Tramfloc Mining Flocculants: A Guide to Water Clarification in Cold Climates

Coagulants and flocculants have been commonly used to treat industrial and mine effluent in temperate climates but have not been widely used in frigid climates such as Alaska and Northern Canada. Attempts to use coagulants and flocculants to treat placer mine effluents in cold climates have had limited success. Effectiveness has been hindered by inadequate mixing and dispersing and by selection of chemicals which do not perform optimally in cold temperatures, or which are not effective in settling ultra-fine clay particles. Lack of adequate pre-settling of heavier particles before applying chemical clarifiers has increased chemical costs and resulted in poor settling.

Recent research on the use of such reagents to treat placer mine effluent in cold climates has shown that such treatment is successful in reducing total suspended solids levels and turbidity. Treatment can be economically feasible if minimum dosages are used to obtain the desired degree of water clarity and if mixing and dispersing systems are designed for remote locations where power supplies are limited.

Coagulants and flocculants used to treat placer mine effluent will increase treatment costs over no treatment or treatment with settling ponds alone. However, chemical treatment may be the most effective means of reducing sediment pollution, especially in areas where fine clays are abundant. Chemical treatment may be most effective when used in combination with other mining practices, including water reduction, filtration and overland discharge.

A. Introduction

The following review briefly discusses the problems of treating placer mining wastewater This paper will review background information on applications of organic and inorganic chemicals to treat wastewater, factors influencing the effectiveness of chemical clarifiers, and methods of application.

B. Placer Mining Wastewater Treatment

In placer mining, gold is separated from lighter sediment by washing, usually through a sluice box with water from a nearby stream. Washing the gold from gravels and soils results in wastewater with high levels of suspended sediments. Many of the suspended sediment particles are heavy and will settle naturally if the water is held in a still pond where turbulence is minimized. Placer mining in Alaska, for example, often occurs in areas with a high content of weathered, clay-sized particles. These fine particles, released during the gravel washing process, settle very slowly or not at all. As a result, turbidity levels that are higher than natural stream levels often persist far downstream from placer mine sites.

The adverse effects of elevated turbidity and total suspended solids on aquatic habitat have been well documented in the literature and more recently by studies conducted in Alaska. For example, Lloyd

(1985) presented a literature review that documented adverse affects of turbidity to primary and secondary productivity in fresh water systems. Burkholder (1985) reported higher mortalities of young-of-the-year (less than a year old) grayling in placer mined streams than in clear water streams. Weber and Post (1985) measured aquatic invertebrate populations ten times greater in clear water streams than in turbid water sites below placer mining.

Peterson et al. (1985) reviewed literature on the effects of turbidity and total suspended solids on biological communities. As a result of data presented in published literature, they recommended that Alaska State Water Quality Standards for fish and other aquatic life should not exceed 5 Nephelometric Turbidity Units (NTU) above background for natural turbidity up to 25 NTU. For waters of natural turbidity above 25 NTU, Peterson et al (1985) recommended that the allowable increase should not exceed 25% of the background turbidity.

C. Description of Chemical Clarifiers

Theories of chemical clarification of wastewater usually involve two processes: (1) increased contact between the suspended particles, and (2) destabilization of the particles to permit attachment when contact occurs (Weber 1972). Solid colloidal particles, insoluble particles that remain suspended in water,have long been observed to move in an electrical field, indicating that these particles carry an electrical charge (FJeber 1972). The charge can be either positive or negative, however, a negative charge is more common on inorganic particles. The electrical charge causes the particles to repel each other. These particles can be made to settle with the addition of organic or inorganic compounds, called coagulants, which neutralize the electrical charges.

The terms coagulant and flocculant are sometimes used interchangeably but the terms apply to specific processes. Coagulants are normally low molecular weight, positively charged compounds that will adsorb onto the solid particles, effectively neutralizing the overall electrical surface charge of the particles. The neutralized particles will adhere to each other forming larger, heavier particles that settle by gravity or the aid of an anionic flocculant. Flocculants are usually high molecular weight compounds that cause settling through two processes: they neutralize the charges on the particles and they "bridge" the particles in suspension, causing the particles to aggregate and settle.

Weber (1972, p.73) discusses a bridging theory for the destabilization of suspended particles: "To be effective in destabilization, a polymer molecule must contain chemical groups which can interact with sites on the surface of the colloidal particle. When a polymer molecule comes into contact with a colloidal particle, some of these groups adsorb at the particle surface, leaving the remainder of the molecule extending out into the solution. If a second particle with some vacant adsorption sites contacts these extended segments, attachment can occur. A particle-polymer-particle complex is thus formed in which the polymer serves as a bridge." Reagents used to form the "bridges" are usually long-chain organic polymers, however inorganic coagulants may also settle particles through bridging.

Coagulants commonly used over the past one hundred years include calcium carbonate (lime), aluminum sulfate (alum) and calcium sulfate (gypsum). Natural materials such as starch and starch derivatives, cellulose compounds, polysaccharide gums, and proteinaceous materials were formerly used as flocculants (Kleber 1973).

In 1967, the first non-toxic and completely synthetic cationic (positively charged) organic polymer was introduced and accepted by the U.S. Public Health Service for treatment of municipal water supplies (Kleber 1973). Since then, a wide range of polymers has been developed for use in municipal water and wastewater treatment. These polymers are more commonly used today for water clarification than naturally occurring organic compounds.

Polymeric flocculants (often called polyelectrolytes) usually consist of long spaghetti-like chains of molecules with repeating electrical charges. All polyelectrolytes can be classified by the type of electrical charge. Polymers with negative charges are "anionic," those with positive charges are "cationic," and polymers with no

Polyelectrolytes are usually in emulsion or powder form. Effective use of these chemicals for water treatment requires a system to mix the polymer with water to develop the long molecular chains, a system to monitor sediment concentrations and to adjust the polymer concentrations, and an effective system to disperse the chemical into the treatment clarifier or lagoon.

D. Application of Treatment Chemicals

Ancient literature from India of about 2000 B.C. suggested a number of vegetable substances as a means of clarifying water. Since 1889, chemical clarification techniques have been used to treat drinking water supplies in the United States (Kleber 1973). Polyelectrolytes have been widely used to reduce turbidity in municipal drinking water and wastewater and in industrial wastewater. There has been some use of polymers for the treatment of wastewater from coal mining and hard-rock mining. Chemical treatment of industria1, including mine, effluent is a common practice in the contiguous United States; however, such treatment has not been widely used in very cold climates such as Alaska.

Flocculants of the cationic, anionic, and non-ionic categories have been found to be more useful than inorganic clarifiers in removing turbidity from municipal water. Kleber (1969) described field applications of cationic polymers for clarifying municipal.

Olson et al. (1973) used polymers to clarify water supplied to a fish hatchery. Prior to treatment, the hatchery supply water reached turbidities of 70 Jackson Turbidity Units, JTU, at which point fish ceased feeding. Fish survival rates and rates of feeding increased after the hatchery water was clarified with polymers. Electrical charge are "non-ionic."

E. Applications of Chemical Clarifiers to Placer Mining

Environment Canada (1983b) conducted limited laboratory evaluations of anionic polymers in treating synthetic placer mining wastewater. They reported that dosages of 0.05 kg/m.t. to 0.15 kg/m.t. TSS produced optimum settling velocities. This work is regarded as preliminary because the investigators did not standardize mixing intensity, develop dosage and supernatant (clear water boundary) quality information on which to base dosage selection, nor test the performance of the flocculants under field conditions.

An in-depth laboratory investigation of polymer flocculant use in the Yukon placer mining industry was conducted by Reid Crowther and Partners (RCP) Limited. Laboratory tests of 6 polymer flocculants were conducted at 15 mines in 14 locations. The tests were conducted in graduated cylinders, and optimum dosage was based on settling rates rather than supernatant clarity. Chemical costs were factored into the results to obtain values for overall efficiency. Non-ionic polymers produced the best overall test results. Optimum dosage requirements for all 6 polymers tested ranged from 0.36 kg per m.t. TSS to 1.30 kg per m.t. TSS.

Stanley Associates Engineering (1985) conducted detailed laboratory and field studies of flocculants used at placer mine sites in northern Canada. Results of field testing showed that anionic polymers were effective in reducing suspended sediment and that settling pond design and maintenance were critical factors in achieving effective treatment with low polymer dosages. The dosage required to achieve a residual TSS concentration of 100 mg/L was twelve times the dosage required to achieve 1,000 mg/L.

Studies on the use of cationic polymers in treating placer mining wastewaters have been limited. Stanley Associates Engineering (1985) reported that some cationic polymers in synthetic placer mining wastewaters in interior Alaska in 1984 were applied successfully. The test dispersions were prepared with 76 grams dried silt per liter of water. Some cationics produced settling rates comparable to those achieved by anionic flocculants, but with improved supernatant clarity.

F. Factors Affecting Clarifier Effectiveness

Chemical clarification agents are designed to reduce turbidity or TSS; they are not intended to reduce levels of settleable solids. The effectiveness of chemicals is reduced and costs are increased when chemicals are added before initial settling of heavier particles.

The effectiveness of chemical clarifiers may be dependent upon physical factors such as concentration of fine sediments in the wastewater, dosage, temperature of the wastewater, characteristics of the sediments, and by thoroughness of mixing and dispersal systems, accuracy of pre-testing, selection of chemicals and dosages, design of settling ponds, pond maintenance schedules, and the use of supplementary filter systems. These factors are discussed below.

1. Physical factors

The effectiveness of all three forms of polyelectrolytes generally increases as the concentration of fines in the water increases. This is probably due to a higher rate of inter-particle contacts in such systems, although other factors may be involved. Shannon and Wilson (1985a) tested a single flocculant to treat placer mine effluent from a single source at suspended solids levels ranging from 15,600 to 92,600 mg/L. They found that less flocculant was required per unit of solids at higher solids concentrations than at low concentrations. When TSS levels were 15,600 mg/L, 0.38 mg flocculant per kg suspended solids was required to achieve final clarity of 100 NTU; however, when TSS levels were 92,600 mg/L, only 0.11 mg/L flocculant per kg TSS was required to achieve the same degree of clarity. Since their results were based upon one test, they may not be applicable to other sites because water chemistry and sediment characteristics may be different.

Stanley Associates Engineering (1985) reported noticeable improvement in polymer efficiency at higher temperatures, and that the temperature effect was more apparent at lower polymer dosages (less than 3.0 mg/L). They attributed the decreased performance at lower temperatures to increased viscosity of the polymer solution and poorer dispersion into the wastewater. In field applications, temperatures of stock polymer solution, dilution water, and wastewater all affect dispersion of the polymers into wastewater.

Morrow and Rausch (1974) found that performances of polyelectrolyte flocculants were not affected by hardness, alkalinity, pH, or temperature; however, the performance of flocculants is likely to be affected by geochemistry of the sediments.

2. Mixing and dispersal systems

McCarthy (1973) stated that the effectiveness of polymers is probably controlled more by mixing and dispersion than by any other factors.

The granular or powder flocculant form requires a well-designed system to dissolve the chemical. Insufficient wetting will result in lumps of polymer which are ineffective as coagulants and which can plug pumps and distribution systems.

Tramfloc, Inc. makes anionic and non-ionic polymers in the form of water-in-oil emulsions. These products are available at active strengths of 25% to 50%, and must be diluted before use. Mixing systems for diluting dispersion or emulsion forms can be simpler than those used for dry forms. Cationic coagulant polymers are available as 50% active liquids and require no dissolution.

Complete and rapid dispersion of the flocculant compound into the mine effluent is necessary to achieve uniform distribution of the flocculant and to force collision with suspended particles. Completeness of the coagulation and flocculation processes depend upon the number of particle collisions (Morrow and Rausch 1974, Shannon and Wilson 1985). Treatment facilities for municipal water supplies often use elaborate mixing tanks and power-driven dispersing systems. A mechanical metering system that allows the flocculant to drip into the effluent at a controlled rate is probably the most feasible dispersal system at remote placer mine sites. Environment Canada (1983) stated that a simple mechanical system can be built cheaply from scrap material.

Clarifying compounds are usually added to the mine effluent at the inflow to the secondary settling pond (i.e.,after initial settling of heavier sediments.) Mixing of the effluent with the clarifying compound can be enhanced by increasing the turbulence at the inflow to the pond. The area of increased turbulence is localized at the pond inlet; the pond itself must be still for effective floc settling.

McCarthy (1973) used a 50 foot long half-round culvert with baffles at 5 foot intervals at the pond inflow. Because field testing of the polymer indicated that the chemical was not as effective as predicted by jar tests, he increased the turbulence by adding angle iron obstructions below the outfall of the culvert. The increased turbulence increased the effectiveness of the polymer and reduced the concentration of flocculant required for settling.

Turbulence can also be achieved with a dike or notched weir at the inflow to the second settling pond. After initial settling, the water flows over the weir and cascades into the second pond. Angle iron or other obstructions can be added at the outfall to increase turbulence.

3. Pre-testing coagulants and flocculants

The effectiveness of a variety of coagulants and flocculants should be tested for specific water and sediment to determine the optimum chemical and dosage. Both settling rates and clarity of the supernatant should be considered when comparing different chemicals. Choice of polymer and dosage should depend primarily upon how well turbidity is reduced and secondarily upon maximum settling rate (Chang 1979). Potentially, a compound and dose that gives the fastest settling rate for a given set of mixing and soil conditions may not give optimum clarity.

Since settling tests are usually conducted over a shorter time span than would occur in the field, final clarities and dosages may vary between test and field results. Therefore, polymers and dosages should be field tested to determine which are most cost effective and produce best field results. Results of pre-testing may not apply to other sites because different sediment and stream water characteristics may give different results.

Settling tests should be repeated for different doses of the same flocculant and then for different flocculants. Results of these tests will show the best dose of each flocculant for the stream water and sediment tested.

Mixing of the flocculant, sediment, and water in settling tests should be similar to the amount of mixing at the placer mine site. For example, if there is no power supply at the placer mine and mixing is minimal, the amount of mixing for settling tests must also be minimal.

Over mixing during settling tests may lead to an overestimate of the actual effectiveness of the flocculant compound at the mining site and an underestimate of the amounts of flocculant needed to achieve desired clarity. Kailing and Green (1982) report that in one test at Livengood, field tests required about twice as much flocculant to attain a turbidity of 50 NTU as was required to attain 25 NTU in the laboratory. They attributed the difference in test results to more thorough mixing in the laboratory. Jennings (1983) reported that results from laboratory tests could not be duplicated in the field because of limited field facilities for mixing and dispersing the polymers. Based upon dosage estimates for field applications, Jennings concluded that it may not be economically feasible to achieve water turbidities of less than 5 NTU above ambient conditions at remote placer mine sites.

4. Settling pond design

Settling ponds or lagoons in a series are most commonly used in a sediment control system that uses chemical clarifiers. The clarifiers are added after initial settling of the heavier particles and before a final polishing pond. The efficiency of chemical clarifiers will be increased if all particles that will settle by gravity are removed before clarifiers are added.

McCarthy (1973) described a control system for surface mine siltation in Washington. The system consisted of two ponds in a series; the first pond was for settling larger particles that were heavy enough to settle naturally, and the second pond was for settling flocculant-treated sediments. Flocculants were added in the raceway between the two ponds. This design proved effective for clarifying surface mine effluent provided there was sufficient turbulence at the entrance to the second pond to achieve thorough dispersion of polymers.

5. Cleaning the pond and dewatering sediments

The settling ponds should be cleaned frequently to maintain sufficient sludge storage capacity and retention time. After settling, the fine sediment should be removed from the pond and spread over the land to dry. Sediments should be placed where they will not erode into the stream. Cleaning settling ponds is not always possible; alternatively full ponds can be covered with tailings and new ponds constructed.

The stability of the sediment-flocculant mixture in the settling pond depends upon the density of the floc and dewatering characteristics of the flocculant.

6. Supplementary filter systems

Clarification of water treated with flocculants may be further enhanced by tailing or sand filters. Sand filters have been commonly used in Europe and the United States to clarify municipal water supplies (Weber 1972). These filters can be highly effective in removing most suspended solids except for fine clays and colloidal solids. Fine particles will penetrate deeply into the filter and the filter cannot be cleaned by removing the upper layers of sand. Where fine clays or colloidal solids were present, sand filters were not adequate to produce drinking quality water (Weber 1972).

Mine tailings have also been used successfully as a filtration medium. A placer miner working in the Kantishna area of Denali National Park, Alaska produced an effluent of 5 NTU above background or less with settling ponds and tailings filtration (Townsend, pers. comm. 1985). The miner did not pre-treat the wastewater with chemical clarifiers. Use of material which is already available at the mine site will substantially reduce operation costs over importing filtration material.

Sand filters have been described more thoroughly in the engineering literature than mine tailings or gravel filters. Although filter systems constructed from mine tailings may be more economic and easier to construct at a placer mine site, a discussion of sand filters is presented to give a general knowledge about filtration systems and some of their limitations.

Weber (1972) described a sand filter as a watertight basin containing a layer of sand 3 feet to 5 feet thick, supported on a layer of gravel 6 inches to 12 inches thick. The gravel is underlain by a series of perforated drain pipes, usually placed 10 feet to 20 feet apart. The perforated drain pipes collect the filtered water to a single outlet where it is discharged. Sand in the 0.35 mm size range is commonly used for treating drinking water to remove sediment, algae, and bacteria. Larger sand may be sufficient in treating mining effluent.

The sand filter is operated with a water depth of 3 to 5 feet above the sand surface. The water slowly percolates through the sand and collects in the perforated drain pipe; sediments usually collect in the upper few inches of sand.

When the water ceases to flow through the sand at an acceptable rate, input to the pond is stopped until the water in the pond has moved through the filter, then the surface is scraped and removed to reveal a clean surface. Sand filters for municipal water treatment are usually cleaned by back flushing, a practice which is impractical or impossible at most placer mine sites. Sand filters at placer mine sites should be constructed so that they can be cleaned by scraping the top layer of sand. This layer would then be spread on the land, away from the stream channel, and allowed to dewater. The frequency of cleaning is determined by the amounts of sediments in the water and how quickly the top layers of sand become clogged with sediment.

Although use of polyelectrolyte compounds will add costs for the chemicals, other costs associated with cleaning and maintaining the filter will be reduced.

Use of polymers for treating municipal wastewater results in a sludge that dewaters more rapidly and does not penetrate into the sand filter (Novak and Langford 1977). Similar results would be expected from mining effluent because the larger, polymer-bound sediment particles would not penetrate through the sand as readily as untreated sediment.

Estimates for dosage of flocculant and cost of the flocculant compound are usually based upon the amounts of fine silts and clays to be settled in the pond rather than the volume of water used for processing (Environment Canada 1983b; Shannon and Wilson 1985b). If known amounts of flocculant and sediment are used for preliminary jar tests, then grams of flocculant compound required to settle a given amount of sediment can be determined. This value can be used to estimate the costs for settling concentrations of silts and clays likely to be found in the placer washwater.

Environment Canada (1983b) presented an example for estimating chemical treatment costs based upon the assumption that 7% of the sluiced material (by weight) was fine silt and clay and settleable by flocculants. Therefore (by their example), if a mine is washing 525 cubic yards per day of gravel at 3,370 pounds per cubic yard (cy):

7% of 3,370 lbs = 236 lbs fine silt and clay.

$$\text{or} \quad \frac{236 \text{ lbs}}{\text{cY}} \times \frac{525 \text{ cy}}{\text{day}} \times \frac{0.00045 \text{ m.t.}}{\text{lb}} = \frac{56 \text{ m.t.}}{\text{day}}$$

If a flocculant dose of 50 grams/m.t. is effective, then :

$$\frac{50 \text{ grams}}{\text{m.t.}} \times \frac{\text{kg}}{1000 \text{ g}} \times \frac{56 \text{ m.t.}}{\text{day}} = \frac{2.8 \text{ kg flocculant}}{\text{day}}$$

If the flocculant costs $6.00 per kilogram, then:

$$\frac{2.8 \text{ kg}}{\text{day}} \times \frac{\$6.00}{\text{kg}} = \frac{\$16.80}{\text{day}} = \text{cost of flocculant per day}$$

Estimates presented above are only for cost of the flocculant. Additional costs will be incurred with freight, capital, and labor costs associated with mixing and dispersal systems and labor required to maintain dispersal systems. Accuracy of any cost estimate depends upon how closely flocculation in jar tests simulates conditions in the settling pond and the accuracy of the estimates for proportions of fine silt and clays found in the sluiced gravel.

G. Toxicity of Coagulants and Flocculants, aka, Chemical Clarifiers

Toxicities of chemical clarifiers have been tested primarily for human consumption, warm-water species of fish, and for various invertebrates. Tramfloc, Inc., for example, is required to conduct toxicity tests. Although these tests are usually limited, they do provide information on toxicity, maximum allowable dosages, and whether or not the chemical has been approved by the Food and Drug Administration for human consumption, fisheries, or other uses.

Few tests have been conducted on clarifier toxicity to salmonid or other cold-water fish. Results of most toxicity tests have shown that critical factors determining toxicity are purity of the chemical, ionic form, and concentration of flocculant used in excess of that required for settling. Chemicals in excess of the amounts required to bind with sediment particles will remain dissolved in the water and are potentially available to the aquatic biota.

Polymeric flocculants can be obtained in various grades, from very pure to standard. The higher grade flocculants contain fewer impurities from manufacture but are more expensive. Therefore, the higher grade chemicals are used for potable water or where toxicity to aquatic organisms is of particular concern.

Brocksen (1971) reported that 1 mg/L or less of cationic flocculant was acutely toxic to rainbow trout (Salmo gairdneri) in 36 hours when tests were conducted in clear water. When suspended sediments were added to the water, the chemicals bound with the sediments and were not available to the fish. Tests with added sediment showed the flocculant to be non-toxic to fish for up to 72 hours (the duration of the test).

Biesinger (1985) tested the detoxification properties of anionic polymers and red clay acting upon cationic polymers in a controlled microcosm. He found that mortalities of both fathead minnows and Daphnia were significantly reduced when either anionic polymers, red clay, or a combination of both was added to clear water-cationic polymermedia. Toxicities were reduced because the cationic polymers were either bound with the red clay particles, neutralized by the anionic polymers, or a combination of both. Therefore, the chemicals were not available to aquatic species in the microcosm. Results of these studies emphasize the importance of using the minimum amounts of chemical required to achieve desired clarity.

Of the three ionic forms of polymer flocculants, researchers found cationic chemicals to be acutely toxic in concentrations of about 2 mg/L to 3 mg/L of water (without sediment), whereas the anionic polyelectrolytes were relatively non-toxic at the same concentrations Other facilities have tested all three poly-electrolyte forms on rainbow trout, lake trout (~alvelinus namaycush), and three crustaceans: a mysid (Mysis relicta), a copepod (Limnocalanus macrurus) and a cladoceran (Daphnia magna). They concluded that some of the cationic polyelectrolytes tested are particularly toxic at concentrations which could be released into aquatic environments. Two cationic polyelectrolytes were also shown to impair reproduction of Daphnia at concentrations of 0.1 mg/L and 1.0 mg/L. These concentrations are within the range of concentrations which may occur with normal use of polyelectrolytes.

Stanley Associates Engineering (1985) reported that cationic polymers are more toxic to fish than other ionic forms because of their affinity for the negatively charged surface of fish gills. The iron mining industry in Quebec (Stanley Associates Engineering 1985) has shown that residual cationic polymer can be removed from wastewater by adding small amounts of anionic polymer, thus reducing the possibility of residual toxicity in particularly sensitive receiving waters.

H. Effects on Gold Recovery

Placer mine operators have expressed concern that residual polymer in recycle water may affect gold recovery. If correct dosages of polymer are used, as predetermined in jar and field tests, there will be very little residual polymer in the wastewater. In fact, we sampled wastewater treated with our anionic flocculants and found concentrations lower than a detection limit of 0.05 mg/L(reported by Stanley Associates Engineering 1985). Polymer molecules have an extremely high affinity for particulates and no residual polymer should be present in solution unless an excessive1 dosage is applied or there is poor mixing of polymer and wastewater. Therefore, recycled water from the supernatant should contain little or no residual clarifiers and should not affect gold recovery.

I. Conclusions

Coagulants and flocculants have been used effectively to reduce turbidity in municipal drinking water and wastewater, industrial wastewater, quarry effluent, and coal-clay wastes. Field tests of chemical coagulants and flocculants to treat placer mine effluent have been limited in some cold climates and have often produced ambiguous or contradictory results. Technology for mixing and dispersing these chemicals has been developed. Toxicities and recommended maximum dosages are established for most commercially available coagulants and flocculants. Cost estimates are available for many types of applications and for many geographic areas.

The effectiveness of coagulants and flocculants clarifiers to treat placer mining effluent can be limited by cold water temperatures, concentrations of fine sediment in the wastewater, dosage, handling procedures, and chemical and physical characteristics of the sediments. The most important factors influencing flocculants are listed below.

1. Adequate mixing and dispersion of the polymers into the wastewater are necessary to achieve low chemical costs and maximum treatment.

2. Primary settling pond design and maintenance are key factors in achieving effective treatment at low polymer dosages.

3. Laboratory jar tests, followed by field testing is an efficient means of selecting the chemical clarifiers that will produce optimum treatment under specific physical and water quality conditions.

4. The effectiveness of chemical clarifiers may be enhanced with supplementary filter systems.

Coagulants and flocculants have been shown to be effective in treating placer mining wastewater under a range of conditions, including those found in northern climates of Alaska. Chemical treatment may be the most effective means of reducing sediment pollution, especially in areas where fine clays are abundant, and in combination with water use reduction and filtration or overland discharge. Chemical clarifiers will provide an effective alternative for reducing turbidity at placer mine sites, particularly where downstream uses will be adversely affected by high turbidity and total suspended sediment loads.

J. Recommendations

1. The application of chemical clarifiers to treat placer mine effluents in cold climates merits further field testing to determine usable products, efficient dispersal systems, and relative costs.
2. A variety of coagulants and flocculants should be pre-tested for site-specific temperature and water chemistry conditions to identify the most efficient clarifiers for a particular mine site. Chemicals selected should not be toxic to the aquatic biota.
3. The most promising chemical formulations should be further tested to determine effectiveness under field applications. Optimum designs for dissolving and dispersing the chemicals and for designing settling ponds should be considered.
4. A simple chemical delivery system should be evaluated at full-scale.
5. Treatment with polymeric chemicals should be tested in conjunction with other treatments, including filtration and overland discharge.
6. All settling ponds intended to contain flocculant-treated sediments should be placed outside the creek-bed to prevent wash-out.