concentration - milligrams per liter of coagulant necessary to obtain the desired results. In the analysis of the candidate coagulants, data provided ranges in necessary dosages, therefore, the maximum dosage was used as the evaluation point. The lower the dosage, the higher the score.

Sedimentation/flocculation time - the amount of time the treatment water must sit idle after addition of the coagulant in order to achieve maximum flocculation. The coagulants were evaluated according to the maximum time necessary to obtain flocs. The lower the time required, the better the score.

Ability as Primary Coagulant - the ability for the candidate coagulant to perform solely as the coagulant, no other aids are required. The evaluation was all points or no points, based on Government requirement of the necessity to perform as primary.

Human Interface (MANPRINT) - a comprehensive technical effort to support system effectiveness by integrating all relevant information concerning human factors engineering, manpower, personnel, training, system safety, and health standards. More specific application includes the amount of human interface required to ensure maximum effectiveness of the coagulants. Evaluation was supported by literature stressing the "ease of use," or "simplicity of use," for the candidate coagulants. The easier to use, the higher the score.

Headloss - decrease in filter effectiveness

Water characteristics - in this study water is characterized by the level of turbidity (ntu's), the amount of color, odor and pH level. For evaluation purposes, the coagulant literature and surveys specified how many types of water the coagulant would be effective in (i.e., high and low turbidity, pH higher than 6, etc.). The more types of water the coagulant can be used in, the higher the score.

Compatibility - the ability for the coagulant to perform effectively without interfering with the raw water characteristics or the effectiveness of the ROWPU.

Effect on pH - alteration of the pH level, either raise or lower, in the raw water source.

Solids/residues created by coagulant - an unusual amount of sludge created by the addition of the coagulant to the water.

Reactivity with Multi-Media filter - the ability of the coagulant to generate flocs large enough to be captured in the multi-media filter.

Reactivity with R.O. Membranes - the ability of the coagulant to perform effectively without altering the performance of the R.O. membranes.

Reactivity with Materials of Construction - the ability of the coagulant to perform effectively without reacting adversely with the materials the ROWPU is constructed with.

Reactivity with Antiscalants - the ability of the coagulant to perform effectively without reacting adversely with the chemicals used to eliminate scaling.

Reactivity with R.O. Cleaning Agents/Acids - the ability of the coagulant to perform effectively without reacting adversely with the chemicals used to clean the R.O. elements.

Reactivity with Water Disinfectants - the ability of the coagulant to perform effectively without reacting adversely with the chemicals used to disinfect the water.

Logistics - the activities and necessary manpower involved in purchasing, storing, transporting, and tracking coagulants.

Shelf-life - the length of time the chemical can remain dormant and still be effective when used later.

Packaging flexibility - multiple packaging options available for the coagulants.

Freeze-thaw characteristics - the ability for the coagulant to withstand extreme temperature variations and remain effective.

Safety considerations - the coagulant must be safe to the users, the equipment, the water undergoing treatment, and the environment.

Biodegradable - the ability for the coagulant to be released into the environment and not cause any harm.

Toxicity - the amount of damage that can be caused from coming into contact with the coagulant.

Corrosiveness - will the coagulant cause a breakdown in storage containers.

Flammability - can the coagulant be kept near heat or flame without combustion

National Sanitation Foundation (NSF) Approved - has the coagulant undergone inspection and received approval for use in potable water treatment

Availability - is the coagulant in sufficient supply

Years in production - how long has the product been in production, (long enough to ensure product effectiveness)

Production rate per year - how much of the product is produced per year

Solution/Dry - is the product a liquid or powder (liquid is the preference)

Cost - the purchase price of the coagulant

Cost per gallon/pound - unit price of the coagulant

Quantity discount - a reduction in price for large quantities purchased

APPENDIX G

**DATA BASE DISKETTE AND
USERS MANUAL
(DISKETTE LOCATED ON BACK COVER)**

APPENDIX G
DATA BASE DISKETTE AND
USERS MANUAL

COAGULANT MARKET SURVEY USER'S GUIDE

INTRODUCTION

The coagulant market survey data base was designed using dBASE III+ to be operable under DOS using an IBM PC, XT, AT or a compatible. The system is menu driven, easy to read, and user friendly. Therefore, a detailed discussion of the data base operations have been omitted.

GETTING STARTED

- * Boot up PC
- * Copy files from diskette onto the hard drive within the dBASE III+ directory. The following files are needed and should be copied to operate the data base:

COAGULAN.DBF	{ data base file }
COAGULAN.NDX	{ index file }
COAGULAN.PRG	{ main command program file }
ADDCOAG.PRG	{ command procedure program file }
UPDCOAG.PRG	{ command procedure program file }

STARTING THE dBASE III PROGRAM

- * At the c> prompt within the dBASE III+ directory, type dBASE.
- * If you are not at the dot prompt, press [ESC] escape now. The (.) should appear in the lower left corner of the screen.
- * Type DO COAGULAN
(This command executes the data base processing system.)
- * Follow the menus for further instructions.

SUMMARY

In support of the US Army Belvoir Research, Development and Engineering Center (BELVOIR), the coagulant market survey data base system is designed to be used as a tracking system to evaluate surveys of coagulants for useage in a Reverse Osmosis (RO) environment. The data base supports the Fuel and Water Supply Division and can be used as a continuous analysis of economical, effective, universal as well as current coagulant users and manufacturers.

APPENDIX H
SURVEY RESPONSES
(UNDER SEPARATE COVER)

APPENDIX I
GOVERNMENT LITERATURE
(UNDER SEPARATE COVER)