Generic Scenario: Water Treatment Coagulants - Application

Industry Description

Approximately 325 billion gallons of water are used daily in the United States. Depending on its use, most water must be treated, including water used by industry, municipalities, and power-generating utilities. Pollutants in the water that may impede its use or discharge into surface waters are treated by physical, chemical, and biological methods. The market for water treatment chemicals in the United States totaled $2.3 billion in 1988 and was estimated to grow to $3.2 billion by 1993 (Taylor, 1990). This overall market equates roughly to 12.9 billion pounds of water treatment chemicals sold in 1988 (Taylor, 1990). Of the total volume of chemicals used in 1988,

- 54% was used to treat municipal, utility, and institutional water.
- 34% was used to treat industrial water, including that used in manufacturing, processing, and refining.
- 12% was used by residential and commercial markets (Taylor, 1990).

About 59,000 public water treatment plants exist in the United States (AWWA, in press). Among them, 612 systems serve 50,000 people or more, 2400 systems serve 10,000 to 50,000 people, and 56,000 serve fewer than 10,000 people. Assuming 180 gal per capita (Achtermann, 1992), average throughputs can be calculated. In addition to public water treatment plants, a total of 15,438 wastewater treatment plants were in operation in 1986. It is estimated that 17,000 wastewater plants will be in existence by the year 2005 (National Council, 1987). About 70% of the population is served by these facilities along with 160,000 industries and an unknown number of commercial establishments. Of these plants, 32% have flowrates in the range of 0.01 to 10 million gallons per day (MGD), 45% in 0.11 to 1.00 MGD, 19% in 1.01 to 10.00 MGD, and 4% greater than 10.00 MGD (National Council, 1987).

Market

Coagulants are used in large quantities at both water and wastewater treatment facilities. In 1988, 1894 million pounds of coagulants were used for water treatment (Taylor, 1990). Two classes of coagulants are used extensively: organic polymers and inorganic salts. The polymers are far more expensive than the inorganic salts. For example, in 1988, organic polymers accounted for 8% by weight of water treatment coagulants; however, they accounted for 55% of dollar sales. Polymers offer several advantages:

- They can be used in much smaller quantities than the organic salts.
- They produce less sludge.
- The solids-to-water ratio in the sludge is much greater.

These advantages reduce both disposal and operating costs (Taylor, 1990).

Classes of Coagulants

Most inorganic coagulants are based on either aluminum or iron. The aluminum compounds include sodium aluminate and aluminum sulfate (commercial alum). The iron coagulants include ferric sulfate, ferrous sulfate, and ferric chloride. Silica is occasionally used in various treatment applications. The organic coagulants are either natural or synthetic water-soluble polymers that are classified according to their charge as either cationic (positive), anionic (negative), or nonionic (neutral). More than one-half of all synthetic polymer coagulants are copolymers in which the principal monomer is acrylamide. Approximately 44% of the acrylamide polymers are anionic, and approximately 49% are cationic (John Wiley & Sons, 1987). Other polymers include Nalcolyte 110A®, a modified food starch; Nalcolyte 8102®, a quaternary polyamine; and Polydiallyl-dimethylammonium chloride (Poly-DADMAC®) (Keifer et al., 1983).

Delivery and Storage

Coagulants are delivered to treatment facilities in either a dry or a liquid state. Dry coagulants commonly used include fine powders, granules, flakes, pellets, rocks, and crystals. Dry coagulants can be received in bags or drums, or in bulk, by rail or tank truck. Liquids are shipped in drums, either by rail or by tank truck. The state of the chemical and quantity used depend on the application as well as the size of the treatment facility. Large treatment facilities tend to purchase the less expensive dry form and blend it to the appropriate form as needed. Smaller treatment facilities generally use liquid chemicals that tend to be more expensive, but need little preprocess preparation. Liquid chemicals also are used in situations where a chemical is needed only sparingly or where a quick addition may be necessary to correct unforeseen problems such as fluctuations in pH (White, 1992). Large treatment facilities generally store the dry chemicals in silos, whereas smaller treatment facilities generally store them in the bags or drums in which they were transported. Liquids generally are received in concentrated form in bulk quantities, either by tank car or truck, or in drums, depending on the size of the facility (Keifer et al., 1983).

Chemical Feed

The dry chemicals are fed either gravimetrically or volumetrically to a mixing tank. The tank generally is automated so that a constant level of slurry is maintained. The slurry is then decanted or pumped to the point of application. Liquids are added in much the same way. The concentrated solution is added to a tank along with a certain quantity of diluting water. The resulting solution is then decanted or pumped to the point of application (Keifer et al., 1983). Figures 1 and 2 depict feed systems for dry chemicals and concentrated solutions (adapted from Keifer et al., 1983).

Coagulant Dosage

The quantity of coagulant needed for an effective treatment varies depending on the type of applications and type of chemicals. Large doses of inorganic coagulants generally are required to produce the same results as small doses of the organic polymers. In some cases, the polymers are blended with the inorganic salts. These blends can decrease the amount of metal hydroxides that would be formed with inorganic coagulants (Taylor, 1990). Typical concentrations of coagulants are depicted in Table 1 (Keifer et al., 1983). Note that for both solids and liquids, 1 ppm is equivalent to 8.34 lb per 1,000,000 gal of water.

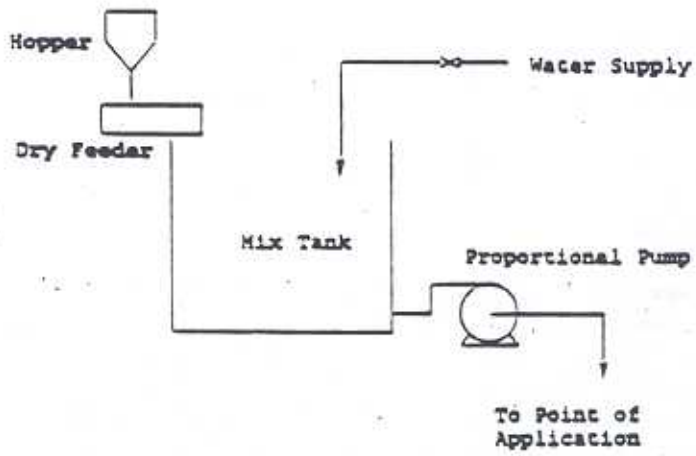

Figure 1. Dry Chemical Feed System

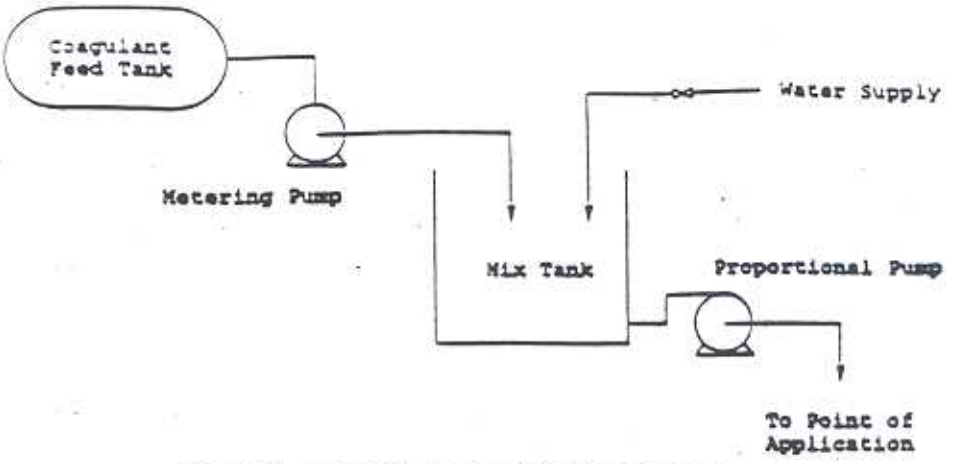

Figure 2. Concentrated Solution Feed System

Worker Exposure

Estimates of treatment facility staff requirements can be made for each type of facility. Water treatment facilities, operating 24 hours a day and treating fewer than 10 MGD, will have an average of 9 staff members, 4 of whom would be operators. A plant operating in the range of 20 to 50 MGD will have an average staff of 40 people, 14 of whom would be operators (Montgomery, 1985). The number of staff in a wastewater treatment plant can be assumed to be 2 people for every 1 MGD of wastewater treated. This number assumes that the treatment facilities utilize secondary as well as primary treatment (White, 1991). Worker exposure is most likely to occur during handling of the chemicals. At small facilities, exposure will be from opening the drums and bags containing the chemicals and feeding the chemicals into the process. At large facilities, workers will be exposed primarily during manipulation of the transfer lines between storage tanks and the treatment process (Keifer et al., 1983).

Table 1. Typical Coagulant Concentrations for Water Treatment

Coagulant	Typical Concentration
Inorganic	
Aluminum sulfate	10 to 150 ppm
Ferric chloride	5 to 150 ppm
Ferric sulfate	10 to 100 ppm
Sodium aluminate	5 to 50 ppm
Organic	
Nalcolyte 110A®	1 to 5 ppm
Nalcolyte 8102®	1 to 50 ppm
Poly-DADMAC®	1 to 20 ppm
Polyacrylamide	0.5 to 5 ppm
Sodium polyacrylate	< 1 ppm

Preliminary manufacturing notice (PMN) materials may be used as additional components or substitutes for current water treatment coagulants. It is assumed that the PMN materials in consideration are non-volatile and are provided in solid (dry) or liquid forms. Do to lack of data in the literature, it will also be assumed that 100% of the coagulant will be removed as sludge. In most cases this is a valid assumption. Research has been conducted by various institutions which indicates that within detection limits all of the polymer becomes part of the sludge (Keifer, et al., 1983).

Variables

- %PMN: weight percent of PMN material in the coagulant.
  Table 2 lists %PMN for coagulants commonly used (Keifer, et al., 1983).
- C: amount of coagulant used at the water treatment plant (kg/site/day).
  Refer to Table 1 for typical dosages.

Table 2. Percent PMN for Commonly Used Coagulants

Chemical Name	Form	%PMN
Aluminum sulfate	Powder Liquid Liquid	17% as Al_2O_3 8.3% as Al_2O_3 49% as $Al_2O_3 \cdot 14\ H_2O$
Ferric chloride	Liquid Crystal Anhydrous	12-17% Fe 20% Fe 34% Fe
Ferric sulfate	Dry	18.5-28% Fe
Ferrous sulfate	Dry	20-21% Fe
Sodium aluminate	Dry Liquid	41-46% Al_2O_3 4.9-26.7% Al_2O_3
Organic polymers	Varies	Varies/Proprietary

Environmental Releases (total kg/site/day)

Solid Wastes: PMN materials in water treatment coagulants will persist through the process to be removed as sludge. If it is assumed that 100% of the coagulant material will be removed as sludge, then the yearly release of the PMN material as sludge is:

$$\% \text{ PMN}/100 * C = \text{kg/site/day} \quad (1)$$

Air Emissions: Air emissions of the coagulant PMN material will depend on whether the product is initially in a solid (dry) or liquid form.

Release to the air of solid coagulant PMN material can be expected to occur during handling and addition of the coagulant, particularly in the case of powder formulations. Typically, the handling and mixing of powders in manufacturing applications leads to air emissions on the order of 0.1 to 1 wt% of bulk powder usage (U S EPA.

1985). Assuming the absence of particulate emission controls at the typical treatment plant, air emissions of powder-based PMN material can be estimated as:

$$C * (0.1-1)\%/100 * \%PMN/100 = ?kg/site/day \quad (2)$$

Improved estimates of the air emissions of powder-based PMN materials can be obtained through measurements of the bulk powder concentrations in the air or by comparisons with analogous powder product concentrations in similar operations.

Air emissions from bead or granular (in contrast to powder) formulations of coagulant products are expected to be negligible. Air emissions of liquid PMN coagulant additive or substitutes also are expected to be negligible.

Water Releases: Releases to water of coagulant PMN material will depend on the solubility of the PMN material, assuming that all insoluble material is removed as sludge following water treatment and that the water-soluble fraction is discharged with the treated water. In most cases, the coagulant will be insoluble in water. Coagulants tend to polymerize upon addition to the water, forming large, insoluble molecules. Therefore, it can be assumed that the quantity of coagulant released in the water is negligible.

Worker Exposure

Worker exposure to the PMN coagulant additive or substitute is most likely to occur from handling and transfer operations at the water treatment facility. The potential routes of exposure are through inhalation of powders of solid PMNs, as well as from dermal exposure to PMNs during transfer and handling of solid or liquid PMN materials. Refer to previous discussion for typical numbers.

Inhalation (mg/day): Assuming that water treatment operations are medium-duty work in terms of the level of physical activity required, an inhalation rate of 1.25 m^3/hr will be assumed (CEB, 1991).

Solid PMNs: Air concentrations of powder-based PMNs can be expected in the workplace due to transfer and handling operations. If the coagulant dust can be classified as an inert or nuisance dust [overall Occupational Safety and Health Administration (OSHA) Permissible Exposure Level (PEL) = 15 mg/m^3; OSHA PEL for the respirable powder fraction = 5 mg/m^3], and H is the number of hours that a worker is exposed to the dust atmosphere (typically 8 hours), the inhalation exposure of a worker during an operating day to powder-based PMN material is:

$$15\ mg/m^3 * 1.25\ m^3/hr * H * \%PMN/100 = ??\ mg/day \quad (3)$$

This calculation assumes a worst-case scenario and, therefore, uses the PEL of 15 mg/m^3. Also, this calculation assumes that the coagulant and the PMN material are inert and can be classified as nuisance dusts. In some cases, however, this assumption may not be applicable. Also, if the components of the coagulant are mixed in an enclosed volume such as a jet mixer and the workers are protected by dust masks or respirators, the actual inhalation exposure to PMN in the dusts will be lower than that estimated above.

Dermal Exposure (mg/day): Dermal exposure can result from the dusts arising during the handling of solid (powder) PMN material in preparing the coagulant, as well as from the transfer and handling of liquid or powder PMN materials. In each of these cases, dermal exposure can be expected to arise from either intermittent or routine contact with the chemical product containing the PMN material. Dermal exposure from airborne dusts likely will be small compared to the dermal exposure from handling and transfer operations.

Assuming that the unloading of drums containing the liquid PMN or of bags/containers containing PMN powders, flakes, or granules can be expressed as a single contact, which is representative of an entire day, and

using estimates of the typical dermal exposure from these types of routine contact operations (Table 4-13, CEB, 1991), the dermal exposure to PMN material is:

$$(6{,}500\text{–}18{,}200)\ \text{mg/day} * \%\text{PMN}/100 = ??\ \text{mg/day for powder PMN} \quad (4)$$

and $$(1{,}300\text{–}3{,}900)\ \text{mg/day} * \%\text{PMN}/100 = ??\ \text{mg/day for liquid PMN} \quad (5)$$

where %PMN is the weight percent of solid or liquid PMN material in the coagulant being prepared. Note that these estimates for dermal exposure are worst-case estimates and the actual dermal exposures would be lower if protective equipment such as gloves, eyewear, etc. were worn by the workers.

Disposal Concerns

The containers used to transport the PMN materials to the facility are assumed to be recycled, cleaned to remove contamination, appropriately landfilled or incinerated. Solid wastes containing the PMN material, such as sludge, are assumed to be disposed using appropriate mechanisms.

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