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Design Manual:

Removal of Fluoride from Drinking Water Supplies by Activated Alumina

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DESIGN MANUAL
REMOVAL OF FLUORIDE FROM DRINKING WATER SUPPLIES BY ACTIVATED ALUMINA

by

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The pollution of our nation's groundwater has been called <u>the</u> environmental problem of the 1980s. When polluted groundwater serves as a source of public drinking water, pollutants must be removed to levels below standards regulated by the Safe Drinking Water Act (Public Law 93-523). Fluoride, in concentrations exceeding the optimum level beneficial to teeth, can become detrimental to new tooth formation in infants and children up to about 12 years old. This design manual shows step by step the actual methods for designing a central water treatment plant for removal of excess fluoride from small community water supplies.

Francis T. Mayo, Director
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ABSTRACT

This manual is an in-depth presentation of the steps required to design and operate a water treatment plant for removal of excess fluoride using the activated alumina method. Low capital and operating costs, simple operation, and ability to closely control the effluent fluoride level are features that highlight this process. The alumina process requires adjustment of raw water pH to 5.5 prior to passing through the treatment media; after treatment, the pH is readjusted to the desired level. Initially, the process removes more than 95 percent of the fluoride in the raw water. Blending may be practiced if initial fluoride is low. As treatment continues, the activated alumina grains adsorb fluoride ions until saturated. Implementation of a caustic soda regeneration releases and totally removes fluoride ions in a highly concentrated wastewater which must be discarded. After regeneration, the pH of the treatment media is lowered to where treatment resumes again and a new cycle commences.

This manual includes discussion of design requirements and details of operation and maintenance. It discusses the capital and operating costs including the many variables which can raise or lower costs for identical treatment systems. Wastewater disposal is also discussed.

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CHAPTER 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

This manual has been prepared to present up-to-date information on design of central treatment plants for the removal of excess fluoride from potable water supplies.

This manual is an independent document. The detailed design information presented herein applies exclusively to granular activated alumina technology for selective removal of excess fluoride. Several other treatment methods have been employed for this application, but none with the cost-effectiveness and process efficiency of the activated alumina method. Some of the more familiar methods and their limitations are covered in Chapter 2.

When excess fluoride is present in potable water in combination with excess quantities of other organic and/or inorganic contaminants, the activated alumina method may not be optimum for the application. Those water supplies must be evaluated on a case-by-case basis for selection of the appropriate treatment method, or combination of methods, for the application. That technology is beyond the scope of this manual.

There has been interest exhibited in "point-of-use" application of the activated alumina technology; however, that area is not included in the scope of this manual.

1.2 BACKGROUND

Under the National Interim Primary Drinking Regulations, maximum contaminant levels (MCL) in potable water supplies have been established for ten inorganic chemicals, including fluoride. The MCL for fluoride varies from 1.4 to 2.4 mg/l depending upon the annual average of maximum daily air temperatures (see Table 1.1). Since it became known that excess fluoride in drinking water caused mottled teeth in children[1], many methods of removing fluoride have been developed. The activated alumina method is one of them.

TABLE 1.1. MAXIMUM CONTAMINANT LEVELS FOR FLUORIDE

Average Maximum Daily °C	°F	Fluoride Level mg/l
12.0	53.7	2.4
12.1-14.6	53.8-53.3	2.2
14.7-17.6	58.4-63.8	2.0
17.7-21.4	63.9-70.6	1.8
21.5-26.2	70.7-79.2	1.6
26.3-32.5	79.3-90.5	1.4

Although many investigators have found that activated alumina is quite effective in reducing fluoride to very low levels in treated water, there is confusion as to the procedure for using the activated alumina process. Churchill[2], in his 1936 patent on the use of activated alumina for fluoride removal, states that a pH of 5 to 6.5 should be used for treatment for best results. There is no stated capacity in his patent. E. A. Savinelli and A. R. Black[3], in their 1958 bench experiments, showed that a capacity of 3,400 grains/cu ft was achieved when the treated water pH was 5.6. These studies were made with tap water to which sodium fluoride had been added. Yeun C. Wu[4] showed that treatment pH is quite important for high removal capacities. He reported maximum removals of 4,200 grains/cu ft with treatment at pH 5 on pure sodium fluoride solutions. Other investigators[5-10] who have made bench, pilot or commercial installation studies have reported much lower capacities because they have not understood or chosen to operate at optimum pH conditions.

There are three plants at which there have been several years of low-cost operating experience in producing waters with fluoride concentrations reduced to acceptable levels. They are:

1. Lake Tamerisk, Desert Center, California (1,100 gpm) - 1970
2. Rincon Water Company, Vail, Arizona (500 gpm) - 1972
3. Town of Gila Bend, Arizona (900 gpm) - 1978

By paying close attention to pH control, the three plants are able to operate routinely with removal capacities exceeding 2,000 grains/cu ft.

As the raw water fluoride concentration increases, the activated alumina capacity increases. For a water with a fluoride concentration of 22 mg/l (not a normal level in U.S.A.), the alumina capacity reaches 4,500 grains/cu ft.[11]

The granular activated alumina employed at the above treatment plants is Alcoa Grade F-1 with mesh size of 28-48. Larger mesh sizes have been tried; they work, but their fluoride capacities are lower. Finer mesh material has not been used in other than laboratory bench-scale work. A new pelletized material, F-100, has been developed by Alcoa and has been tested in the field. This material will soon be available. It is the same mesh size (28-48) as the F-1 and has the same fluoride removal capacity. Its advantage is in having very few fines. It is, therefore, easier to handle. There are other manufacturers that produce an activated alumina product similar to the Alcoa F-1. However, to-date, there has been very little demonstration work to verify the performances.

1.3 FLUORIDE IN WATER SUPPLIES

Fluorine, a gaseous halogen, is not found in the free state, but occurs in combination with other elements as fluoride compounds. Most of these compounds are a complex of calcium-fluoride-phosphate. Fluoride ions normally exist in small concentrations in all water supplies. Unless contaminated by fluoride-bearing wastes, the concentrations in surface water supplies are normally low. Frequently surface waters with low fluoride concentrations receive fluoridation treatment to raise the level to an optimum desired for consumer protection from tooth decay. The optimum level established by the U.S. Public Health Service is one-half of the MCL. Well water supplies have higher fluoride concentrations due to the fact that exposure to fluoride-bearing minerals is far greater. There are, however, many well water supplies with fluoride levels low enough to require the above-mentioned fluoridation treatment. The vast majority of well water contains fluoride levels close to optimum, or within the MCL. Nevertheless, per Letkiewicz[13], there are more than 2,000 water supplies in the United States in which the fluoride MCL is exceeded. Of those, nearly all have fluoride levels occurring between the MCL and 12 mg/l. There are known water supplies with natural fluoride levels as high as 30 mg/l. In those water supplies, the concentration of other minerals is usually too high to be used for potable water service without desalinization.

1.4 HEALTH EFFECTS

Due to the natural affinity of fluoride ions for calcium, there is a complex interaction between ingested fluoride and skeletal components. Medical studies have been conducted for many years to determine the health effects on animals and humans resulting from that interaction. Results have not been conclusive. These studies are very difficult to control because, except for dental fluorosis (mottled teeth) in children, the skeletal effects develop over long periods of time. During those periods there are many other elements interacting with the skeletal system as well as with the fluoride ions. The specimens observed during the studies may also have ingested fluoride from sources other than water; or may have absorbed airborne fluoride ions through the lungs or even the skin.

In the field of veterinary medicine there are many documented cases, covering dairy cattle and other farm animals, that have experienced fluoride toxicosis (bone deterioration due to excessive fluoride) from ingestion of water with fluoride levels ranging from 6 to 12 mg/l. This affliction results in crippling and death.[12]

Dental fluorosis is recognized as a direct result of ingestion of water with fluoride content exceeding the MCL by children ranging in age up to twelve years old. Dental fluorosis can vary from a mild discoloration of the tooth enamel to a severe pitting and embrittlement of the tooth structure. The severity of the condition varies directly with the concentration of the fluoride and the amount of water ingested. Once the adult teeth are fully formed, there is no further deterioration. This condition is considered as a health problem by some health experts; but others state that it is a cosmetic problem which is not to be considered as detrimental to health.

1.5 REDUCTION OF FLUORIDE

It is desirable to control the concentration of fluoride in potable water supplies as close to the optimum level as possible. The optimum is one-half of the MCL (see Table 1.1). In water supplies where the fluoride level exceeds the MCL, steps must be taken to reduce that level to below the MCL (preferably to the optimum level). This design manual addresses removal of excess fluoride by the activated alumina method. There are other treatment methods which could be considered (see Chapter 2). There are also other options which may offer less costly solutions. These optional solutions all involve alternate sources of supply.

The first choice is an existing water supply within the service area with known quality that complies with the fluoride MCL in addition to all other MCL's (both organic and inorganic). If another source complies with the fluoride MCL but exceeds another MCL (or MCL's), it may still be feasible to blend the two sources and achieve a water quality that complies with all MCL's. There are other features of this option that may present liabilities during its consideration. These would include, but not be limited to, high temperature or undesirable quantities of non-toxic contaminants such as turbidity, color, odor, hardness, iron, manganese, chloride, sulfate, sodium, etc.

Another option is to drill a new well (or wells) within the service area. This approach is attempted only when there is sound reason to believe that sufficient quantity of acceptable quality water can be located. The cost (both capital and operating) of a new well must not exceed the cost of treating the existing source. There is an element of risk in this approach.

Another approach is to pump good quality water to the service area from another service area. As the distance increases, the rise in elevation increases and/or the existence of physical barriers occurs, the costs of installing the delivery system and delivering the water become increasingly unfavorable. Similar to the alternate source within the service area, this imported source can also be blended as described above.

Use of bottled or other modes of imported acceptable quality water to be used only for potable water purposes is also an option. The reliability, the cost and the assurance that the consumers will only use that source are deterrents to be considered.

Other options such as "point-of-use" treatment systems are viable alternatives. However, the treatment reliability of such units cannot be assured unless there are stringent controls governing their operation and maintenance. Also the problem of assuming that all users consume only water that has been treated where untreated water is also available must be addressed.

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CHAPTER 2

TREATMENT METHODS FOR FLUORIDE REMOVAL

2.1 INTRODUCTION

There are several central treatment plant methods that can remove excess fluoride from potable water supplies. This manual only addresses the activated alumina method which to date has been the most successful. Alternative physical/chemical processes which include adsorption, ion exchange, membrane separation and chemical precipitation are described briefly in this chapter. The status of the alternate methods has already been summarized by several authors. An AWWA Journal article by Sorg[1] covers the subject quite well.

2.2 GRANULAR ACTIVATED ALUMINA

The granular activated alumina method which is an adsorption process is the most efficient and least costly treatment method available to date. Exceptions can occur at existing treatment installations where minor modifications to the treatment process can remove the necessary quantity of fluoride. This design manual is directed toward implementation of the granular activated alumina method for the selective removal of excess fluoride from potable water supplies.

The treatment media specification is provided in Chapter 1. The material is a by-product of aluminum production. It is primarily an aluminum oxide which has been activated by exposure to high temperature and caustic soda. The material is extremely porous. Therefore, the surface area per unit of weight is quite high. The material is ground into a granular form, and screened into various mesh sizes ranging from one half inch gravel down to fine dust which passes a 325 mesh screen. Each of the various sizes is adapted to specific applications[2], which include drying of air/gas and catalysts.

There have been many papers written on the application of granular activated alumina to the removal of fluoride from water. Some of these are included in the References for Chapter 1. One of the earliest and most publicized activated alumina fluoride removal plants which was built in Bartlett, Texas in 1952 operated for many years; the raw water fluoride level was 8 mg/l. Initially the raw water pH which was above 8.0 was not adjusted. Eventually, it was adjusted to 7.0. The alumina capacity for fluoride ions was reported at 700 grains/cu ft. At a later date, a new well was developed which had a fluoride level of 3 mg/l. With raw water pH adjusted to 7.0, the reported fluoride capacity of the alumina was reduced to 450 grains/cu ft. This plant is no longer operational. The current basic process technology was formally published in an EPA Technical Report[3] in 1978. Other researchers have since duplicated this work and published reports covering laboratory, pilot-scale and full-scale plant projects.

By carefully adjusting raw water pH to 5.5, maximum fluoride removal is reliably achieved. Fluoride ions are attracted and held to the vast surface area thorughout the pores of the activated alumina grains. The attractive forces are strongest in the pH range of 5.0-6.0. As pH deviates from that range, fluoride adsorption forces decrease at an increasing rate. In this optimum pH range other ions that compete with fluoride for the same adsorption sites are not adsorbed. Included are silica which is adsorbed in the pH range 6 through 10 and some hardness ions which are removed in the pH range 7 through 10. Hardness removal occurs at the start of a treatment run. However, activated alumina adsorption is preferential to fluoride; therefore, as the run progresses, hardness removal ceases. Alkalinity is not adsorbed at the optimum fluoride removal pH; in the pH range 7 through 10 a negligible amount of alkalinity is removed. At the optimum fluoride removal pH, some organic molecules and some trace heavy metal ions are adsorbed; however, except for arsenic, these are completely regenerated along with the fluoride. Since these ions compete for the same adsorption sites with the fluoride, their presence depletes the alumina capacity for fluoride. Arsenic presents a problem as it is preferentially adsorbed over fluoride by the alumina at the same optimum pH. Arsenic is more difficult to regenerate than fluoride. Therefore, when excess fluoride and arsenic are present in a water supply, a special treatment technique[3] is required. That subject is beyond the scope of this manual.

Modes of operation for this process are described in detail in Chapters 4, 5, and 6 of this manual.

Several investigators have developed varying theories that cover the physical/chemical interaction between activated alumina and fluoride ions during the separate modes of operation. Singh and Clifford[5] have researched this subject. They suggest the following simplified series of chemical reactions to explain the ion exchange adsorption of fluoride and the subsequent regeneration of the packed bed of fluoride - exhausted alumina:

SIMPLIFIED PICTURE OF ALUMINA
ADSORPTION AND REGENERATION REACTIONS

1. NEUTRAL ALUMINA

   Alumina + HOH   Alumina HOH

2. ACIDIFICATION

   Alumina HOH + HCl   Alumina HCl + HOH

3. ION EXCHANGE IN ACIDIC SOLUTION

   Alumina HCl + NaF   Alumina HF + NaCl

4. REGENERATION

Alumina HF + 2NaOH   Alumina NaOH + NaF + HOH

5. ACIDIFICATION

Alumina NaOH + 2HCl   Alumina HCl + NaCl + HOH

2.3 ALTERNATE TREATMENT METHODS

Some of the methods that have been employed to remove excess fluoride from potable water include bone char adsorption, ion exchange, reverse osmosis, electrodialysis, alum coagulation and lime softening. A brief summary of these methods is included for reference only.

The bone char process for fluoride removal is very similar to the activated alumina process. It selectively removes fluoride (and arsenic) and is regenerated by means of dilute caustic soda. However, it has drawbacks which normally disqualify it when compared to activated alumina. The media (when produced) cost 50 percent more than the alumina; its initial fluoride capacity was far less than the alumina; its fluoride capacity was lost during each successive regeneration; was susceptible to attack by low pH; and irreversibly adsorbed arsenic. These negative characteristics have discouraged further development of the bone char method.

Several full scale fluoride removal plants using bone char have been operated for varying periods. The one most publicized was the USPHS plant at Britton, South Dakota which operated from 1953 to 1971. The reported data indicate that this plant removed 5 mg/l fluoride and that the average fluoride capacity of the media was 450 grains/cu ft.

There is no current interest in this method.

The ion exchange treatment method is not considered viable for the removal of fluoride from potable water supplies. Strong base anion resins have the ability to remove fluoride along with all other anions. However, the cost of this treatment for potable water supplies is not compatible with the financial resources of the small community. Some researchers[6] have reported on this method, but their findings are not favorable.

The reverse osmosis (R/O) process employs the use of semi-permeable membranes for the separation of dissolved solids from water. The process is primarily used to reduce the total dissolved solids (TDS) content of a water supply. When used for potable water applications, its function is to reduce the TDS to below the recommended maximum of 500 mg/l which is a secondary EPA standard. If the high TDS water also has excessive levels of fluoride, R/O may reduce the fluoride to a level within the MCL.

Fluoride ion rejection by R/O membrane is pH and temperature sensitive. At low pH (5.5), the fluoride rejection is close to 50 percent. Therefore, adequate fluoride removal can only be accomplished at relatively low raw water fluoride concentrations (4 mg/l) unless the pH is raised. At the higher pH, calcium fluoride precipitation creates membrane fouling problems. New membrane development indicates that fluoride rejection approaching 90 percent can be achieved in the lower pH range.

Reverse osmosis is an energy intensive process. Energy cost is a function of raw water TDS and reject water flow rate. Although, under some conditions higher product to reject water flow ratios (conversion) can be used, 75 percent is usually an upper limit. Therefore, at least 25 percent of the raw water pumped through the process must go to waste. Discharge of that water is also a large cost item associated with this process. This water also contains at least 90 percent of the original TDS in the raw water.

Desalting systems such as R/O and electrodialysis (E/D) cannot be cost competitive with the activated alumina process for the selective removal of excess fluoride except for very small systems. This applies to both installation and operating costs. However, low solids water achieved by these processes produce other desirable qualities such as: low hardness, low sodium, and low sulfate which may have appeal to select groups. Thereby, "high purity" water could be an attraction in health oriented, prestige, or retirement communities. In communities with very high population densities a two pipe system (one with desalted water for potable service, the other with untreated water for toilets, bathing, laundry, and irrigation) could be economically feasible.

Electrodialysis is also a membrane separation method that is used to remove dissolved salts from brackish water.[7] The process removes ionized salts from water by the passing of ions through ion permeable membranes by means of direct current electrical energy. The membranes are stacked in pairs of anionic and cationic permeable membranes. Raw water flows between pairs through labyrinths which create turbulence while the direct current drives the anions through the anion permeable membrane and the cations through the cation permeable membrane. These ions collect in a reject stream which flows to waste or can be partially recycled. As with R/O, the E/D process is not selective; it removes all inorganic ions. It does not remove non-ionic dissolved solids or suspended solids. Also, as with R/O, concentrations of ions in the brine or reject stream can lead to precipitation of scale-forming material which can foul the process. Presence of hardness, iron and manganese ions, can lead to high maintenance cost. Membrane maintenance is an economic drawback for this system.

The advantage of E/D is that it operates at low pressure where R/O operates at pressures approaching 400 psig. E/D is still an energy intensive process due to the current required to move the charged ions through their respective membranes.

The E/D method like R/O is not practical for selective removal of fluoride from potable water. However, when fluoride is present in a brackish water supply, and the capital requirements are within the means of the community,

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these membrane separation methods are technically capable of delivering the desired treatment water quality.

Alum coagulation is a chemical precipitation process which employs alum, an inorganic coagulant aid, to react with fluoride and other ions in solution to form an insoluble solid. This process, though effective for some applications, is expensive. Sorg[1] reports on other researchers who found that 250 mg/l of alum were required to reduce the fluoride level in a water supply from 3.5 mg/l to 1.5 mg/l and 350 mg/l of alum were required to reduce the fluoride level to 1.0 mg/l. Many variables such as pH, temperature, raw water chemistry and mixing procedures affect this process.

Several investigators[8,9,10] have shown that lime softening, a chemical precipitation process, can remove fluoride from potable water supplies. The fluoride removal mechanism is a co-precipitation with magnesium hydroxide. Finkbeiner[10] reported that according to his formula 70 mg/l of magnesium must be removed to reduce fluoride from 4 mg/l to 1.5 mg/l and 137 mg/l magnesium removal reduces fluoride from 8 mg/l to 1.5 mg/l. If sufficient magnesium is not present in the water, magnesium salt in appropriate quantities must be added to accomplish the desired level of fluoride removal.

Because of the large quantities, and therefore costs, of chemicals required, this method is very limited. It does apply to water supplies with moderate levels of fluoride that require lime softening for large amounts of magnesium.

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CHAPTER 3

DESIGN OF CENTRAL TREATMENT SYSTEM

3.1 INTRODUCTION

The design of a central treatment plant for the selective removal of fluoride from potable water supplies is a straightforward process. Fluoride removal treatment can be applied to existing potable water systems that have a history of high fluoride and new wells with high fluoride which must be reduced prior to being allowed to deliver to distribution.

The designer must be careful to clearly define the design criteria prior to initiating the preliminary design. The most important items are the following:

1) Comprehensive chemical analyses (see Figure 3-1) of representative raw water samples (includes all historical analyses).

2) Treated water quality compliance standards issued by the regulatory agency within whose jurisdiction the system resides.

3) Wastewater discharge ordinance issued by the responsible regulatory agency.

4) Accurate data on system production and consumption requirements (present and future).

5) State and local codes and health department requirements.

6) Comprehensive climatological data.

The treatment system is a subsystem within the larger water utility system. Other subsystems are the well pump, the storage reservoirs, the pressurization system and the distribution system. Defluoridation generally is the only treatment required; however, removal of other contaminants such as bacteria, suspended solids, hardness, organics or other objectionable qualities may also be required.

The sequence of other treatment steps must be compatible with fluoride removal. Removal of suspended solids, organics and hardness should take place upstream of the fluoride removal process. Disinfection with chlorine should

EXAMPLE

FLUORIDE REMOVAL WATER TREATMENT PLANT

REPORT OF WATER ANALYSIS

NAME AND ADDRESS

SOURCE OF WATER
CONTAINER
SAMPLE DATE
TAKEN BY:

	Analysis No./Date								
PARTS PER MILLION AS CALCIUM CARBONATE	Calcium								
	Magnesium								
	Sodium								
	Total Cations								
	Total Alkalinity(M)								
	Phenolphthalein Alkalinity (P)								
	Total Hardness								
	Sulfate								
	Chloride								
	Nitrate								
	Total Non-Carbonate Solids								
	Silica								
	Free Carbon Dioxide								
PARTS PER MILLION	Iron (Fe) Unfiltered								
	Iron (Fe) Filtered								
	Manganese (Mn)								
	Turbidity								
	Color								
	Fluoride								
	Arsenic								
	pH								
	Specific Conductance (micromhos)								
	Temperature ($^{\circ}F$)								

WATER ANALYSIS REPORT FORM

FIGURE 3-1

take place after fluoride removal because chlorine exposure degrades activated alumina performance. No known investigation has revealed the amount of chlorine that can be tolerated by the alumina; however, process degradation has been eliminated on projects where pre-chlorination was terminated. Other treatment processes may be required upstream of the fluoride removal, but the decision must be made on a case by case basis.

The most practical concept is to install the treatment plant in the immediate vicinity of the well (space permitting). The well pump will then deliver the water through treatment into distribution and/or storage. If the existing well pump is oversized (pumps at a much higher flow rate than the maximum daily requirement), it should be resized to deliver slightly more (say 125 percent) than the peak requirement, the reason being that the flow rate dictates the treatment equipment size and therefore, the capital cost. Reducing flow rate for an oversized pump results in excessive energy costs. As explained later, the treatment media volume is a function of flow rate. Consequently, the treatment vessels, pipe sizes and chemical feed rates all increase as the flow rate increases. Storage should be provided to contain a minimum of one half the maximum daily consumption requirement. This is based on the premise that consumption takes place during twelve hours of the day. Then, if treatment operates during the entire twenty four hours, storage drawdown occurs during twelve hours and recovers during the remaining twelve hours.

Materials of construction must comply with local building code and health department requirements in addition to being suitable for the pH range of 2-13. Treatment system equipment must be protected from the elements. Although not mandatory, it is prudent to house the system within a treatment building. Wastewater resulting from backwash and regeneration of the treatment media can only be discharged in accordance with local ordinance. There are several options for disposal; however, they are subject to climate, space and other environmental limitations. Since each of the variables can significantly affect both capital and operating costs, the designer must carefully evaluate the available wastewater handling options prior to making conceptual selections.

Throughout this manual English Units are employed. For designers working with Metric Units, a tabulation of English to Metric conversion is provided in Appendix E.

3.2 CONCEPTUAL DESIGN

The basic design for an activated alumina fluoride removal water treatment plant is very flexible. This stage of design provides a definition of the process. However, it does not provide equipment size, arrangement, material selection detail or specifications.

The designer has four basic options from which to select a conceptual design. Every combination of options will perform the process and, under a selected set of conditions, a certain combination may be preferred. The options are as follows:

1) gravity or pressure flow
2) single or multiple treatment bed(s)
3) upflow or downflow treatment flow direction
4) series or parallel treatment vessel arrangement

Through extensive experimentation the most efficient, cost effective configuration was found to be the parallel downflow multiple bed pressure system. For maximum cost effectiveness (both capital and operating) two treatment beds are optimum. The two bed series configuration yields the highest fluoride loading on the treatment media and the lowest treated water fluoride level. However, this low fluoride level is undesirable and the benefits (economy and water quality) achieved in the blending of treated product water of the parallel bed configuration (described in Chapter 5) are not available. The multiple bed parallel configuration also provides greater flexibility in treatment flow rate than the series configuration. The single treatment unit configuration is less efficient unless there is an exceptionally large treated water storage capacity. In that case, the economy of treated water blending can take place in storage. Because of the space and capital requirements, this is not an economic concept. A gravity flow system does not provide the economics of a pressure system. Treatment flow rates are lower; repumping of treated water is always required; and capital costs are higher. Unless extraordinary measures are taken to allow for loss of head, gravity flow can be sensitive to fine suspended solids in the raw water. Downflow treatment in pilot test experiments has consistently yielded higher fluoride removal efficiency than upflow. Since the downflow concept utilizes a packed bed, the flow distribution has been superior. If the upflow beds were restrained from expanding, they would in effect also be packed. However, they would forfeit the necessary capability to backwash. Once the bed configuration is defined, a basic schematic flow diagram is prepared (See Figure 3-2). This diagram presents all of the subsystems. A summary of this information, including subsystem components, is listed in Appendix A. Figure 5-3 is included in Chapter 5, "Treatment Plant Operation", to assist the designer in understanding the flow pattern for a treatment unit during each mode of operation.

Regeneration wastewater treatment is a separate technology which can be handled by several different processes. That subject is beyond the scope of this manual. For this design manual the lined evaporation pond concept is implemented for disposal of regeneration wastewater. This concept is only applicable in arid climates where evaporation rates are high and land required for the basins is available at low cost. In regions where evaporation rates are low, backwash and regeneration wastewater can be neutralized and contained in a surge tank from which slow discharge to a sewer system is permissible. This latter disposal method can only be employed when local regulatory agency approval is provided.

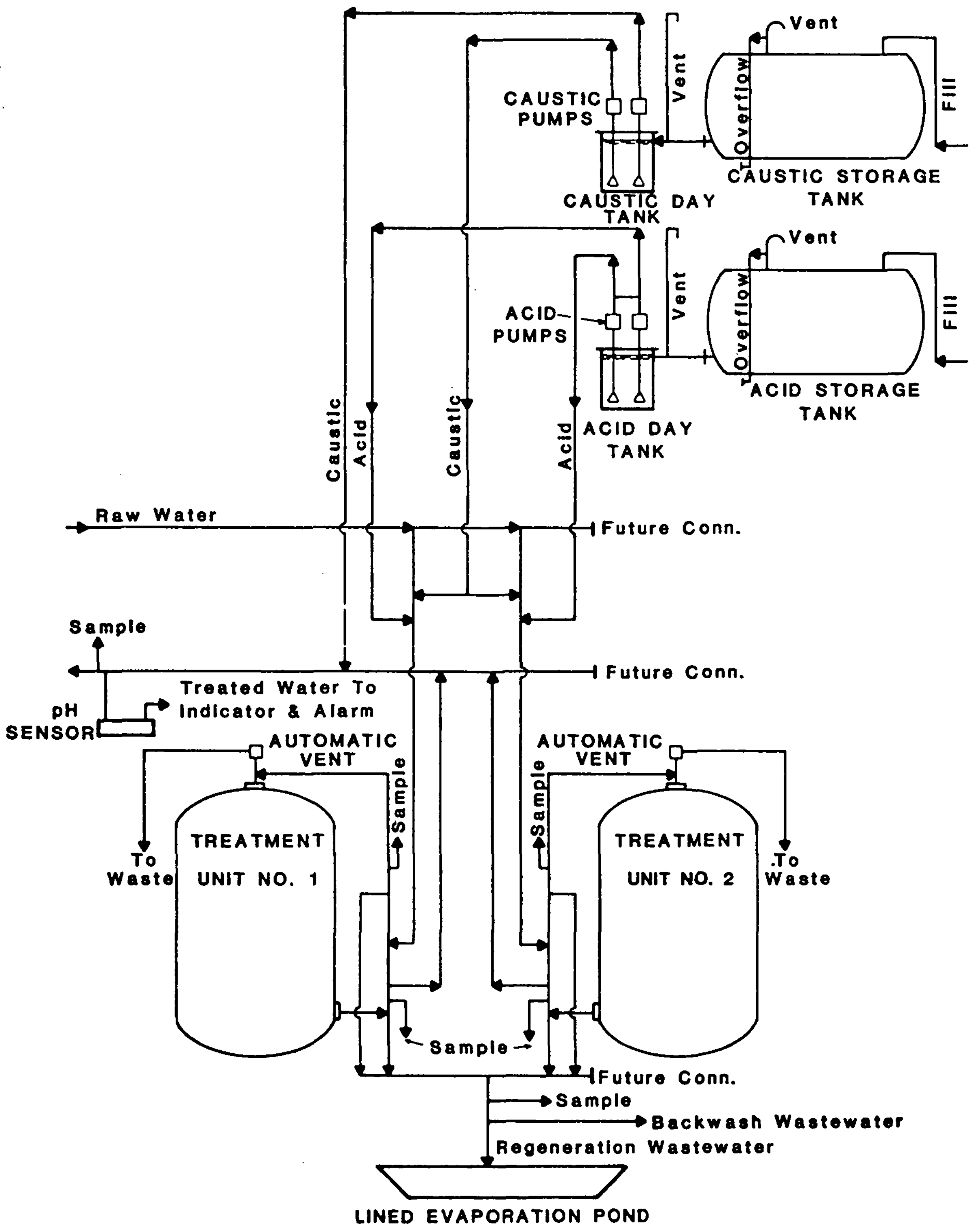


FIGURE 3-2 BASIC FLOW DIAGRAM

Prior to proceeding with the design, financial feasibility must be determined. Funding limits for the project must be defined. The designer must make a determination that funding is available to proceed with the project; this requires a preliminary rough project estimate with an accuracy of plus or minus thirty percent (±30%). If the preliminary rough estimate exceeds the available funds, adjustments must be made to increase funding or reduce project costs.

Prior to proceeding into the next phase, Preliminary Design, the designer must finalize the Design Criteria listed in Section 3.1.

3.3 PRELIMINARY DESIGN

After completion and approval of the Conceptual Design by the client, the regulatory agency(s), and any other affected party, the designer proceeds with the Preliminary Design. This includes sizing of the equipment, selecting materials of construction, determining an equipment layout and upgrading the Preliminary Capital Cost Estimate to a 20 percent (±20%) accuracy. The deliverable items are:

1) Process & Instrumentation Diagrams (See Figures 3-3.1 and 3-3.2)

2) Preliminary Process Equipment Arrangement Drawings (See Figures 3-5 and 3-6)

3) Outline Specifications

4) Preliminary Capital Cost Estimate (See Figure 3-7)

Upon completion and approval of the Preliminary Design, the designer proceeds with the Final Design.

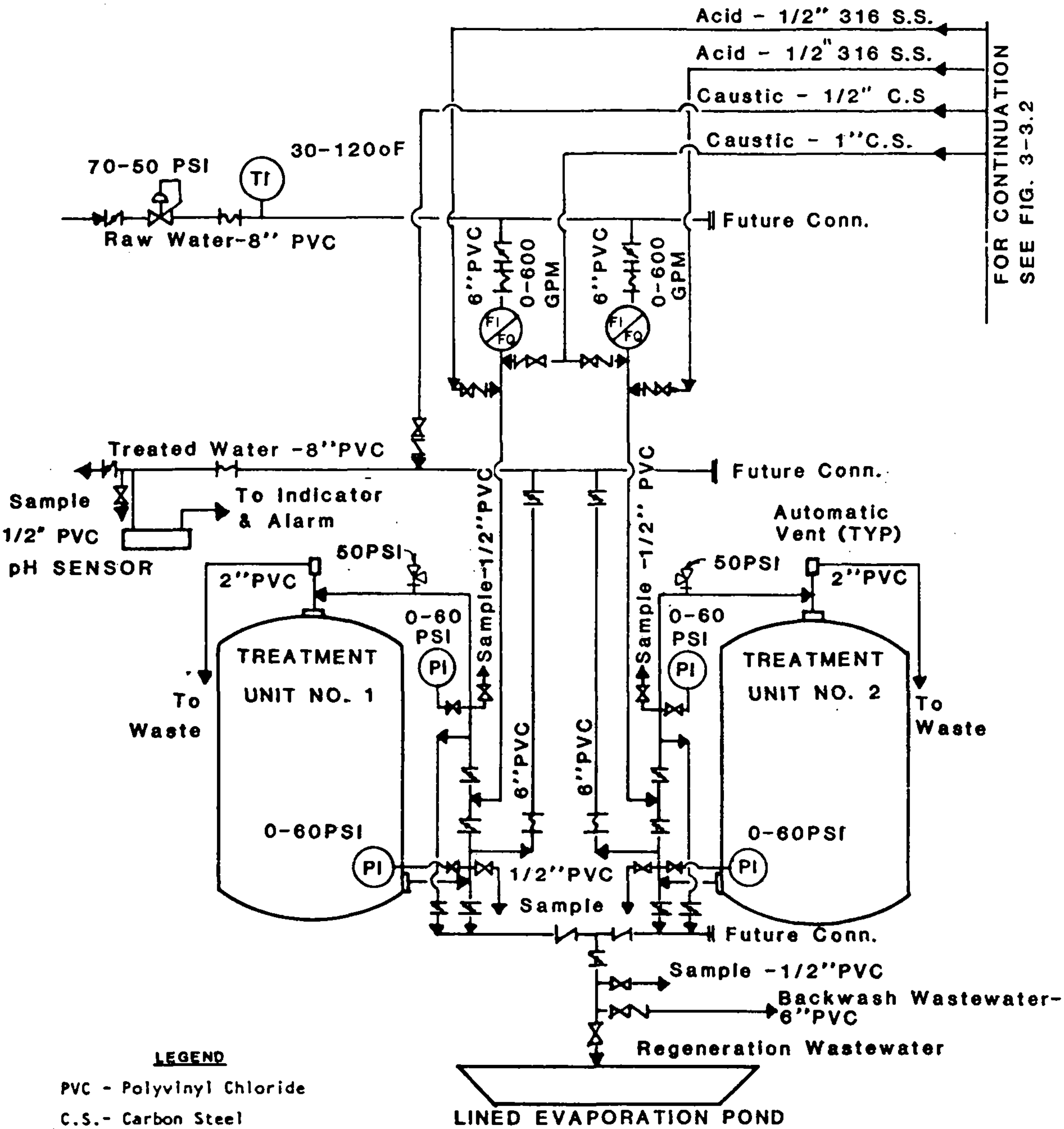
3.3.1 <u>Treatment Equipment Preliminary Design</u>

This section provides the basic methodology for sizing equipment items and selecting materials of construction. An example illustrating this method is provided in Appendix B.

3.3.1.1 Treatment Bed and Vessel Design

Per discussion presented in Section 3.1, the recommended treatment concept is based upon the use of two treatment pressure vessels piped in parallel using the downflow treatment mode. The recommended materials of construction are carbon steel (grade selection based upon cost effective availability) for ASME Code - Section VIII, Division 1 pressure rating with 3/16 in. thick potable water grade natural rubber interior lining. Vessel pressure rating to be minimum necessary to satisfy system requirements.

Basic technology which has evolved from experience at existing central plants dictates that the volume of treatment media (V) be one cubic foot per



LEGEND

PVC - Polyvinyl Chloride
C.S.- Carbon Steel
S.S.- Stainless Steel
- Shut-off Valve
- Butterfly Valve
- Check Valve
- Pressure Control Valve
- Expansion Joint
(PI) - Pressure Indicator
(TI) - Temperature Indicator
(FI/FQ) - Pressure Indicator/Totalizer
- Pressure Relief Valve
S/S - Straight Side

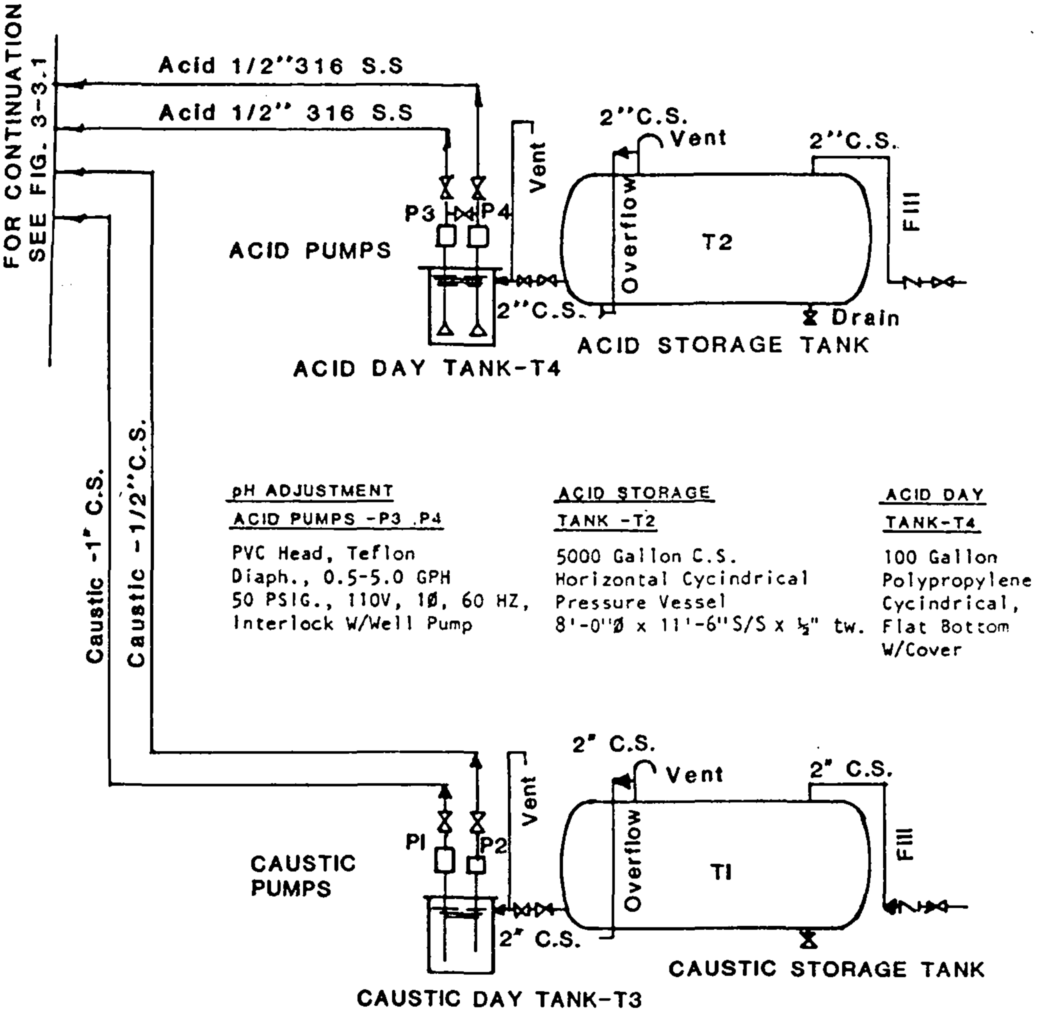
TREATMENT UNITS NO. 1 & 2

Vertical Cylindrical C.S.
Pressure Vessel
ASME Code 50 PSIG @ 175°F
9'-0" Dia.x 8'-0" S/S
Lining-3/16" Natural White
Rubber

NOTE

The Design Data Shown on
This Diagram Are Taken From
Example in Appendix B

FIGURE 3-3.1 PROCESS AND INSTRUMENTATION DIAGRAM (P & ID)



REGENERATION CAUSTIC PUMP-PI
Cast Iron Positive Displacement
2 GPM, 50 PSIG, 110V, 1Ø, 60 HZ
Interlock W/Well Pump

pH ADJUSTMENT CAUSTIC PUMP -P2
PVC Head, Teflon
Diaph.,0.25-2.5 GPH
50 PSIG.,110V,1Ø,60HZ
Interlock W/Well Pump

CAUSTIC STORAGE TANK -TI
5000 Gallon C.S.
Horizontal Cycindrical
Pressure Vessel
8'-0"Ø x 11'-6" S/S x 3/8" tw.
W/10KW Immersion
Heater

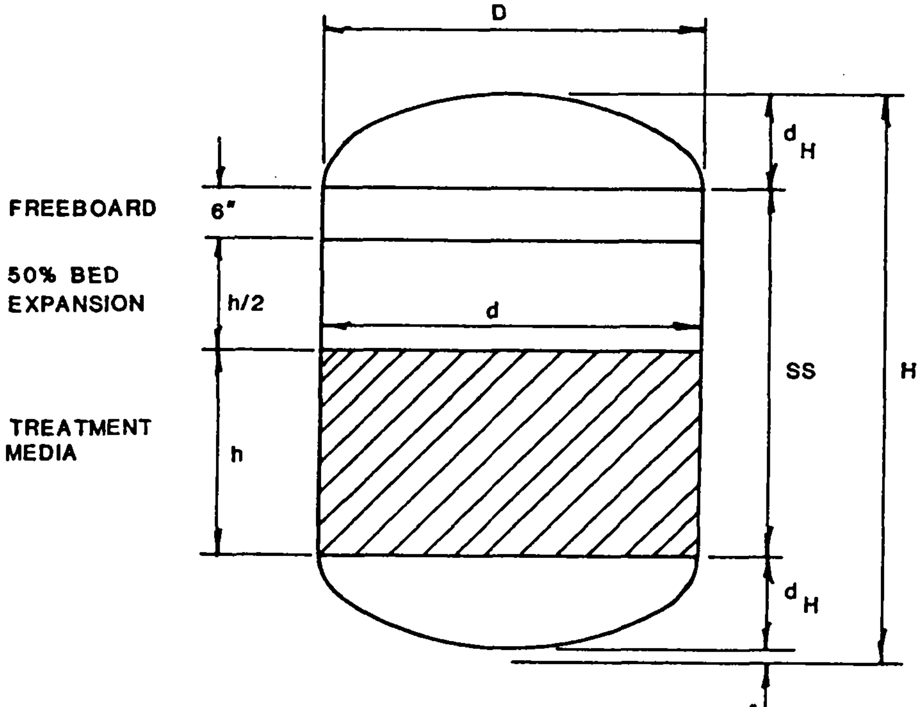
CAUSTIC DAY TANK -T3
150 Gallon
Polypropylene
Cycindrical
Flat Bottom
W/Cover

FIGURE 3-3.2 PROCESS AND INSTRUMENTATION DIAGRAM (P & ID) gallon per minute of treated water flow rate (g). This provides a superficial (or empty bed) residence time of 7.5 minutes, which is conservative. Actual residence time is approximately half the superficial residence time. That is true because the space between the grains of media is approximately 50 percent of the total bed volume. Where multiple beds are used, the volume of treatment media per unit is equal to the total treatment flow rate divided by the number of treatment beds (N). See Figure 3-4 for Treatment Unit illustration. (NOTE: When raw water is bypassed and blended back with treated water, only the treated water is included in sizing the bed.) In order to prevent "wall effects", bed diameter (d) should be equal or greater than the bed depth (h). Good practice dictates that bed depth be a minimum of three feet and a maximum of six feet. At lesser than minimum depth, distribution problems may develop; and, at greater than maximum depth, fine material removal and pressure loss may become a problem.

At the Gila Bend, Arizona fluoride removal plant, there are two 10 ft-0 in. diameter by 5 ft-0 in. deep treatment beds. At design flow each 380 ft^3 bed treats 380 gpm. Each treatment unit operates at 450 gpm during peak consumption periods. Each unit has been successfully operated at treatment flows as high as 600 gpm, a treatment rate that exceeds one and one-half gallons per minute per cubic foot. That flow rate reduces the superficial residence time to five minutes which is recommended as a minimum limit. As the superficial residence time decreases, two undesirable features occur. First, the treatment is less efficient, that is, treated water fluoride concentration does not reach as low a level; and second, regeneration frequency increases requiring more operator attention and proportionately more downtime for regeneration of the beds. Conversely, lowering the treatment flow rate below the suggested 1 gpm/ft^3 level increases the size of the treatment beds and their vessels, thereby increasing capital cost and space requirements.

Pressure vessel fabrication is standardized by diameter in multiples of 6 in. increments. Tooling for manufacture of pressure vessel dished heads is set up for that standard. Design dimensions differentiate between pressure vessel and treatment bed diameters. The vessel outside diameter (D) is approximately 1 in. greater than the bed (or vessel inside) diameter which provides for both vessel walls with lining. If the pressure is high (100 psig or greater) the 1 in. will increase to reflect the increased vessel wall thickness.

Although there are many methods of distributing the water flow through a treatment bed, the method which has been successfully used in fluoride removal plants that are presently in operation is recommended. The water is piped downward into the vessel. This diverts the flow into a horizontal pattern. From there it radiates in a horizontal plane prior to starting its downward flow through the bed. The bed, in turn, is supported by a false flat bottom which is supported by the bottom head of the vessel by means of concentric rings. The false flat bottom also supports the horizontal header and plastic fabric sleeved perforated lateral collection system. Treatment media is placed in the vessel through a circular manway (minimum diameter 16 in.) with



TREATMENT VESSEL

<u>SYMBOLS</u>

q - Treated water flow rate (gpm)

N - Number of Treatment Beds

d - Treatment bed diameter (ft.)

h - Treatment bed depth (ft.)

V - Treatment bed volume - $\frac{\pi d^2 h}{4}$ (ft.^{3})

M_d - Density of Treatment Media (lb./ft.^{3})

M_w - Weight of Media

D - Outside diameter of Treatment Vessel (ft.)

d_H - Depth of Dished Pressure Head (ft.)

H - Overall height of Treatment Vessel (ft.)

GIVEN

$h < d$, $3'\text{-}0'' < h < 6'\text{-}0''$, $V = q/N$ (ft.^{3})

$H = 2\ d_H + h + h/2 + 6''$, $d = 4q/N\ \pi\ h$

$D = d + 1''$

$M_d = 50$ lb./ft^3 (varies with packing characteristics of media in vessel)

$M_w = M_d \times V = 50V$ (lb.)

FIGURE 3-4 TREATMENT BED AND VESSEL DESIGN CALCULATIONS

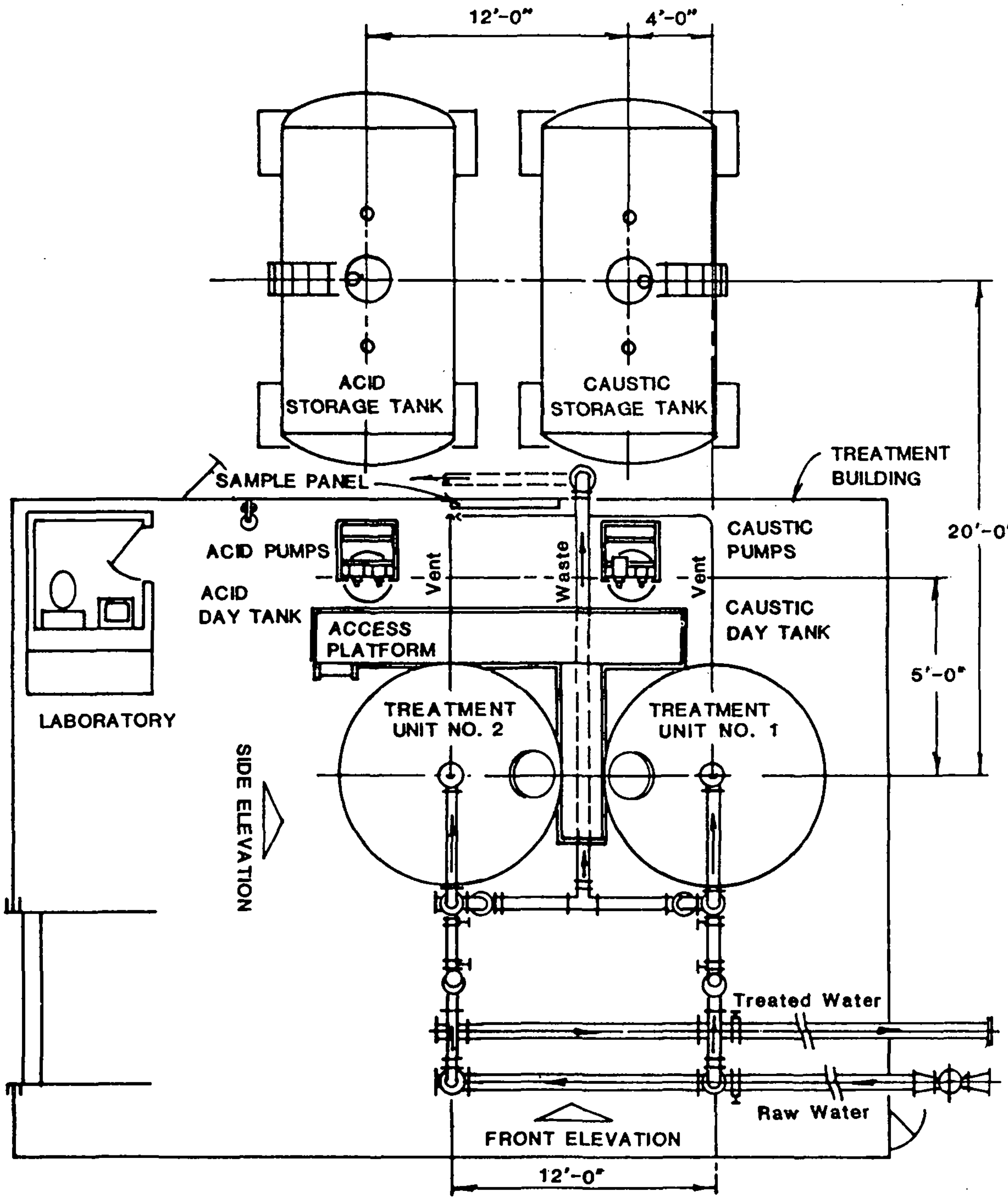


FIGURE 3-5 PRELIMINARY EQUIPMENT ARRANGEMENT PLAN

hinged cover in the top head of the vessel. The Treatment Bed and Vessel Design is illustrated in Figure 3-4. A typical example for determining treatment bed and treatment vessel dimensions is presented in Appendix B.

3.3.1.2 Pipe Design

Material must be suitable for ambient temperature, pH 2-13, system pressure and potable water service. Due to the low pH, carbon steel is not acceptable. Stainless steel is acceptable; however, it is too costly. There are several plastic materials such as PVC, polypropylene, and high density polyethylene that are satisfactory. Of those, PVC is usually the best selection because of its availability and ease of fabrication and assembly. The drawbacks to the plastic materials are their loss of strength at elevated temperatures (above $100^{\circ}F$); their coefficient of thermal expansion; their external support requirements; their deterioration from exposure to sunlight; and their vulnerability to damage from impact. Nevertheless, these liabilities are greatly outweighed by the low cost and suitability for the service. The designer can easily protect the piping from all of the above concerns, except elevated ambient and/or water temperatures. If elevated temperature exists, the use of polypropylene lined carbon steel flanged pipe (and cast iron fittings) is recommended. This material provides the strength and support that is lacking in the pure plastic materials.

The designer must economically size the piping system to allow for delivery of design flow without excessive pressure losses. If water velocities present conditions for water hammer (due to fast closing valves, etc.), the designer must include shock absorbing devices to prevent that occurrence.

Isolation and process control valves should be wafer style butterfly type, except in low flow rate systems where small pipe size dictates the use of true union ball valves (See Figure 3-2 for location). The use of inexpensive, easily maintained valves that operate manually is recommended. The valves could also be automated by the inclusion of pneumatic or electric operators and controls. Automation is not recommended because the cost of the hardware and its maintenance outweighs the savings of plant operators' time.

See Appendix B for pipe size design using the example previously employed for vessel and treatment media design.

3.3.1.3 Instrumentation Design

Design is a misnomer for this category of equipment. Literally the designer specifies the system functional requirements which are adapted to commercially available instruments. Included are:

Instrument	Range	Accuracy
pH sensor/indicator/alarm	0-14	$\pm$ 0.1
pressure indicator	varies*	$\pm$ 1%
temperature indicator (optional)	30°-$120^{\circ}F$	$\pm$ 1%
flow indicator/totalizer	varies*	$\pm$ 2%

*range to be compatible with application, maximum measurement not to exceed 90 percent of range.

3.3.1.4 Acid Storage and Feed Subsystem

The acid storage tank is sized to contain tank truck bulk delivery quantities of concentrated sulfuric acid. Bulk delivery provides the lowest unit price for the chemical. In small plants (less than 175 gpm) acid consumption may not be enough to justify large volume purchase of chemicals. In the smaller plants, drums or even carboys may be more practical; therefore, for that type operation, the requirement for a storage tank is eliminated. A 50,000 pound tank truck delivers 3,250 gallons of 66 B'H_2SO_4 (15.5 lb/gal). A 5,000 gallon tank provides a 50 percent cushion. The example in Appendix B illustrates the method of designing the components of this system.

The carbon steel tank does not require an interior lining; however, the interior must be sand blasted and vacuum cleaned prior to filling with acid. The storage tank must be placed outside of the treatment building. The 66^{o}B'H_2SO_4 freezes at -20^{o}F. Therefore unless the treatment plant is located in an extremely cold climate, no weather protection is required. The tank should be painted white to reflect sunlight; this will prevent heat gain in the tank which heats the acid making it more aggressive. All piping is to be 2 in. carbon steel with threaded cast iron fittings.

The acid pumps are standard diaphragm models with materials of construction suitable for 66 B'H_2SO_4 service. Standard chemical pumps are specified by the designer. In the preliminary design, the sizing is adequate for layout and estimating. Acid feed rate varies with the total alkalinity and the free carbon dioxide content of the raw water, and in some cases, is much higher, requiring larger pumps and day tanks. The actual acid feed rate is easily determined experimentally by adjusting a raw water sample pH to 5.5 by acid titration. Acid consumption for raw water pH reduction is discussed in Appendix C. In normal treatment plant operation, the water quality will vary from time to time. Therefore, the plant operator must check the pH periodically and maintain it at 5.5. The pump stroke speed and length are to be adjustable to accommodate these variations. The pH probes that are used to control pH must be calibrated against standard buffers at least once per month.

3.3.1.5 Caustic Soda Storage and Feed Subsystem

The caustic soda storage tank is also sized to contain tank truck bulk delivery quantities of 50 percent sodium hydroxide. The caustic is used for treatment bed regeneration and neutralization of treated water. Regeneration frequency is a function of raw water fluoride concentration, flow rate and treatment media fluoride capacity. The amount of caustic required to neutralize the treated water, that is to raise the pH from 5.5 to 7.5, varies considerably. The actual caustic feed rate is easily determined experimentally by readjusting the treated water pH by titrating a sample with caustic until the desired pH is achieved. In raw water with high alkalinity the lowering of pH produces high levels of dissolved carbon dioxide (CO_2). In those waters removal of the CO_2 by aeration raises the pH to the desired level providing a less expensive alternative than addition of caustic. In low alkalinity water the chemical addition is less expensive. The sizing of the carbon steel caustic storage tank is covered in Appendix B. This vessel must be heat treated to stress relieve welds. The carbon steel does not require an interior lining; however, it does require sand blasting and vacuum cleaning prior to filling. All piping is to be 2 in. carbon steel with threaded cast iron fittings.

Fifty percent sodium hydroxide freezes at 55°F; therefore, it must maintain a minimum temperature of 70°F. This is handled by a temperature controlled electrical immersion heater. For safety reasons the storage tank must be outside of the treatment building where ambient temperatures might drop quite low. To conserve electrical energy required for heating, the storage tank may be insulated and/or housed in a separate enclosure. If not insulated or housed, the tank must be painted white to reflect sunlight and prevent chemical overheating.

A pump is required to feed 50 percent NaOH into the effluent main where the low pH treated water is neutralized. For regeneration, a larger caustic feed pump is required for pumping the concentrated caustic to a mixing tee in the raw water branch pipe. In the mixing tee the caustic is diluted to the 1 percent (by weight) concentration required to regenerate the treatment bed.

3.3.1.6 Wastewater Lined Evaporation Pond

In the example used in Appendix B we have assumed that the wastewater disposal option that is most cost effective as well as preferred by the regulatory agency is a lined evaporation pond. This method is used in arid regions in the desert southwest. It is not a viable method in the humid southeast or cold climate of the northern tier of states. In those areas a viable disposal option is to neutralize the regeneration wastewater with acid as it leaves the treatment vessel and collect the entire regeneration wastewater batch in a surge tank. The neutralized wastewater is then bled at a controlled flow rate to the sanitary sewer. In the sewer it blends with the defluoridated water that has been discharged to waste.

To size the lined evaporation pond the basic information required is the average annual volume of regeneration wastewater to be evaporated and the average annual evaporation rate. The former is determined by the designer and the latter is obtained from the national weather bureau (or in some cases, state university climatological departments). Treatment plant production is normally much higher in summer than winter, and evaporation rate is also correspondingly higher in summer. The ponds have sloped sides, pond depth to be 8 ft (minimum). Ponds are to be lined with 30 mil reinforced hypalon, a material that is not vulnerable to ultraviolet radiation deterioration or exposure to pH 12. The dissolved solids will concentrate and precipitate in the pond.

3.3.2 Preliminary Equipment Arrangement

With all of the major equipment size and configuration information available, the designer proceeds to prepare a layout (arrangement drawings). The layout provides sufficient space for proper installation, operation and maintenance for the treatment system as well as each individual equipment item.

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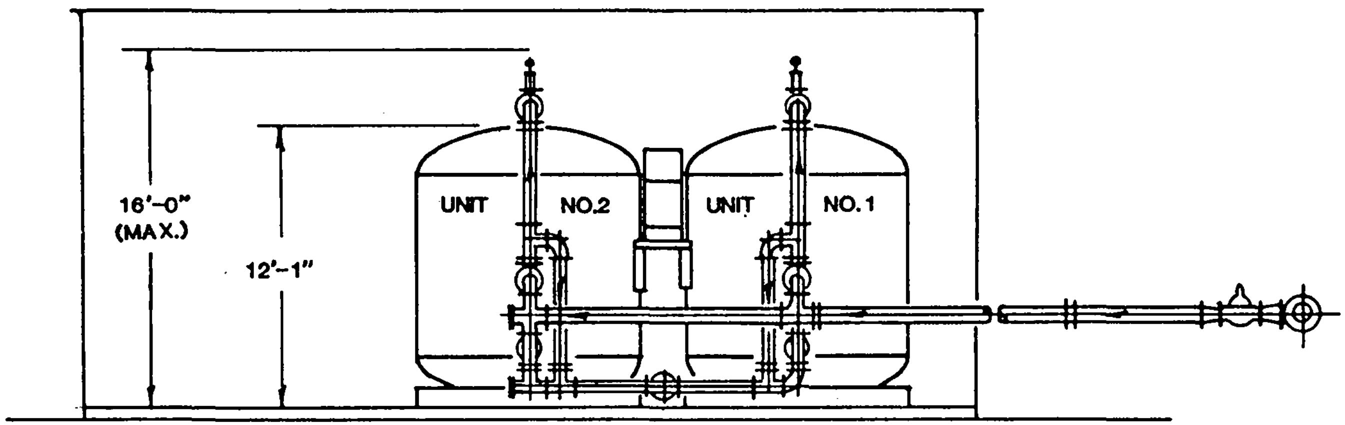
U.S. Occupational Health and Safety Administration (OSHA) regulations must be applied to the designer's decisions during the equipment arrangement effort. These requirements may be supplemented or superceded by state or local health and safety regulations, or, in some cases, insurance regulations. The designer must also adhere to a compact arrangement to minimize space and resulting cost requirements. Figures 3-5 and 3-6 illustrate a typical preliminary arrangement plan and elevation. This arrangement provides no frills; but it does have ample space for ease of operation and maintenance. Easy access to all valves and instruments reduces plant operator effort.

The building that protects the treatment system (and operator) from the elements is normally a standard pre-engineered steel building. These buildings which are modularized units are low cost. The designer selects the standard building dimensions that satisfies the installation, operation and maintenance space requirements for the treatment system. There are many suppliers of this type of building; installed costs are highly competitive. The building must provide access doors, emergency shower and eye wash, and a lab bench with sink. All other features are optional.

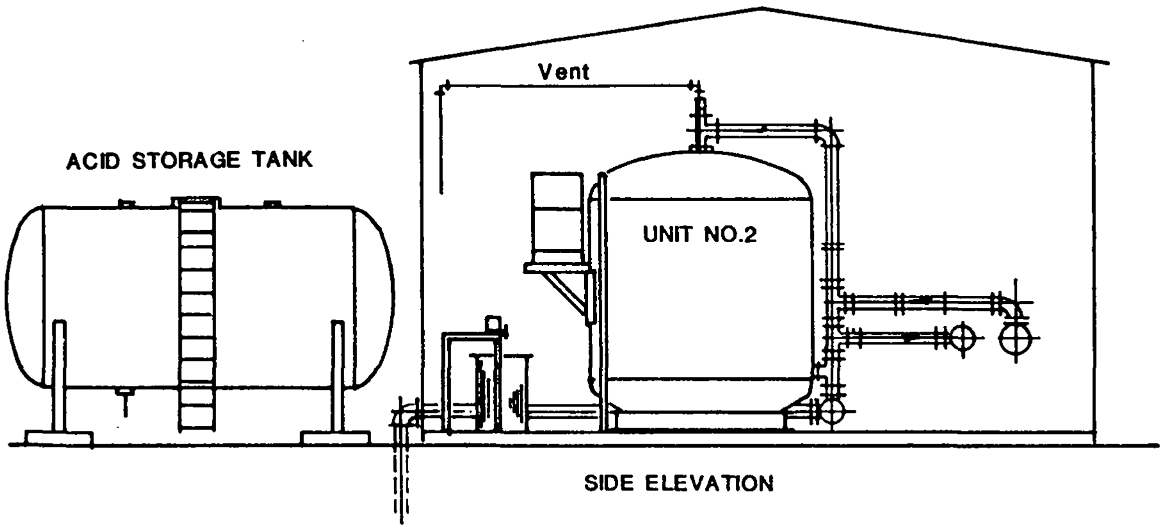
When the arrangement is completed, the designer can proceed with the preliminary cost estimate.

3.3.3 Preliminary Cost Estimate

The designer prepares the preliminary cost estimate based upon the equipment that has been selected, the equipment arrangement and the building selection. The designer then takes off the equipment, applies unit prices to labor and material, and finally summarizes in a format that is preferred by the owner. (See Table 3-1 for example). This estimate is to have an accuracy of plus or minus 20 percent ($\pm$20%). In order to assure sufficient budget for the project it is prudent to estimate on the high side at this stage of design. This may be accomplished by means of a contingency to cover unforeseen costs, an inflation escalation factor, or estimating with budget prices furnished by suppliers and contractors. Budget prices are roughly 10 percent higher than competitive bid prices.



FRONT ELEVATION



SIDE ELEVATION

FIGURE 3-6 PRELIMINARY EQUIPMENT ARRANGEMENT ELEVATIONS

TABLE 3.1. PRELIMINARY COST ESTIMATE-EXAMPLE FOR FLUORIDE REMOVAL WATER TREATMENT PLANT PRELIMINARY CAPITAL COST ESTIMATE

Location:
Flow Rate: 600 gpm
Date:

Process Equipment		Cost, $
Treatment Vessels		37,000
Treatment Media		21,000
Process Piping, Valves and Accessories		18,000
Instruments and Controls		10,000
Chemical Storage Tanks		22,000
Chemical Pumps, Piping and Accessories		6,000
	Subtotal	114,000
Process Equipment Installation		
Mechanical		35,000
Electrical		10,000
Painting and Miscellaneous		5,000
	Subtotal	50,000
Miscellaneous Installed Items		
Wastewater Lined Evaporation Pond		140,000
Building and Concrete		30,000
Site Work, Fence and Miscellaneous		10,000
	Subtotal	180,000
Contingency 10%		36,000
	*Total	380,000

*Engineering, Finance Charges, Real Estate Cost and Taxes not included.

3.3.4 Preliminary Design Revisions

The Preliminary design package (described above) is then submitted for approval prior to proceeding with the Final Design. This package may require the approval of regulatory authorities, as well as the owner. If there are any changes requested, the designer must incorporate them and resubmit for approval. Once all requested changes are included and Preliminary Design approval is received, the designer can proceed with the Final Design.

3.4 FINAL DESIGN

After completion and approval of the Preliminary Design by the client et al, the designer proceeds with the Final Design. This includes detail design of all of the process equipment and piping, complete process system analysis, complete detail design of the building including site work, and a final capital costs estimate accurate to within ten percent. The deliverable items are:

1) Complete set of construction plans and specifications

2) Final Capital Cost Estimate (See Table 3-2)

TABLE 3.2. FINAL COST ESTIMATE-EXAMPLE FOR FLUORIDE REMOVAL WATER TREATMENT PLANT FINAL CAPITAL COST ESTIMATE

Location:
Flow Rate: 600 gpm
Date:

Process Equipment		Cost, $
Treatment Vessels		33,000
Treatment Media		20,500
Process Piping, Valves and Accessories		16,400
Instruments and Controls		8,300
Chemical Storage Tanks		21,000
Chemical Pumps, Piping andf Accessories		6,300
	Subtotal	105,500
Process Equipment Installation		
Mechanical		36,000
Electrical		7,000
Painting and Miscellaneous		4,500
	Subtotal	47,500
Miscellaneous Installed Items		
Wastewater Lined Evaporation Pond		138,000
Building and Concrete		28,000
Site Work, Fence and Miscellaneous		11,000
	Subtotal	177,000
Contingency 4%		17,000
	*Total	347,000

*Engineering, Finance Charges, Real Estate Cost and Taxes not included.

The designer starts the Final Design with the treatment system equipment (including the lined evaporation pond); continues with the building (including concrete slabs and foundations, earthwork excavation/backfill/compaction, heating, cooling, bathroom, painting, lighting and utilities); and completes with the site work (including utilities, drainage, paving and landscaping). The latter items apply to every type of treatment plant; but, though they are integral with the treatment system, they are not addressed in this manual. The only portions of the Final Design that will be discussed are the pertinent aspects of the treatment equipment which were not covered in the Preliminary Design sections. During the Conceptual Design and Preliminary Design the designer concentrated on defining the basic equipment that accomplished the required function. The decision was cost conscious using minimum sizes (or standard sizes) and least expensive materials that satisfied the service and/or environment. However, in the Final Design this effort can be defeated by not heeding simple basic cost control principles. Some of these are:

1) Minimize detail (e.g. pipe supports-use one style, one material and components common to all sizes).

2) Eliminate bends in pipe runs (some bends are necessary - those that are optional increase costs).

3) Minimize field labor-shop fabricate where possible (e.g. access platforms and pipe supports can be supported by brackets that are shop fabricated on vessel).

4) Skid mount major equipment items (skids distribute weight of vessels over large floor areas, thereby costly foundation work is eliminated).

5) Use treatment vessels as heat sink to provide building cooling or heating or both. (Eliminates heating and/or cooling equipment in addition to reducing energy cost.)

6) Simplify everything.

Besides holding down costs the designer must analyze all subsystems (refer to P&ID in Figures 3-3.1 and 3-3.2) and account for all components in both equipment specifications and installation drawings. The drawings must provide all information necessary to manufacture and install the equipment. The designer must exercise extra effort to eliminate ambiguity in detail and/or specified requirements. All items must be satisfactory for service conditions besides being able to perform required functions. Each item must be easy to maintain; spare parts necessary for continuous operation must be included with the original equipment. All tools required for initial startup as well as operation and maintenance must be furnished during the construction phase of the project. Once construction, equipment installation and check out are complete, the treatment plant should proceed into operation without disruption.

When all components in each of the subsystems have been selected, the designer should run hydraulic analysis calculations to determine the velocities and pressure drops[1] through the system. Calculations are to be run for normal treatment flow and backwash flow. The latter is more severe but of short duration. If pressure losses are excessive, the designer must modify the design by decreasing or eliminating losses (e.g., increase pipe size, eliminate bends or restrictions).

The designer must include several functional checkout requirements to be accomplished upon completion of installation. All piping must be cleaned and pressure tested prior to startup. All leaks must be corrected and retested. Recommended test pressure is 150 percent of design pressure. Potable water piping and vessels must be disinfected prior to startup. All electrical systems must satisfy a functional checkout. All instruments are to be calibrated; if accuracy does not meet requirements stated in Section 3.3.1.3, the instruments are to be replaced.

When the plant operation begins, a check on actual system pressure drop is required. If there is a discrepancy between design and actual pressure drop, the cause must be determined (obstruction in line, faulty valve, installation error, design error, etc.) and rectified. Pressure relief valves must be tested; if not accurate, they must be adjusted or replaced.

3.4.1 Treatment Equipment Final Design

This section provides discussion on details that apply specifically to Fluoride Removal Water Treatment Plants.

3.4.1.1 Treatment Bed and Vessel Design

The treatment medium was designed by determination of bed dimensions and resulting weight in the Preliminary Design (see Section 3.3.1.1). It is recommended that ten percent extra treatment medium be ordered. For lowest price and ease of handling, the material is to be ordered in 100 pound bags on pallets. The material specification requires Alcoa F-1, 28+48 mesh activated alumina, or equal (see Section 1.2). If an "equal" is to be furnished, a pilot test must demonstrate that the process capability as well as the physical durability of the substitute material be equal to that of the specified material.

The vessel design must be simple. The vessel must have a support system to transfer its loaded weight to the foundation and ultimately to the soil. The loaded weight includes the media, the water, attached appurtenances (platform, pipe filled with liquid, etc.) as well as the vessel itself. The support legs should be as short as possible reducing head room requirements as well as cost. The legs are to be integral with a support frame (skid) that will distribute the weight over an area greater than the dimensions of the vessel. This distribution eliminates point loads of vessel support legs, thereby costly piers, footings, and excavation requirements are eliminated. The skid must have provisions for anchorage to the foundation. Exterior brackets (if uniform and simply detailed) are not costly and provide supports that eliminate need for cumbersome costly field fabrications. Conversely, interior brackets though required to anchor (or support) vessel internal distribution or collection systems must be held to bare minimum as they are very costly to rubber line. Rubber lining is recommended over less costly coatings because of its resistance to granular activated alumina abrasion. Rubber lining resiliency provides better resistance to abrasion than hard epoxy type linings. Vessel interior lining is to extend through vessel openings out to the outside edge of flange faces. Openings in the vessels must be limited to the following:

1) Influent pipe - enters vertically at center of top head.

2) Effluent pipe - exits horizontally through vertical straight side immediately above false flat bottom in front of vessel.

3) Air/vacuum valve (vent) - mounts vertically on top head adjacent to influent pipe.

4) Media Removal - exits horizontally through vertical straight side immediately above false flat bottom at orientation assigned to this function.

5) Manway - 16 in. diameter (minimum) mounted on top head with center line located within three feet of center of vessel and oriented towards work platform. Manway cover to be hinged or davited.

It is recommended that pad flanges be used for pipe openings in lieu of nozzles. Pad flanges are flanges that are integral with the tank wall. The exterior faces are drilled and tapped for threaded studs. These save cost of material, labor and are much easier to line; they also reduce the dimensional requirements of the vessel. The vessel also requires lifting lugs suitable for handling the weight of the empty vessel during installation. Once installed the vessel must be shimmed and leveled. All space between the bottom surface of the skid structure and the foundation must be sealed with an expansion type grout; provisions must be included to drain the area under the vessel.

The type of vessel internal distribution and collection piping used in operational fluoride removal plants is defined in the Preliminary Design (see Section 3.3.1.1). Since there are many acceptable vessel internal design concepts, configuration details will be left to sound engineering judgement. The main points to consider in the design are as follows:

1) Distribution to be uniform

2) Provide minimum pressure drop through internal piping (but sufficient to assure uniform distribution)

3) Prevent wall effects and channeling

4) Collect treated water within two inches of bottom of treatment bed

5) Anchor internal piping components to vessel to prevent any horizontal or vertical movement during operation

6) Materials of construction to be suitable for pH range of 2-13, (PVC, polypropylene, stainless steel are acceptable)

Underdrain failures are undesirable; treatment media loss, service disruption and labor to repair problems are very costly. A service platform with access ladder is required for use in loading treatment media into the vessel. Handrail, toe plate and other OSHA required features must be included.

3.4.1.2 Pipe Design

The designer reviews each piping subsystem to select each of the subsystem components (see P&ID, Figures 3-3.1 and 3-3.2). Exclusive of the chemical subsystems, there are five piping subsystems which are listed in the Conceptual Design (see Section 3.2); they are:

1) Raw water influent main

2) Treated water effluent main

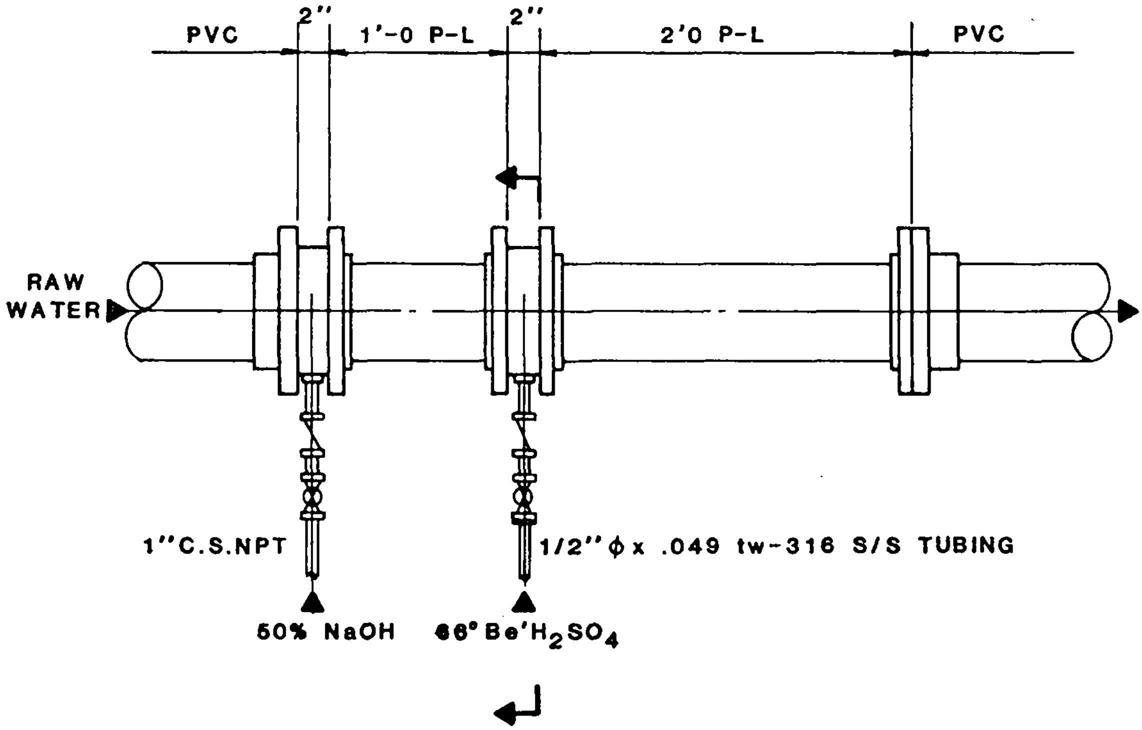
3) Wastewater discharge main

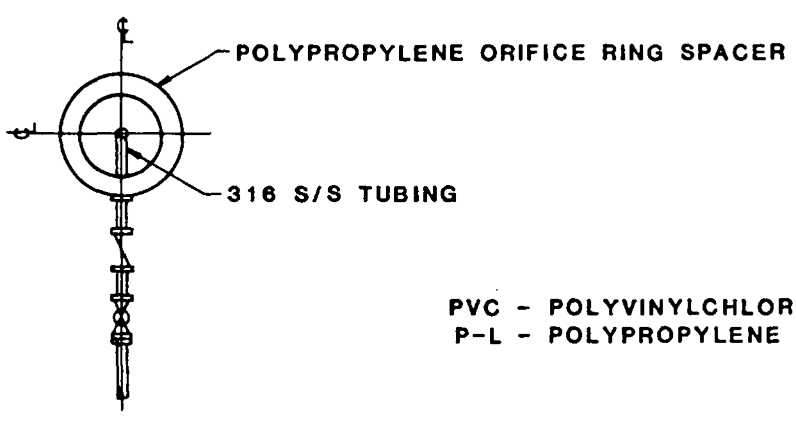
4) Treatment unit branch piping

5) Sample panel piping

The designer now proceeds with the detail design of each of those subsystems. First, the designer defines the equipment specification for each equipment component in each subsystem. This is followed by a detailed installation drawing which locates each component and provides access for operation and maintenance. As each subsystem nears completion the designer incorporates provisions for pipe system support and anchorage, as well as for thermal expansion/contraction.

The interface where the concentrated chemical and treatment unit branch piping join is designated as a mixing tee. A special detail (see Figure 3-7) is required to assure that heat of dilution of concentrated corrosive chemicals imparts no damage to the piping materials. The key factor is to prevent flow of concentrated chemical when raw water (dilution water) is not flowing. The dilution water will dissipate the heat. The actual injection must take place in the center of the raw water pipe through an "injection quill" that extends from the concentrated chemical pipe. The quill material must be capable of withstanding the high heat of dilution that develops specifically with sulfuric acid and to a lesser degree with caustic soda. Type 316 stainless steel and teflon are satisfactory. It is also very important that the concentrated





PVC - POLYVINYLCHLORIDE PIPE
P-L - POLYPROPYLENE LINED PIPE

FIGURE 3-7 CHEMICAL MIXING TEE DETAIL

chemical be injected upward from below; otherwise concentrated chemicals with specific gravity higher than the water will seep by gravity into the raw water when flow stops. As described later, the chemical pumps are to be de-energized when the well pump is not running.

The treated water pH must be carefully monitored. A pH sensor installed in the treated water main indicates the pH at an analyzer mounted at the sample panel. This analyzer is equipped with adjustable high and low level pH alarms. The alarms are interlocked with the well pump control (magnetic starter), shutting it down when out of tolerance pH excursions occur. A visual and/or audio alarm is also initiated to notify the operator regarding the event.

A chemical mixing tee identical to those in the treatment unit branch piping is employed in the treated water main for the injection of caustic to raise pH in the treated water. If aeration for removal of CO_2 is used in lieu of caustic injection for raising treated water pH, then system pressure is dissipated and the treated water must be repressurized. If the water utility has ground level storage tanks, the aeration-neutralization concept can be accomplished without need for a clearwell and repressurization. The aerator can be installed at an elevation that will permit the neutralized treated water to flow to storage via gravity.

Easy maintenance is an important feature in all piping systems. Air bleed valves shall be installed at all high points; drain valves shall be installed at all low points. This assists the plant operator in both filling and draining pipe systems. Air/vacuum valve and pressure relief valve discharges are to be piped to drains. This feature satisfies both operator safety and housekeeping requirements. Bypass piping for flow control, pressure control, flow meter and other in-line mechanical accessories is optional. Bypass piping is costly and requires extra space. However, if continuous treatment plant operation is mandatory, bypass piping must be included.

3.4.1.3 Instrument Design

Ease of maintenance is very important. Instruments require periodic calibration and/or replacement. Without removal provisions, the task creates a mess. Temperature indicators require thermal wells installed permanently in the pipe. Pressure indicators require gauge cocks to shut off flow in the branch to the instrument. pH probes require isolation valves and union type mounting connections (avoids twisting of signal cables). Supply of pH standard buffers (4.0, 7.0 and 10.0) are to be specified for pH instrument calibration. A lab bench is to be located near the Sample Panel. Lab equipment to be specified to include wall cabinet, base cabinet with chemical resistant counter top and integral sink (with cold water tap), 110V/10/60Hz 20 amp duplex receptacle, lab equipment/glassware/reagents for analysis of fluoride and other ions.

3.4.1.4 Acid Storage and Feed Subsystem

Operator safety for work within close proximity of highly corrosive chemicals takes priority over process functional requirements. Emergency shower and eyewash must be located within thirty feet of any work area at which operator exposure to acid (or caustic soda) exists. Protective clothing must be specified. Neutralization materials (e.g. sodium carbonate) must be provided to handle spills. Potential spill areas must be physically contained. Containment volumes must be sufficient to retain maximum spillage.

To minimize corrosion of acid pipe material, acid flow rate is recommended to be less than 0.1 ft/sec. Threaded pipe and fittings are not recommended; tubing and Swagelok fittings are recommended. PVC is also adequate except for its vulnerability to damage from external loads for which reason it is not recommended. Positive backflow prevention must be incorporated in each branch. Day tanks must be vented to atmosphere, have a valved drain, and have a fill line float valve for fail safe backup control to prevent overflow.

There is one acid feed pump for each treatment vessel. Acid pump power should be interlocked with the well pump so that the acid pump is de-energized when well pump is not running. Acid pumps are to have ball checks and pressure relief which recycles acid back to the day tank. Acid flow rate is to be manually controlled to provide the required raw water pH. If the feed pumps are mounted above the day tank, foot valves are required. The designer must also include anti-siphon provisions in the system.

3.4.1.5 Caustic Soda Storage and Feed System

The safety requirements stated for acid (Section 3.4.1.4) also apply to caustic soda. Vinegar is satisfactory for neutralization of minor caustic spills.

The day tank and pump design features recommended for acid systems also apply to caustic. The polypropylene day tank should be translucent with gallon calibrations on the tank wall. The regeneration pump can be calibrated by means of timing the flow and adjusting as necessary to arrive at the design flow rate. An optional rotameter can be used, but varying caustic temperatures will affect accuracy. Carbon steel threaded pipe is recommended for the service. PVC is not recommended because of its vulnerability to damage from external loads.

3.4.1.6 Wastewater Lined Evaporation Pond

Pond bottom and top of berm elevations are to be established to provide:

1. Positive drainage away from pond.

2. Anchorage for pond liner on top of berm.

3. Balance of cut and fill. All excavated material is used to form berm.

4. Top of berm to provide 1 ft-0 in. minimun freeboard above top level of pond. In high wind locations, the designer must provide

sufficient freeboard to prevent waves from breaking over top of berm.

The hypalon liner is to be factory assembled for minimum number of field joints. Placement of liner and sealing of field joints must be performed under strict supervision of manufacturer's trained representatives. A steel or concrete splash pad is required to absorb impact of wastewater stream entering pond. The hypalon liner does not require protective gravel, sand or soil on its sloped banks; however, in order that the liner be held in place, six inches of water shall be placed in the pond immediately after placement and testing.

3.4.2 Final Drawings

As stated above, all of the information required for complete installation of a fluoride removal water treatment plant must appear in the final construction drawing and specification package.

Isometric drawings for each piping subsystem are recommended; these views clarify the assembly for the installer. Cross referencing drawings, notes, and specifications are also recommended.

3.4.3 Final Capital Cost Estimate

Similar to the preparation of the preliminary cost estimate, the designer prepares the final cost estimate based upon a take off of the installed system. The estimate is now based upon exact detailed information rather than general information which was used during the preliminary estimate. The estimate is presented in the same format (see Table 3-2) and is to be accurate within ten percent ($\pm$10%). Since financial commitments are consummated at this stage, this degree of accuracy is required.

3.4.4 Final Design Revisions

Upon their completion, the final construction drawings and specifications are submitted for approval to the owner and the regulatory authorities. If there are changes or additional requirements requested, the designer must incorporate them and resubmit for approval. If the designer has communicated with the approving parties, time consuming resubmittals should not be necessary. Upon receipt of approval, the owner with assistance from the engineer goes out for bids for the construction of the fluoride removal water treatment plant.

3.5 REFERENCES

1. Alcoa Product Data, Calculating Pressure Drop through Packed Beds of Spheres and Mesh Granular Material, January 1, 1971, #GB4A, Aluminum Company of America, Pittsburgh, Pennsylvania.

CHAPTER 4

CENTRAL TREATMENT SYSTEM CAPITAL COST

4.1 INTRODUCTION

The designer is obligated to provide his client with the least expensive central treatment system that can remove the excess fluoride from a sufficient quantity of potable water that will satisfy all consumption requirements. The economic feasibility evaluation must include the initial capital cost along with follow-up operating and maintenance costs. This chapter is devoted to the capital cost which is affected by many factors including operating costs.

The amount of water to be treated is the most obvious factor by which capital costs are based; but it is never the only factor, and may not even be the most significant one. Other factors which can have varying impact upon the capital cost include, but are not limited to, the following:

1) Raw water quality (temperature, pH, fluoride concentration, alkalinity, iron, manganese, arsenic, sodium, sulfate, etc.)

2) Climate (temperature, evaporation rate, precipitation, wind, etc.)

3) Seismic zone

4) Soil conditions

5) Existing facility - number of wells (location, relative to each other) storage, distribution
   - water storage (amount, relative elevation, relative location)
   - distribution (relative location, peak flows, total flow, pressure, etc.)
   - consumption (daily, annual)

6) Backwash and regeneration wastewater disposal concept

7) Chemical supply logistics

8) Manual versus automatic control

9) Financial considerations (cost trends, capital financing costs, cash flow, labor rates, utility rates, chemical costs, etc.)

Once familiar with the capital cost impact that each of the above variables can create, the designer quickly realizes that a cost curve (or tabulation) based upon flow rate alone is meaningless. Such a curve is presented later in this chapter, employing the hypothetical design example used in Appendix B. A tabulation of the breakdown of these capital costs is provided in Appendix D. If the cost derived from that curve with the influence associated with the variables are weighed, the designer can arrive at a meaningful Preliminary Rough Project Cost Estimate (as described in Section 3.2 - Conceptual Design).

4.2 DISCUSSION OF COST VARIABLES

Each of the variables mentioned above has direct impact upon the total installed cost for a central treatment system. Ideally, conditions could exist which allow the designer to design a minimum cost system. A hypothetical example would resemble the following:

1) Raw water quality presents no problem (moderate temperature, low alkalinity, etc.)

2) Warm moderate climate (no freezing, no high temperature, minimal precipitation, no high wind-therefore, no requirement for weather protection)

3) No earthquake requirements

4) Existing concrete pad located on well compacted high bearing capacity soil

5) Single well pumping to subsurface storage reservoir with capacity for peak consumption day

6) Existing wastewater disposal capability adjacent to treatment site (e.g. a large tailings pond at an open pit mine)

7) Acid and caustic stored in large quantities on the site for other purposes

8) Manual operation by labor that is normally at the site with sufficient spare time

9) Funding, space, etc. available

This ideal situation, though possible, never exists in reality. Occasionally one, or more, of the ideal conditions occur; but the frequency is low. If we revise the final estimate for the example used in Appendix B to incorporate the above ideal conditions, the cost estimate would be reduced from $347,000 to $132,300 (see Table 4-1). Conversely adverse conditions could accumulate resulting in a cost in excess of $500,000 for the same treatment capability. The following subsections provide the designer with the basic insight needed to minimize the cost impact resulting from the above variables.

TABLE 4.1. FINAL COST ESTIMATE EXAMPLE FOR IDEAL LOCATION
FLUORIDE REMOVAL WATER TREATMENT PLANT
FINAL CAPITAL COST ESTIMATE

Location:
Flow Rate: 600 gpm
Date:

Process Equipment		**Cost, $**
Treatment Vessels		33,000
Treatment Media		20,500
Process Piping, Valves and Accessories		16,400
Instruments and Controls		8,300
Chemical Storage Tanks		0
Chemical Pumps, Piping and Accessories		5,300
	Subtotal	83,500
Process Equipment Installation		
Mechanical		30,000
Electrical		5,000
Painting and Miscellaneous		4,000
	Subtotal	39,000
Miscellaneous Installed Items		
Wastewater Lined Evaporation Pond		0
Building and Concrete		3,500
Site Work, Fence and Miscellaneous		0
	Subtotal	3,500
Contingency 5%		6,300
	*Total	132,300

*Engineering, Finance Charges, Real Estate Cost and Taxes not included.

4.2.1 Water Chemistry

The water chemistry can affect capital as well as operating costs. With a clear picture of the raw water quality, its possible variations and its adverse characteristics, the designer can readily determine its effect on the capital cost. High water temperature (greater than 100°F) requires higher cost piping material and/or pipe support. Varying water temperature requires inclusion of special provisions for thermal expansion and contraction. Very high fluoride (greater than 8 mg/l) may require larger treatment units to reduce the frequency of regeneration. High alkalinity requires higher acid consumption for pH adjustment resulting in larger feed pumps, day tank, piping, etc. This would also probably result in an aeration step for post treatment pH adjustment in lieu of caustic addition. High arsenic, iron, manganese, and/or suspended solids can require the addition of pretreatment steps to accomplish removal prior to fluoride removal.

Each of the physical and chemical characteristics of the raw water must be evaluated by the designer. The technical as well as the economical feasibility for the entire project could hinge on these factors.

4.2.2 Climate

Temperature extremes, precipitation and high wind will necessitate a building to house the treatment system equipment. High temperature along with direct sunlight adversely affects the strength of plastic piping systems. Freezing is obviously damaging to piping and in some extreme cases also to tanks. Temperature variation introduces requirements for special thermal expansion/contraction provisions. A building with heating and/or cooling and adequate insulation will eliminate the above problems and their costs; but will introduce the cost of the building. The building cost will reflect wind loads as well as thermal requirements. Operator comfort in lieu of economic considerations may dictate building costs.

The evaporation rate will dictate lined evaporation pond disposal of regeneration wastewater technical feasibility as well as cost.

The installed cost of building and evaporation ponds along with their associated civil work become a major portion of the overall capital cost. The designer must exert great care in interpreting the climatological conditions and their requirements.

4.2.3 Seismic Zone

The designer must adhere to the seismic design requirements of the local building codes. Buildings and tall slender equipment are vulnerable to seismic loads. The designer must determine magnitude of seismic design requirements and adhere to them. In zones of extreme seismic activity low profile equipment and buildings are recommended.

4.2.4 Soil Conditions

Unless soil boring data is already available for the treatment system site, the designer is advised to require at least one boring in the location of the foundation for the heaviest equipment item (either treatment vessel or sulfuric acid storage tank). If the quality of the soil is questionable (fill, or very poor load bearing capacity), a soil boring should be obtained for each major equipment item. Poor soil may require costly excavation/backfill and foundations.

Combinations of poor soil with rock or large boulders can make foundation work more complex and costly. Rock and boulders in combination with extreme temperatures can result in very high installation costs for subsurface raw, treated and wastewater pipe mains.

4.2.5 Existing Facility

There are many existing facility configurations that can either significantly increase or decrease the capital cost. The most important factors are discussed here.

4.2.5.1 Number and Location of Wells

When there is only one well, the removal of excess fluoride must be accomplished prior to entering the distribution system. Theoretically, treatment can occur before or after entering storage. Practically speaking, treatment prior to entering storage is much easier to control because the treatment plant flow rate will be constant. If treatment takes place after storage, or if there is no storage, flow rate is intermittent and variable. Then pH control is only achievable by sophisticated automatic pH control/acid feed systems. These are expensive and have difficulty maintaining the required tight pH treatment tolerance.

When there is more than one well, the designer must decide whether a single treatment plant treating water from all wells manifolded together or individual treatment plants at each well present a more efficient and cost effective concept. Factors such as distance between wells, distribution arrangement, system pressure, variation in water quality, etc. must be weighed in that decision. If all of the wells are in close proximity and pump similar quantity and quality water, a single treatment plant serving the entire system becomes preferable. When wells are widely dispersed manifolding costs become prohibitively expensive thus dictating implementation of individual treatment plants at each well. Frequently the distances may be such that the decision is not clear cut; the designer then has to relate to other variables such as water quality, system pressure, distribution configuration, land availability, etc.

Systems that require multiple treatment plant installations can achieve cost savings by employing an identical system at each location. This results in an assembly line approach to procurement, manufacture, assembly, installation and operation. Material cost savings, labor reduction and engineering for a single configuration will reduce the cost for the individual plant.

4.2.5.2 Storage Facilities

Similar to the wells, the number, size and location of storage tanks can greatly affect treatment plant size (flow rate) and capital cost. If there is no storage capacity in the system, the well pump must be capable of delivering a flow rate equal to the system momentary peak consumption; this could be many times the average flow rate for a peak day. The designer will quickly conclude that if there is no existing storage capacity, a storage tank must be added with the treatment system.

Most systems have existing storage capacity. The storage may be underground reservoirs, ground level storage tanks or elevated storage tanks (located on high ground or structurally supported standpipes). The first two require repressurization; the latter does not. The elevated storage tanks apply a back pressure on the ground level treatment system requiring higher pressure (more costly) construction of treatment vessels and piping systems. If aeration of treated effluent for pH adjustment is selected with an elevated storage tank, the treated water must be contained in a clearwell and repumped to storage. However, the treatment system vessels and piping may be low pressure construction. When ground or below ground level storage, loss of system pressure is not a factor.

The amount of storage capacity is also a factor affecting treatment system cost. The larger the storage capacity (within limits) the lower the required treatment plant flow rate (and resulting cost). A minimum storage capacity of one half of system peak day consumption is recommended.

4.2.5.3 Distribution and Consumption

These are the factors that determine the sizing of the treatment system (including the well pump flow rate, the storage capacity, etc.). Those features must be coordinated to provide a capacity to deliver a peak treated water supply to satisfy all possible conditions of peak consumption. If there is adequate storage capacity, the momentary peaks are dampened out. The peak day then defines the system capacity. The well pump is then sized to deliver a minimum of the peak daily requirement. The treatment system in turn is sized to treat a minimum of what the well pump delivers.

The distribution system may anticipate future growth or increased consumption. The well pump must then either pump a flow equal to or larger than the maximum anticipated peak daily flows or be able to adjust to future increased flow rate. The treatment plant in turn must incorporate capacity to treat the ultimate peak flow rate or include provisions to increase the treatment capacity in the future.

4.2.6 Backwash and Regeneration Disposal Concept

Depending on discharge limits established by the EPA, state and local regulatory agencies, waste disposal can be the single most costly item in the capital (and operating) cost projection. Requirements can vary from zero discharge to discharge in an available existing receiving facility. The zero discharge can be accomplished by chemical precipitation of either calcium fluoride or aluminum hydroxide with subsequent dewatering of solids and adjustment of pH. The wastewater supernatant is then fed back to the head of the treatment plant. This has been successfully accomplished on a pilot scale. However, this concept has not been incorporated in a full scale treatment plant. There are many other methods of disposal; however, as mentioned previously, those are beyond the scope of this manual.

4.2.7 Chemical Supply Logistics

Sulfuric acid (normally $66^{o}B'H_2SO_4$) and caustic soda (normally 50 percent NaOH) are readily available and are usually the least expensive chemicals to use for pH adjustment. Other chemicals such as hydrochloric acid and caustic potash are technically acceptable, but almost always more costly, and therefore not used. The acid and caustic are much cheaper when purchased in bulk quantities, usually 50,000 pound tank trucks. In very small plants, the cost of storage tanks for those volumes is not justified and therefore, higher unit price, smaller volumes are procured (drums and carboys). In very large treatment plants procurement via 200,000 pound railroad tank cars present a still cheaper mode. This concept, however, requires a rail siding and rail unloading facility. Nevertheless, it does present an option of lowering the overall cost.

A chemical unloading rail terminal presents another intriguing option for facilities with multiple treatment plants. In this concept smaller site storage tanks are supplied via "mini tank trucks" relaying chemicals to the treatment site from the rail terminal. This brings down the size (and cost) of chemical storage tanks at each site. However, this could increase the truck traffic of corrosive chemicals through populated areas, a risk which may not be acceptable.

4.2.8 Manual Versus Automatic Control

Automatic controls are technically feasible. However, the periodic presence of an operator is always a requirement. The capital cost of automation (valve operators, control instrumentation, etc.) as well as maintenance costs are usually a burden which the client will not accept. However, in locations where operating labor rates are extremely high, the client may prefer an automatic system.

4.2.9 Financial Considerations

Many financial factors must be considered by the designer and his client. The client can superimpose financial restrictions (beyond any of the technical factors mentioned above) upon the designer which result in increased (or decreased) capital cost. These include, but are not limited to the following: inflationary trends, interest rates, financing costs, land costs (or availability), cash flow, labor rates, electric utility rates, chemical costs, etc. All or part of this group of factors could effect the capital cost of a given treatment plant. The client may desire higher capital investment with reduced operating cost because interest rates are low, inflation is anticipated, cash is available, labor and electric utility rates are high. Or the opposite can be true. The varying combinations of these factors which could develop are numerous; each one will affect the ultimate capital cost.

4.3 RELATIVE CAPITAL COST OF FLUORIDE REMOVAL CENTRAL WATER TREATMENT PLANTS BASED UPON FLOW RATE

The relative capital costs of central treatment plants based upon the treated water flow rate are presented in Figures 4-1 and 4-2. Both cost curves are based on the same treatment system design criteria. Tabulations of the breakdowns of the capital costs for both curves is provided in Appendix D. The curve in Figure 4-1 is based on the facility criteria employed in the hypothetical design for the 600 gpm treatment fluoride system in Appendix B. The curve in Figure 4-2 is based on the "bare bones" facility requirements presented earlier in this chapter for the same treatment system (see Table 4-1). This information demonstrates the dramatic differences in capital cost that can occur for the same treatment plant in different circumstances. The costs related to the curve in Figure 4-1 are representative of average capital costs.

4.4 REFERENCES

1. Rubel and Hager, Inc., Final Report - Pilot Test Program - Removal of Excess Fluoride from Activated Carbon Effluent at Rocky Mountain Arsenal, Colorado, April 30, 1980.

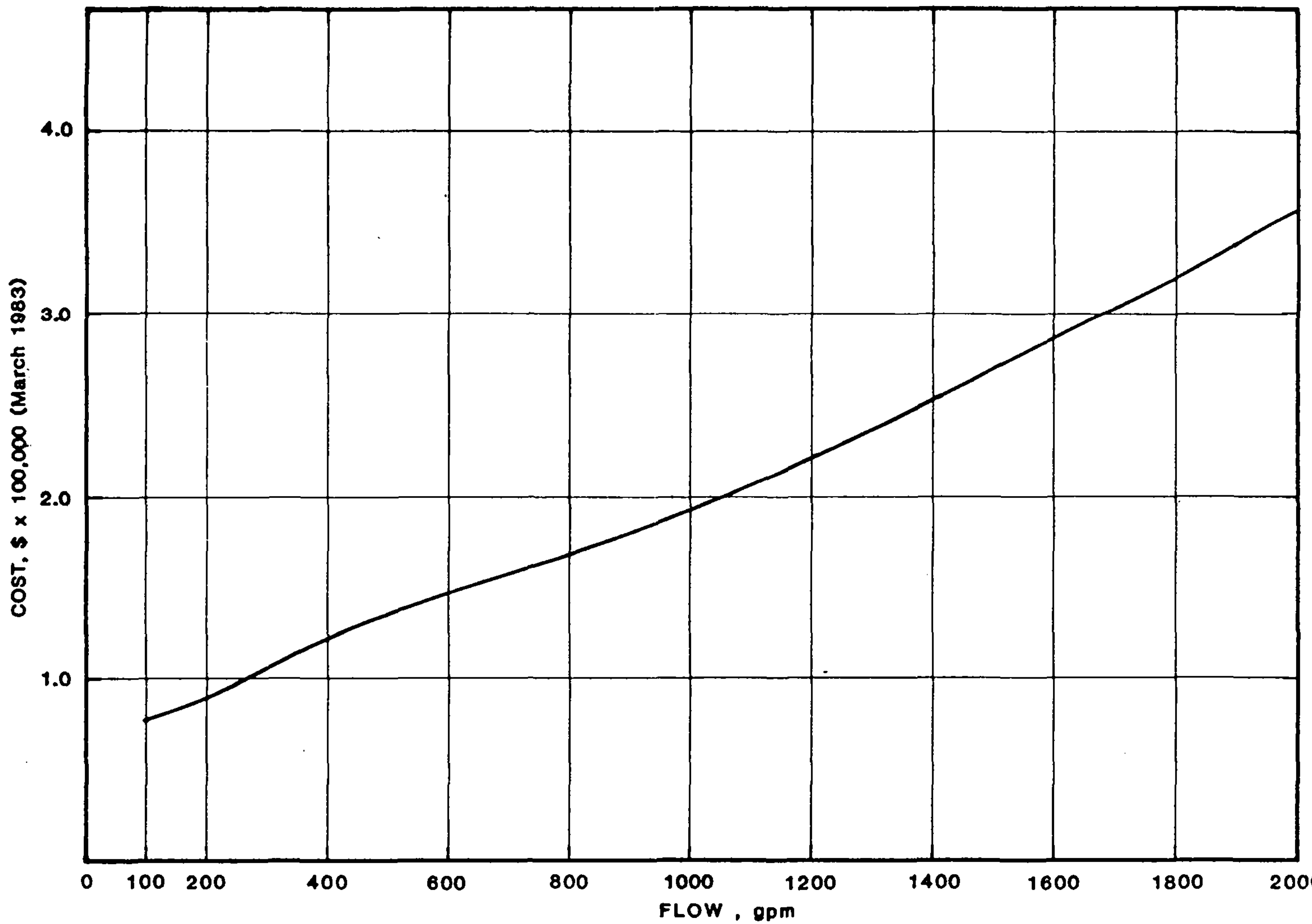


FIGURE 4-1 COST OF FLUORIDE REMOVAL AT AN IDEAL LOCATION

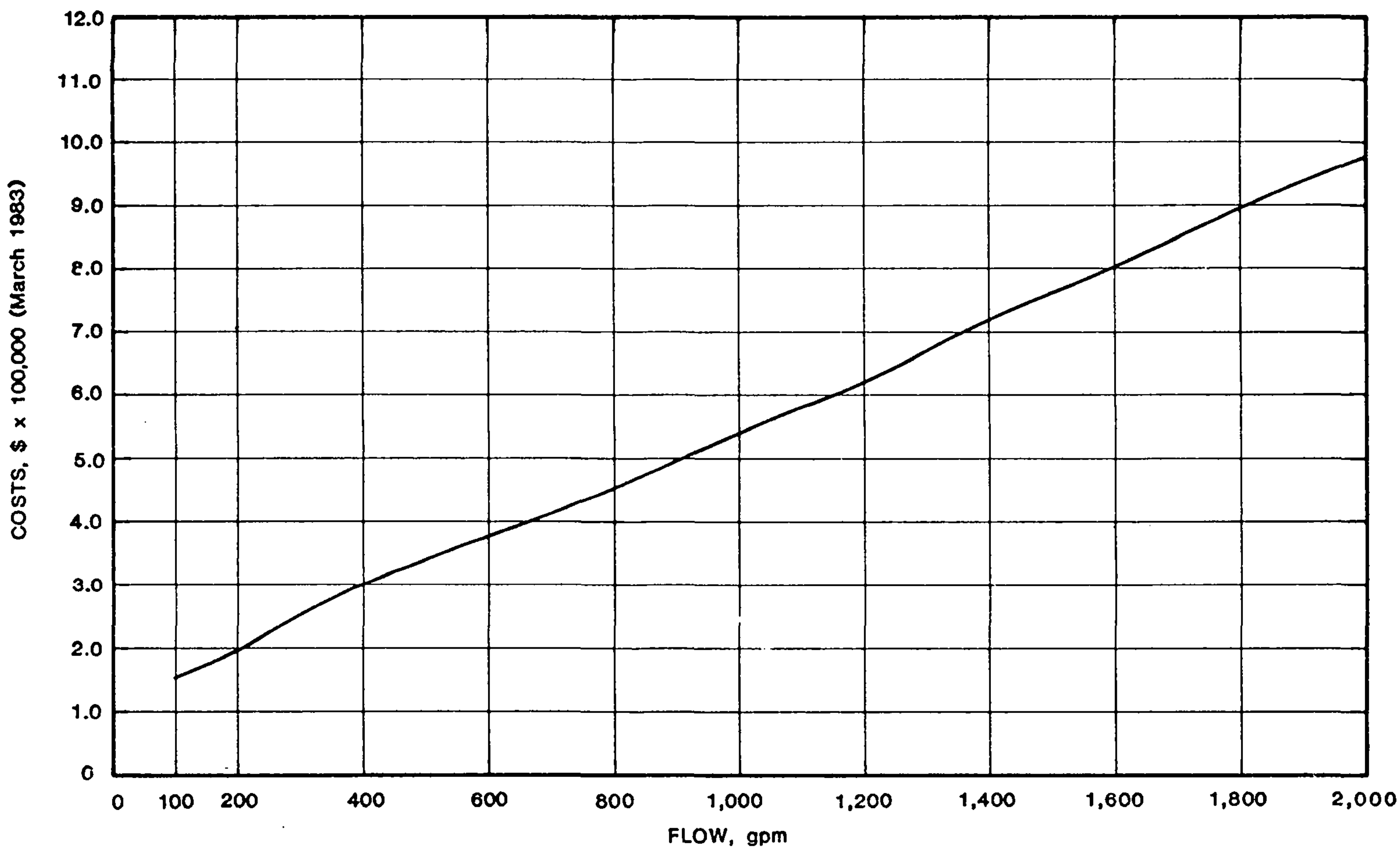


FIGURE 4-2 COST OF FLUORIDE REMOVAL FOR A TYPICAL LOCATION

CHAPTER 5

TREATMENT PLANT OPERATION

5.1 INTRODUCTION

Upon completion and approval of the final design package (plans and specifications), the owner (client) proceeds to advertise for bids for construction of the treatment plant. The construction contract is normally awarded to the firm submitting the lowest bid. Occasionally, circumstances arise that disqualify the low bidder in which case the lowest qualified bidder is awarded the contract. Upon award of the construction contract, the engineer (designer or his representative) may be requested to supervise the work of the construction contractor. This responsibility may be limited to periodic visits to the site to assure the client that the general intent of the design is being fulfilled; or it may include exhaustive, day to day inspection and approval of the work as it is being performed. The engineer is requested to review and approve all shop drawings and other information submitted by the contractor and/or subcontractors and material suppliers. All acceptable substitutions are to be approved in writing by the engineer. Upon completion of the construction phase of the project, the engineer is normally requested to perform a final inspection. This entails a formal approval indicating to the owner that all installed items are in compliance with the requirements of the design. Any corrective work required at that time is covered by a punch list and/or warranty. The warranty period (normally one year) commences upon final acceptance of the project by the owner from the contractor. Final acceptance usually takes place upon completion of all major punch list items.

Preparation for treatment plant startup, startup and operator training may or may not be included in the construction contract. Although this area of contract responsibility is not germane to this manual, the activities and events that lead up to routine operation are. This chapter discusses those steps in the sense that the operator is performing them. The operator could be the contractor, the owner's representative or an independent third party.

System operating supplies, including treatment chemicals, laboratory supplies and recommended spare parts must be procured, and set in place. The treatment plant operating and maintenance instructions (O&M Manual) must be available at the project site. Included in the O&M Manual are the valve number diagram (see Figure 5-1) which corresponds to brass tags on the valves and a valve directory furnished by the contractor, and a valve operation chart (see Table 5-1).

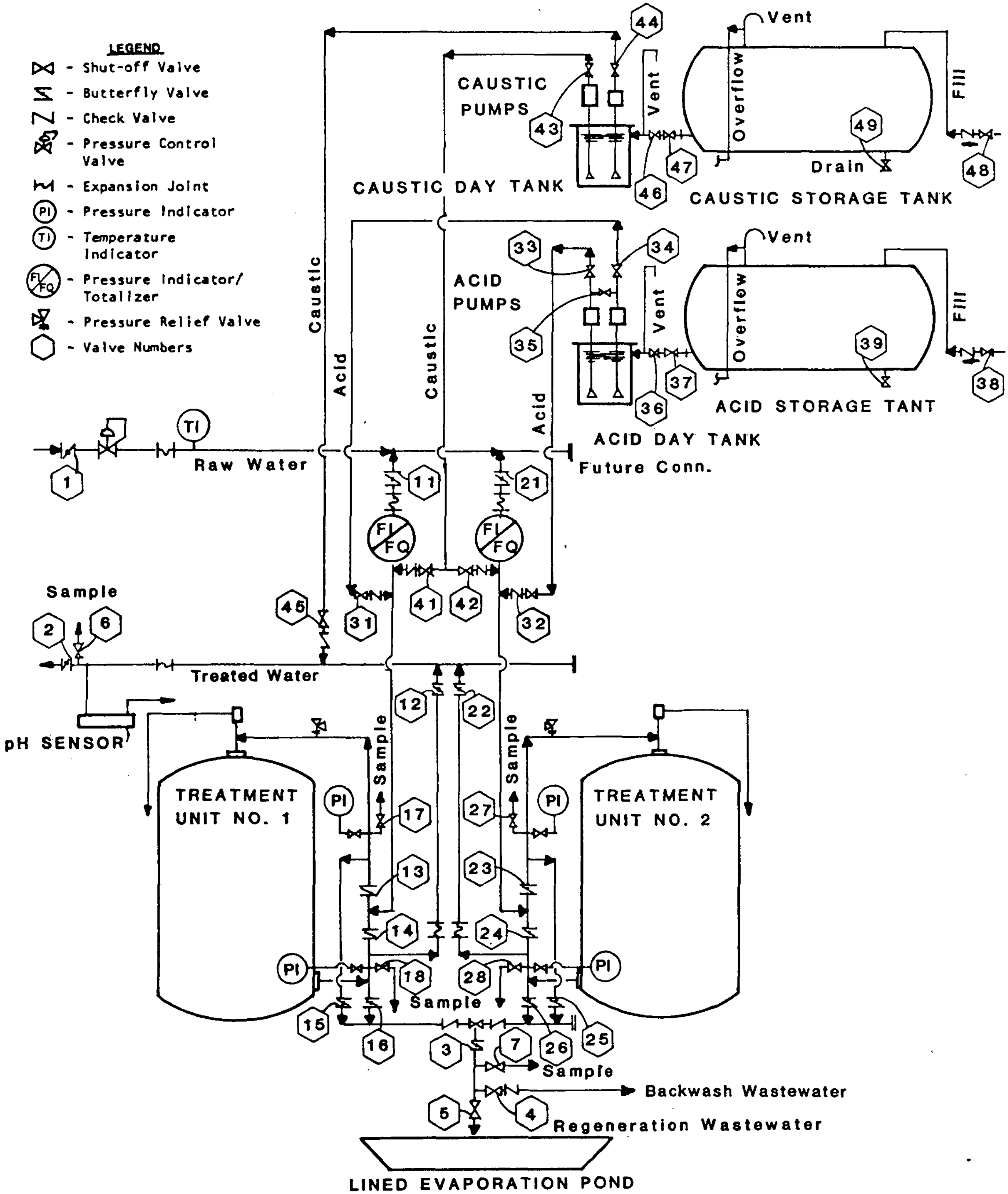


FIGURE 5-1 VALVE NUMBER DIAGRAM

TABLE 5-1. FLUORIDE REMOVAL WATER TREATMENT PLANT VALVE OPERATION CHART
(Refer to Figure 5-1 for Valve Location)

Function		Valve Numbers																																	
		Unit No. 1 Operation						Unit No. 2 Operation						System Isolation					Sample							Chemical Shutoff				
Unit No. 1	Unit No. 2	11	12	13	14	15	16	21	22	23	24	25	26	1	2	3	4	5	6	7	17	18	27	28	31	32	41	42	43
Treatment	Treatment	O	O	O	X	X	X	O	O	O	X	X	X	O	O	X	X	X	P	X	P	P	P	P	O	O	X	X	O
Drain	Treatment	X	X	X	X	X	O	O	O	O	X	X	X	O	O	O	O	X	X	X	X	X	P	P	X	O	X	X	O
Backwash	Shutoff	O	X	X	O	O	X	X	X	O	X	X	X	O	O	O	O	X	X	O	X	X	X	X	X	X	X	X	X
Drain	Treatment	X	X	X	X	X	O	O	O	O	X	X	X	O	O	O	O	X	X	X	X	X	X	X	X	O	X	X	O
Upflow Regen.	Treatment	O	X	X	O	O	X	O	O	O	X	X	X	O	O	O	X	O	X	P	X	X	X	X	X	O	O	X	O
Upflow Rinse	Treatment	O	X	X	O	O	X	O	O	O	X	X	X	O	O	O	X	O	X	X	X	X	X	X	X	O	X	X	O
Drain	Treatment	X	X	X	X	X	O	O	O	O	X	X	X	O	O	O	X	O	X	X	X	X	X	X	X	O	X	X	O
Downflow Regen.	Treatment	O	X	O	X	X	O	O	O	O	X	X	X	O	O	O	X	O	X	P	X	X	X	X	X	O	O	X	O
Drain	Treatment	X	X	X	X	X	O	O	O	O	X	X	X	O	O	O	X	O	X	X	X	X	X	X	X	O	X	X	O
Neutralization	Treatment	O	X	O	X	X	O	O	O	O	X	X	X	O	O	O	X	O	X	P	O	P	X	X	O	O	X	X	O
Treatment	Treatment	O	O	O	X	X	X	O	O	O	X	X	X	O	O	X	X	X	P	X	P	P	P	P	O	O	X	X	O
Treatment	Drain	O	O	O	X	X	X	X	X	X	X	X	O	O	O	O	O	X	X	X	P	P	X	X	O	X	X	X	O
Shutoff	Backwash	X	X	O	X	X	X	O	X	X	O	O	X	O	O	O	O	X	X	O	X	X	X	X	X	X	X	X	X
Treatment	Drain	O	O	O	X	X	X	X	X	X	X	X	O	O	O	O	O	X	X	X	X	X	X	X	O	X	X	X	O
Treatment	Upflow Regen.	O	O	O	X	X	X	O	X	X	O	O	X	O	O	O	X	O	X	P	X	X	X	X	O	X	X	O	O
Treatment	Upflow Rinse	O	O	O	X	X	X	O	X	X	O	O	X	O	O	O	X	O	X	P	X	X	X	X	O	X	X	X	O
Treatment	Drain	O	O	O	X	X	X	X	X	X	X	X	O	O	O	O	X	O	X	X	X	X	X	X	O	X	X	X	O
Treatment	Downflow Regen.	O	O	O	X	X	X	O	X	O	X	X	O	O	O	O	X	O	X	P	X	X	X	X	O	X	X	O	O
Treatment	Drain	O	O	O	X	X	X	X	X	X	X	X	O	O	O	O	X	O	X	X	X	X	X	X	O	X	X	X	O
Treatment	Neutralization	O	O	O	X	X	X	O	X	O	X	X	O	O	O	O	X	O	X	P	X	X	O	P	O	O	X	X	O
Treatment	Treatment	O	O	O	X	X	X	O	O	O	X	X	O	O	O	X	X	X	P	X	P	P	P	P	O	O	X	X	O

Legend: 0 - Valve Open
X - Valve Closed
P - Periodic Sample

The treatment bed material is then placed in the treatment vessels and the plant is ready to start operation.

There are four basic modes of operation: treatment, backwash, regeneration and neutralization. Operating details for each of these modes are covered in this chapter. It is important to note that each of the above modes uses raw water during each operation, never treated water.

5.2 INITIAL STARTUP

The operator first thoroughly reviews the O&M Manual, familiarizes himself with every component of the plant and resolves any question that he may have.

The placement of the activated alumina in the treatment vessel which takes place immediately prior to startup is a critical step in the future system performance. The dry material is delivered in 100 pound bags (least expensive), 100 pound drums, or 400 pound drums. The volume of the media is determined on a dry weight basis. The actual density varies with the degree of packing of the bed, (45-55 pounds/ft^3). Fifty pounds/ft^3 is recommended. The virgin granular material is "coated" with caustic. There is a small amount of fines (less that 1 percent) that can become airborne and are irritating to the personnel who are handling them. Eye, skin, and inhalation protection are mandatory during vessel loading activity. The vessel should be half filled with water prior to placing the alumina. As the alumina is carefully distributed into the vessel from above, the water dissipates the heat generated by the heat of wetting of the caustic "coating" on the alumina grains. This prevents cementing of the bed. The water also separates the fines from the granular materials, protects the underdrain assembly from impact, and initiates stratification of the bed. It is recommended that the bed be placed in two or three lifts. In treatment systems with two or more treatment beds, alternate placing of media and backwashing steps can be worked together between the treatment units. Thereby, media placement can be a continuous operation. The bed is to be thoroughly backwashed with raw water after each lift. During bed placement, each backwash step should be a minimum of thirty minutes and could extend to two hours. The purpose of this stringent effort is to remove all of the fines from the bed. If the fines remain in the bed, possible problems such as channeling, excessive pressure drop or even cementing can develop. The extra backwashing effort during bed placement permits fines at the bottom of the bed to work their way up and out to waste. Since the lower portions of the bed which contain the largest particles do not expand during backwash, fines not backwashed out of the bed at that stage may be permanently locked into the bed. The initial backwash water should be directed to the lined evaporation pond.

5.3 TREATMENT MODE

Upon completion of backwashing of a virgin bed, the bed should be drained and the vessel opened. Approximately 1/8-1/4" of fine bed material should be skimmed from the top of the bed. This is the finest grain material which tends to blind the bed causing channeling and/or excessive pressure drop. Once that material is removed, the vessel can be closed and refilled with water.

At this point the plant should be cleaned up. Airborne fines that form a dustlike coating on piping and equipment must be removed. Good housekeeping should begin now and be continued on a permanent basis.

The pressure loss checkout mentioned in Section 3.4, Final Design, should be accomplished at this point, just prior to startup. See Table 5.2 for calculated pressure drop through the treatment media. If there is a pressure loss problem, it should be corrected prior to treatment startup.

TABLE 5.2. CALCUALTED DOWNFLOW PRESSURE DROP DATA
Alcoa F-1, 28-48 Mesh Activated Alumina

Water flow rate gpm/ft^2	Pressure drop in PSI per foot of bed depth	Modified Reynolds number
2.0	0.10	2375
3.0	0.018	3555
4.0	0.028	4735
5.0	0.040	5900
6.0	0.053	7111
7.0	0.068	8291

Prior to start of operation, the pH instrumentation is to be calibrated. The most critical requirement for efficient low cost operation is the control of the raw water adjusted pH. The optimum environment for fluoride removal exists when the treatment pH is in the range of 5.0-6.0. The best results have occurred when the pH is held rigidly at 5.5. Because acid feed rates are a function of raw water alkalinity, they vary from one water to another. As raw water pH moves above 6.0 or below 5.0 fluoride removal capacity deteriorates at an increasing rate. However, when the alkalinity of the raw water is extremely high and/or the cost of acid is very high, it can be more cost effective to operate in a pH range of 6.0-6.5 to reduce the acid consumption (even though fluoride removal efficiency is also reduced).

The downflow treatment for the first (virgin) run can now begin. See Valve Operation Chart (Table 5-1) for valve positions for this function. It is recommended that one vessel be placed in operation at a time. This allows the operator to concentrate on initial raw water pH adjustment on one treatment unit until it is in stable operation; he can then devote full concentration to the next treatment unit. It is also beneficial to stagger treatment unit operation so that treated water from each unit is at different stages of its respective treatment run. That facilitates blending of treated water which provides the most cost effective operation. Water flow rate can be controlled accurately through each treatment vessel by manually adjusting the effluent valve (valve numbers 12 and 22) or the influent valve (valve numbers 11 and 21).

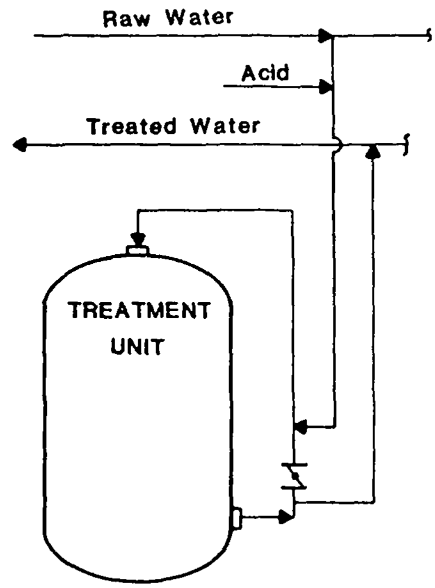
The basic flow schematic for the treatment mode is illustrated in Figure 5-2.

The initial effluent pH is high with no fluoride removal (similar to the neutralization mode explained later). After a short period both pH and fluoride in the treated water drop to anticipated levels. At that time the treated water can be directed to storage and/or distribution. Depending on the requirements of the state or local regulatory agency, samples may have to be analyzed at a certified testing laboratory prior to approval of distribution of treated water.

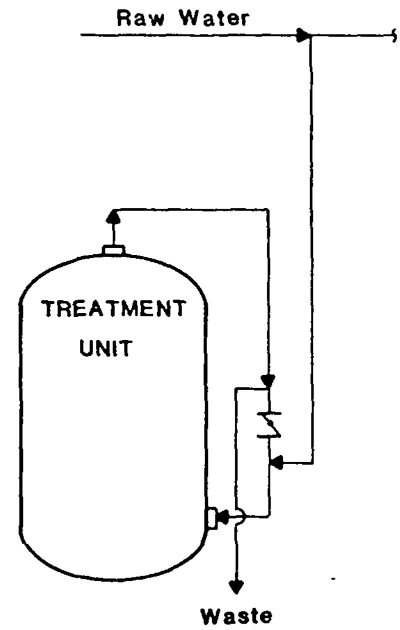
The fluoride in the treated water drops rapidly to a very low level (normally less than 0.2 mg/l) and remains stable until breakthrough begins. At that point, the fluoride level increases gradually until the treatment run is terminated.

Concurrently, the treated water pH gradually drops to the adjusted raw water pH level where it remains through the duration of the run. This level is lower than the normally accepted minimum pH of 6.5; therefore, it must be raised either by chemical addition, aeration or blending with raw water. Regardless of the method of adjustment, it must take place and be stabilized at the desired level prior to delivering the treated water into distribution. High pH in the treated water is also a concern. Normally the maximum allowable pH is 8.5; however, there are exceptions where 9.0 is permitted. Most systems desire pH in the 7.5-8.0 range. When the treated water is approved and the pH stabilized for distribution, it flows out of the plant past a fail-safe pH sensor with high and low level alarms. If there is a pH excursion exceeding the allowable limits, an interlock (incorporating the pH alarms with the well pump(s) magnetic starter) de-energizes the well pump(s). Simultaneously, the chemical pumps shut down as their controls are interlocked with the well pump(s) power circuitry. The fail-safe pH override automatically prevents any treated water, which is out of tolerance pH, from entering the distribution system. In the event of such an excursion, the operator manually controls the well pump(s) to divert the unacceptable water to waste, determine the cause of the deviation and make corrections prior to placing the treatment system back on line. Probable causes for treated water pH deviations are: change in water flow rate, change in acid flow rate, change in caustic flow rate, change in raw water chemistry.

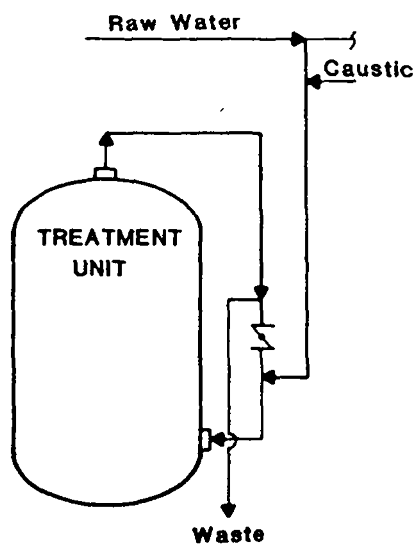
A treatment run can be extended by blending treated water in which the fluoride level exceeds the MCL with treated water with a low fluoride level. This can either be done in the effluent main leaving the treatment plant, in the storage reservoir or bypassing raw water to blend with treated. During a treatment run there is a long period when the fluoride content of the treated water is well below the optimum level (one half of the MCL). As breakthrough



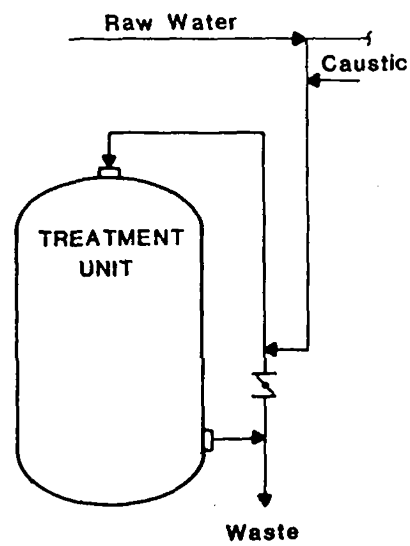
TREATMENT AND DOWNFLOW RINSE



BACKWASH AND UPFLOW RINSE



UPFLOW REGENERATION



DOWNFLOW REGENERATION

NOTE: For Clarity Only Relevant Pipes And Shutoff Valves Are Shown.

FIGURE 5-2 BASIC OPERATING MODE FLOW SCHEMATICS occurs, there is a long period of slowly increasing fluoride concentration in the treated water. Blending in the effluent main entails staggering the treatment cycles of two or more treatment units. This can be accomplished by continuing treatment in one unit after its increasing fluoride level has surpassed the MCL and blending it with low fluoride effluent from one (or more) unit that is in the early stage of a treatment cycle. The operator can extend the run until the fluoride level reaches at least twice the MCL before terminating the run. As the fluoride level gets higher the operator must reduce the flow rate to maintain the combined high and low fluoride levels at an acceptable average. The same processes take place in the storage reservoir using one (or more) treatment unit(s).

This increases the fluoride loading on the alumina and results in lower operating cost. The loading can significantly exceed the 2000 grains/ft^3 mentioned in the design criteria in Chapter 3. Capacities in the 2500-3000 grains/ft^3 are normal. Capacities exceeding 4000 grains/ft^3 have been achieved in certain waters. It should be noted that the higher the raw water fluoride level, the greater the adsorption (driving force) capacity. For example, the alumina capacity for a water with a fluoride level of 3 mg/l may only be 2100 grains/ft^3 while the capacity for a similar water with a fluoride level of 8 mg/l is 3000 grains/ft^3. Since there are many other factors that can affect this capacity, the precise amount is difficult to predict. The operator must be cognizant of the fact that the more water treated during a run, the lower the operating cost.

In raw waters where the fluoride level does not exceed two times the MCL, part of the raw water can bypass treatment and be blended back with the treated water. Water with higher fluoride levels can also profit from bypassing, but the economic benefits rapidly diminish.

The operator can reduce chemical consumption by blending high pH with low pH treated waters. This is accomplished during the period when one treatment unit has recently been regenerated and treated water pH is still high. A skilled operator develops many techniques such as this to minimize operating costs.

High iron content in the raw water can cause problems during a treatment run. The ion oxidizes, precipitates, and is filtered from solution by the treatment media. This results in increased pressure drop, channeling, premature fluoride breakthrough, and shortened treatment runs. Raw water iron content greater than 1.0 mg/l is cause for concern. Special backwashing procedures during treatment runs can be employed to cope with this problem. Special procedures such as intra-run backwashing are beyond the scope of this manual.

5.4 BACKWASH MODE

For two reasons it is important that the bed be backwashed with raw water after each treatment run prior to regeneration. First, any suspended solids that have been filtered from the raw water by the treatment bed tend to blind the bed. Therefore, these particles must be removed from the bed. Second, even though filtration may have been negligible, the downward flow tends to pack the bed. An upflow backwash will then expand the bed, and break up any tendency towards wall effects and channeling. A backwash rate of 8-9 gpm/ft^2 will expand the bed approximately 50 percent, which is recommended. As mentioned in prior sections, this rate varies with extreme water temperatures. Care must be taken to avoid backwashing granular bed material out of the treatment unit. Normally backwashing lasts ten minutes.

Refer to Table 5-1, Valve Operation Chart, for valve positions for the backwash mode. The basic flow schematic for the backwash mode is illustrated in Figure 5-2. For most effective backwash, it is recommended that the vessel be drained prior to backwash. As backwash water flows into a drained bed, it lifts the entire bed approximately one foot prior to the bed fluidizing. This action provides an efficient scouring action without excessive abrasion to the alumina grains. Backwash water samples must be inspected frequently to determine that filtered material is still being removed and treatment media is not being washed out of the bed. Excessive backwash causes abrasion that wears down the alumina grains. That also wastes raw water and increases the wastewater disposal volume. Therefore, backwash volume must be minimized. It is prudent to periodically inspect the media level of each treatment bed.

5.5 REGENERATION MODE

The most efficient cost effective method of regenerating a treatment bed upon completion of a treatment run includes two discrete regeneration steps. The first step is upflow following draining of the bed after the backwash mode. The regeneration is followed by an upflow rinse. The unit is then drained to the top of the treatment bed prior to the second regeneration step (which is downflow). Both steps use a 1 percent (by weight) NaOH solution.

The objective of regeneration is to remove all fluoride ions from the bed before any part of the bed is returned to the treatment mode. Fluoride ions lose their attraction (adsorption force) and become repelled by the alumina when the pH rises above 10.5. The higher the pH, the faster and more efficient the regeneration. However, too high a pH not only costs more (because of higher caustic consumption), but is also increasingly aggressive to the alumina. The above mentioned one percent NaOH solution is the maximum concentration required for high efficiency regeneration (recovery of total fluoride capacity). A skilled operator can reduce the concentration of the NaOH to 0.75 percent with the same high efficiency performance. However, below 0.75 percent, efficiency deteriorates rapidly. This lower caustic concentration can reduce caustic consumption for regeneration up to 25 percent. As described in Chapter 3, the dilution of the caustic takes place at a mixing tee in the raw water branch piping at each treatment unit. Both the raw water and the 50 percent NaOH are metered prior to entering the mixing tee. The accuracy of the metering ranges from ± 2 percent to ± 5 percent depending on the quality of the flow meters. If using a 0.75 percent NaOH concentration, meter readings that are low for water and high for caustic result in a lower than planned caustic concentration and loss of regeneration efficiency.

The rule of thumb for the volume of one percent caustic solution required per regeneration step is fifteen gallons per cubic foot of treatment media. The minimum time recommended for the solution to flow through the bed is thirty minutes. The maximum time is unlimited; but for practical purposes, thirty-five minutes is recommended. For a 5'-0" deep treatment bed a flow of 2.5 gpm/ft^2 for a period of thirty minutes for each regeneration step is sufficient. This equates to 0.2 gallons 50 percent NaOH per cubic foot of treatment media for each regeneration step (upflow and downflow).

For the valve positions during each step of the regeneration mode, refer to Table 5-1. The basic flow schematics for the regeneration modes are illustrated in Figure 5-2. After backwash, prior to the upflow regeneration step, the bed must be drained to remove water which dilutes the caustic concentration. Upon completion of draining, the upflow regeneration starts as described above. Upon completion of the upflow regeneration, the caustic feed pump is turned off and the day tank refilled. The raw water continues to flow for sixty minutes at 2.5 gpm/ft^2 flow rate upward through the bed, flushing out the fluoride. After this rinse step is completed, the vessel is drained to the top of the treatment bed, again to remove dilution water. The downflow regeneration is followed by draining of the bed prior to the start of the neutralization mode.

5.6 NEUTRALIZATION MODE

The neutralization mode is critical to the success of the following treatment run. The object of this mode is to return the bed to the treatment mode as rapidly as possible without dissolving the activated alumina. The pH of the treatment media after completion of the regeneration is 12+. It must be adjusted down to 5.5. Therefore, it must pass through pH ranges where ions that compete for adsorption sites on the alumina will be loaded into the bed. The minimum pH that can be safely exposed to the granular activated alumina is 2.5. A pH lower than that is too aggressive and is not recommended.

At the start of the downflow neutralization mode the valves are positioned per Table 5-1, and after fifteen minutes the flow is adjusted to the normal treatment mode rate. The basic flow schematic for the neutralization mode is illustrated in Figure 5-2. The acid pump is started; and the pH of the raw water is adjusted to 2.5. Acid feed rate again varies with the alkalinity of the raw water. The raw water flow rate may have to be reduced to achieve pH 2.5 at the maximum acid pump feed rate.

As the neutralization mode proceeds, the pH of the treated water gradually drops below 12. The rate of pH reduction increases at an increasing rate. As the treated water pH drops below 10, the treated water fluoride level begins to drop below that of the raw water. At that time, treatment begins. At the point where the fluoride level drops below the MCL, the water becomes usable and can be directed to storage. The pH may still be high (9.5) in the water; however, this can be blended with treated water with lower pH from other treatment units. When the treated water pH drops to 8.5, the raw water pH is adjusted up to 4.0 as the bed rapidly neutralizes. When the treated water pH drops to 6.5, the raw water pH is adjusted up to 5.5 where it remains through the duration of the run. The operation is now starting the next cycle in the treatment mode.

The volume of wastewater produced during the regeneration of a treatment bed will vary with the physical/chemical characteristics of the raw water. A rule of thumb that can assist the operator in his logistical handling is "300 gallons of wastewater is produced per cubic foot of treatment media during each regeneration". Typical volumes of wastewater generated during each regeneration step for a hypothetical treatment bed are as follows:

Backwash		-	60 gallons
Upflow Regeneration		-	15 gallons
Upflow Rinse		-	30 gallons
Downflow Regeneration		-	15 gallons
Neutralization		-	180 gallons
	Total		300 gallons

Operational experience at a specific treatment plant will present deviations from these quantities.

5.7 OPERATOR REQUIREMENTS

A qualified operator for a fluoride removal water treatment plant must have thorough fluoride removal process training, preferably at an existing treatment plant. The operator must be able to service pumps, piping systems, instrumentation, and electrical accessories. The operator must be totally informed about the characteristics of both acids and caustics in all concentrations. Corrosive chemical safety requirements as to clothing, equipment, antidotes, and procedures must be thoroughly understood. The operator must be thoroughly trained to run routine water analyses including at least two methods for determining fluoride levels. The operator must be well grounded in mathematics for operation cost accounting and treatment run record keeping. The operator, above all, must be dependable and conscientious.

5.8 LABORATORY REQUIREMENTS

In addition to the Operations and Maintenance (O&M) Manual, the treatment plant should have the latest edition of Standard Methods for the Examination of Water and Wastewater prepared jointly by the APHA-AWWA-WPCF (American Public Health Association - American Water Waste Association - Water Pollution Central Federation). This supplies the plant operator with all necessary information for acceptable methods for analyzing water. A recommended list of items for analysis is illustrated in Figure 3-1. The primary requirement is for accurate analysis of fluoride and determination of pH. As long as pH meters are calibrated and cleaned regularly, high precision measurements are easily obtained. Care must be exercised to prevent contamination of pH buffers. Fluoride measurement can be achieved in several ways. Ion-specific electrodes are accurate and reliable provided that the correct buffer (TISAB) is employed for the water to be treated. There are two wet chemistry methods which are also quite accurate. They are SPADNS and Alizarin. Distillation and/or correction for interfering ions (e.g. alkalinity, aluminum, iron, sulfate, etc.) are required for accurate results.

5.9 OPERATING RECORDS

A system of records must be maintained on file at the treatment plant covering plant activity, plant procedures, raw water chemical analyses, plant expenditures, and inventory of materials (spare parts, tools, etc.). The plant operator should have the responsibility of managing all aspects of the treatment plant operation. The operator is accountable to the water system management. The recommended record system should include, but not be limited to the following items:

5.9.1 Plant Log

A daily log in which the plant operator records daily activities at the plant. This record should include a listing of scheduled maintenance, unscheduled maintenance, plant visitors, purchases, abnormal weather conditions, injuries, sampling for state or other regulatory agencies, etc. This record should also be used as a tool for planning future routine and special activities.

5.9.2 Operation Log

The operator should maintain a log sheet for each treatment run for each treatment unit. Thereby, a permanent plant performance record will be on file. Figure 5-3 illustrates a copy of a suggested form.

5.9.3 Water Analysis Reports

The plant operator should run an analysis of raw and treated fluoride levels once each day for each unit. He should run a total raw water analysis once per week. Changes in raw water may necessitate changes in the treatment process. Figure 3-1 illustrates a copy of a suggested form. A permanent file of these reports will be a valuable tool.

5.9.4 Plant Operating Cost Records

Using accounting forms supplied by the water system's accountants, the plant operator should keep a complete record of purchases of all spare parts, chemicals, laboratory equipment and reagents, tools, services, and other sundry items. This should be supplemented by a file of up-to-date competitive prices for items that have been previously purchased.

FIGURE 5-3

FLUORIDE REMOVAL WATER TREATMENT PLANT
OPERATION LOG

Unit #__________ Run #______________ Date Start __________ Date End ________

SERVICE TO RESERVOIR

Meter End ______________ Meter Start ____________ Total Treated ________ M-Gal.

BACKWASH TO SEWER

Meter End ______________ Meter Start ____________ Total ______________ M-Gal.

REGENERATION SOLUTION TO POND

Upflow:
Meter End ____________ Meter Start ____________ Total ______________ M-Gal.

Downflow:
Meter End ____________ Meter Start ____________ Total ______________ M-Gal.

RINSE TO POND

Meter End ______________ Meter Start ____________ Total ______________ M-Gal.

NEUTRALIZATION RINSE TO POND

Meter End ______________ Meter Start ____________ Total ______________ M-Gal.

TOTAL WASTE WATER SUMMARY

Total to Pond____________ gal. TOTAL WATER USED __________________ Gallons
Total to Sewer____________ gal.
Total to Waste____________ gal. PERCENT WASTE ______________________ %

TREATED WATER LOG

Date	Meter Reading M-Gal	(Δ) M-Gal	Total (Q) M-Gal	F_R Raw Fluoride F_R (mg/l)	F_T Treated Fluoride F_T (mg/l)	(Δ) F_TAvg.	$\frac{\Sigma(\Delta)F_T\text{Avg.}^*}{Q}$

*Average Treated Water Fluoride

5.9.5 Correspondence Files

The plant operator should retain copies of all correspondence pertaining to the treatment plant in chronological order. Included would be intra-departmental notes and memos, in addition to correspondence with other individuals and/or organizations.

5.9.6 Regulatory Agency Reports

The plant operator should maintain a complete file of copies of all reports received from state, county, or other regulatory agencies pertaining to the treatment plant.

5.9.7 Miscellaneous Forms

The operator should have an adequate supply of accident, insurance, and other miscellaneous forms.

5.10 TREATMENT PLANT MAINTENANCE

The maintenance concept for the fluoride removal water treatment plant is to isolate the equipment to be serviced by means of shutoff valves, vent and drain lines (as required), repair or replace equipment, fill lines, open valves, and start service. To accomplish this, all equipment items are equipped with isolating valves, and all piping systems have vents at high points and drains at low points.

Equipment manufacturer's recommended spare parts are to be stocked at the treatment plant to avoid lengthy maintenance shutdowns.

If the entire treatment plant needs to be shutdown, the plant itself can be bypassed. This can be done by closing the butterfly valves in the raw water and treated water line and then opening the butterfly valve in the bypass line. This would result in untreated water with excessively high fluoride being pumped to distribution, an event that should not occur without the approval of the water system manager.

In the event the entire treatment plant must be shut down, the local regulatory agency must be notified immediately.

5.11 EQUIPMENT MAINTENANCE

Equipment manufacturer's maintenance instructions are to be included in the Suppliers Equipment Instructions Section of the O&M Manual.

5.12 TREATMENT MEDIA MAINTENANCE

Plant operator should inspect the surface of each treatment bed at least once every three regenerations. If the level of a bed lowers more than eight inches, makeup activated alumina must be added. Makeup alumina should be evenly distributed. There should be a minimum depth of 1'-0" of water above the surface of the existing bed. The vessel should be closed immediately and backwashed at flow rates varying between 8 and 9 gpm/ft^2 for at least one hour. It is very important to flush the fines out of the virgin activated alumina as soon as it is wetted.

It is important that the treatment beds should not remain in the drained condition for more than an hour. Treatment units not in use must remain flooded.

5.13 TREATMENT CHEMICALS SUPPLY

The operator should carefully monitor the consumption of liquid chemicals and reorder when necessary. He must have a method of determining the depth of liquid in the storage tank (e.g. dip stick) and equating that to the volume of liquid in the tank. Figure 5-4 illustrates a liquid depth versus volume curve for a 6,000 gallon horizontal cylindrical tank with dished head.

5.14 HOUSEKEEPING

The plant operator should wash down all equipment at least once per month. Floors should be swept daily. Bathroom and laboratory fixtures should be cleaned once per week. All light bulbs should be replaced immediately upon failure. Emergency shower and eyewash should be tested once per week. Any chemical spill should be neutralized and cleaned up immediately. Hardware should be polished once per month and lubricated per manufacturer's directions. Equipment should be repainted at least once every five years.

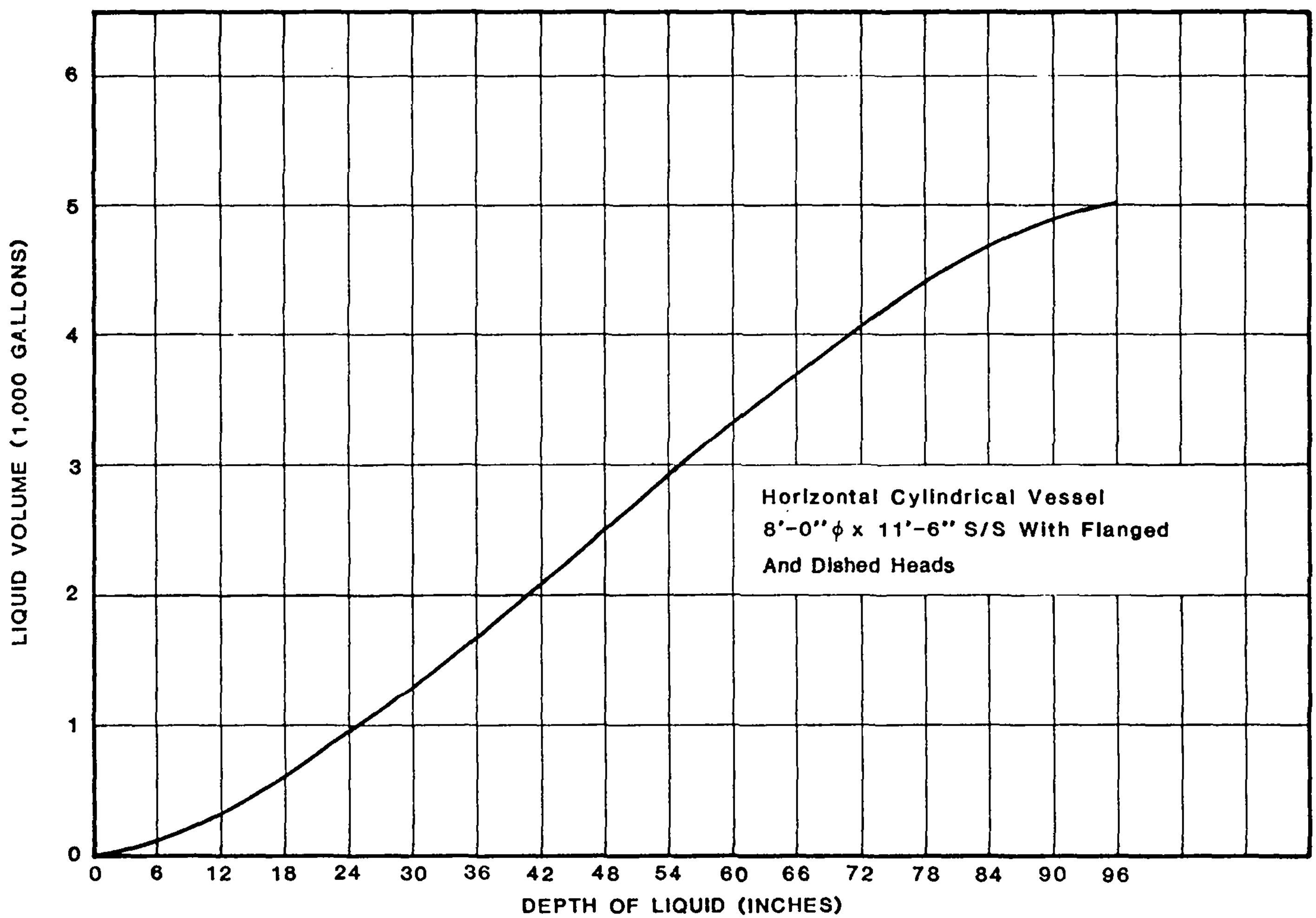


FIGURE 5-4 5,000 GALLON CHEMICAL STORAGE TANK-LIQUID VOLUME

CHAPTER 6

CENTRAL TREATMENT PLANT OPERATING COST

6.1 INTRODUCTION

The prime objectives in central treatment plant design are to provide the client with a low-capital cost installation that works efficiently and reliably; is simple to operate; and above all, is inexpensive to operate. Operating costs are normally passed directly onto the water user in the monthly water bill. These costs include the following:

1. Treatment chemical costs

2. Operating labor costs

3. Utility costs

4. Replacement treatment media costs

5. Replacement parts and miscellaneous materials costs

As the bill is normally based on metered water consumption, the costs for treatment are prorated on the unit of volume measurement. The units are usually 1,000 gallons, and occasionally 100 ft^3 (750 gallons). Some systems do not meter consumption; instead they charge a flat monthly rate based upon size of branch connection to the water main. Though this latter mode of distribution saves the cost of meters as well as the reading of meters, it does not promote water conservation. Therefore, far more water is pumped, treated and distributed, resulting in a net increase in operating cost. The accounting/billing methods are handled in many ways; that subject, however, is not addressed in this manual. The common denominator that applies to both the operating cost and the bill for water consumption is the unit of volume, 1,000 gallons. Each operating cost factor can be reduced to cost/1,000 gallons. Each of the above mentioned operating costs is discussed in the following sections. The sum total of the annual operating costs based upon total water production yields the cost per 1,000 gallons (the unit cost to be applied to the consumer's bill).

6.2 DISCUSSION OF OPERATING COSTS

Similar to capital cost, there are many variables that affect operating cost. Operator attitude is a key intangible which has an impact on the ultimate cost. The conscientious operator strives to improve plant performance and reduce operating cost. In contrast, the disinterested operator is not concerned with plant performance or cost. The following subsections delve into each of the operating costs previously listed.

6.2.1 Treatment Chemical Costs

The treatment chemicals discussed herein are limited to sulfuric acid and caustic soda. There are other acids and bases than can be substituted for those chemicals; but they are more costly which defeats a prime objective of this process. Other chemicals could also be used for special requirements such as: corrosion inhibition, precipitation of regeneration wastewater solids, dewatering of precipitated solids in wastewater, etc.; however, these are site specific requirements that are not covered in this manual.

Since these chemicals are being used in treatment of water for public consumption, it is recommended that samples of each chemical delivery be analyzed for chemical content. It is also recommended that the chemical supplier be required to certify that the containers used to store and deliver the chemicals have not been used for any other chemical; or if they have, that they have been decontaminated according to procedures required by the governing regulatory agency.

Chemical costs are variable. Like all commodities, they are sensitive to the supply and demand fluctuations of the marketplace. The geographic location of the treatment plant site in relation to that of the supplier has a major impact on the delivered cost. In many cases, the delivery costs are much greater than the cost of the chemical. The commodity price of each chemical can vary dramatically from one region of the country to another. The designer in his conceptual design must evaluate the chemical logistics and determine the most cost effective mode of procurement.

The chemistry of the raw water to be treated is the most significant factor affecting treatment chemical consumption and cost. Fluoride and alkalinity are the key ingredients in the raw water; the higher that each of these are, the higher the chemical cost.

6.2.1.1 Acid Cost

The most cost effective commercially available chemical available for lowering pH is concentrated sulfuric acid. The commercial designation is $66^{o}B'H_2SO_4$; its concentration is 93.14 percent. The remaining 6.86 percent is water (plus other constituents). The other chemicals that could be present must be evaluated. Frequently, these are small quantities of iron and trace amounts of heavy metals. For potable water service, there are stringent limits on the levels of contaminants in the acid which must and rigidly enforced.

The acid usually is a byproduct of the copper smelting process. Sulfide in the ore is oxidized to sulfur dioxide which is then converted to sulfuric acid. Some sulfuric acid supplies are only suitable for commercial applications; not potable water treatment. These are designated as "dirty acid". Reputable suppliers screen the chemicals when they are advised of the service requirements. Therefore, when placing an order for acid, "Potable Water Service" must be designated. The most economical method of procuring acid is in tank truck quantities (50,000 pounds) which are 3,200 gallons each. The tank trucks are loaded at the acid manufacturer's site and delivered directly to the treatment plant where it is transferred to the acid storage tank. Transfer is accomplished by means of compressed air which is provided by an air compressor on the truck. In addition to the lower commodity price resulting from minimum handling and storage of the chemical, there is minimum chance of contamination. At large treatment plants where there is potential for high acid consumption, rail tank car quantity (200,000 pounds) delivery, which is still cheaper, may be justified. Capital expenditure for a 16,000 gallon (minimum) storage tank and a rail spur with unloading equipment are then required.

The delivered cost of tank truck quantities of sulfuric acid presently ranges from $30-$125/ton depending on the geographic location of the treatment plant. Rail tank car delivered costs can provide savings ranging up to 40 percent.

The acid is consumed in two phases of the treatment process at every fluoride removal plant. First, it is used to adjust the raw water pH to the treatment requirement (5.5); secondly, it is used to rapidly neutralize the treatment bed immediately after regeneration. At some locations, it is also used to neutralize the high pH of regeneration wastewater for discharge to sewers or other receiving facilities. This latter application does not apply to treatment systems that discharge regeneration wastewater to lined evaporation ponds. The raw water alkalinity dictates the weight of acid required for the pH adjustment step. The activated alumina fluoride removal process has been employed on natural waters with alkalinities ranging from 10-1,500 mg/l.

The acid consumption for pH adjustment can be accurately projected by running a titration on a raw water sample. The cost of acid required for pH adjustment is then determined by extending the acid addition in mg/l to the weight (lbs.) required per 1,000 gallons and multiplying by the commercial rate for the acid.

The acid consumption for neutralization after regeneration is a function of the caustic concentration employed during regeneration and the raw water alkalinity. Once again, even though small, this quantity does vary considerably from site to site. The consumption is also a function of the raw water fluoride level which dictates the frequency of regeneration and the volume of water over which this cost is dispersed. The higher the fluoride level, the less gallons treated per regeneration. A rule of thumb to employ when projecting chemical costs and volumes is 10,000 gallons of treated water per cycle per ft^3 of treatment media with 6 mg/l raw water fluoride (this decreases to 4,000 gallons/ft^3 at 20 mg/l fluoride and increases to 16,000 gallons/ft^3 at 3 mg/l fluoride). This rule of thumb information is presented in Figure 6-1. The weight of acid required for neutralization after regeneration should be in the range of 1-2 lbs/ft^3 of treatment media.

The actual acid cost will normally fall in the range of $0.02 to $0.08 per 1,000 gallons of treated water.

6.2.1.1 Caustic Cost

Caustic soda (sodium hydroxide) can be procured in either solid (100 percent NaOH) or liquid (50 percent NaOH or lower). The 50 percent NaOH is the most practical concentration to obtain for water treatment applications. That concentration is a byproduct of the chlorine manufacturing process. Therefore, it requires minimum handling to place it into a 50,000 pound tank truck (4,000 gallons) or a 200,000 pound rail tank car. At plants where tank car delivery of caustic is feasible, a 20,000 gallon (minimum) storage tank is required. The main problem with the 50 percent NaOH concentration is that it freezes at $55^{o}F$; it is also very viscous at temperatures below $70^{o}F$. Therefore, it frequently requires heating. Also, since it is 50 percent water by weight, the freight is a major cost factor. Solid caustic in bead or flake form is also readily available in drums or bulk. Its freight cost is roughly half that of the liquid, but getting it into solution is difficult and dangerous. Regardless of the economics, solid caustic is not recommended for this application. Caustic in the 20 percent NaOH concentration which is commercially available has a freezing point of $-20^{o}F$; however, freight costs for shipping this material are very high (80 percent water). Capital cost for much larger storage and pumping requirements are also increased. Even though heating and temperature protection are required, the 50 percent NaOH is recommended. Transferring caustic from tank trucks to storage tanks is accomplished with compressed air similar to the method for acid.

The delivered cost of tank truck quantities of 50 percent NaOH presently ranges from $150-$350/ton depending on the geographic location of the treatment plant. Rail tank car delivered costs can provide savings up to 25 percent.

The caustic is consumed in two phases of the treatment process. First, it is used to raise the pH of the raw water to the level required for treatment media regeneration; secondly, it is used to raise the pH of the treated water back to the level desired for distribution. The latter phase may be replaced by aeration of the treated water to strip the free carbon dioxide. The volume of 50 percent NaOH required for a 1 percent NaOH concentration regeneration (includes upflow and downflow requirements) is 0.4 gallons (5 lbs.) per ft^3 per regeneration. As with the acid required for neutralization, the causti consumption is a function of the raw water fluoride level which dictates the

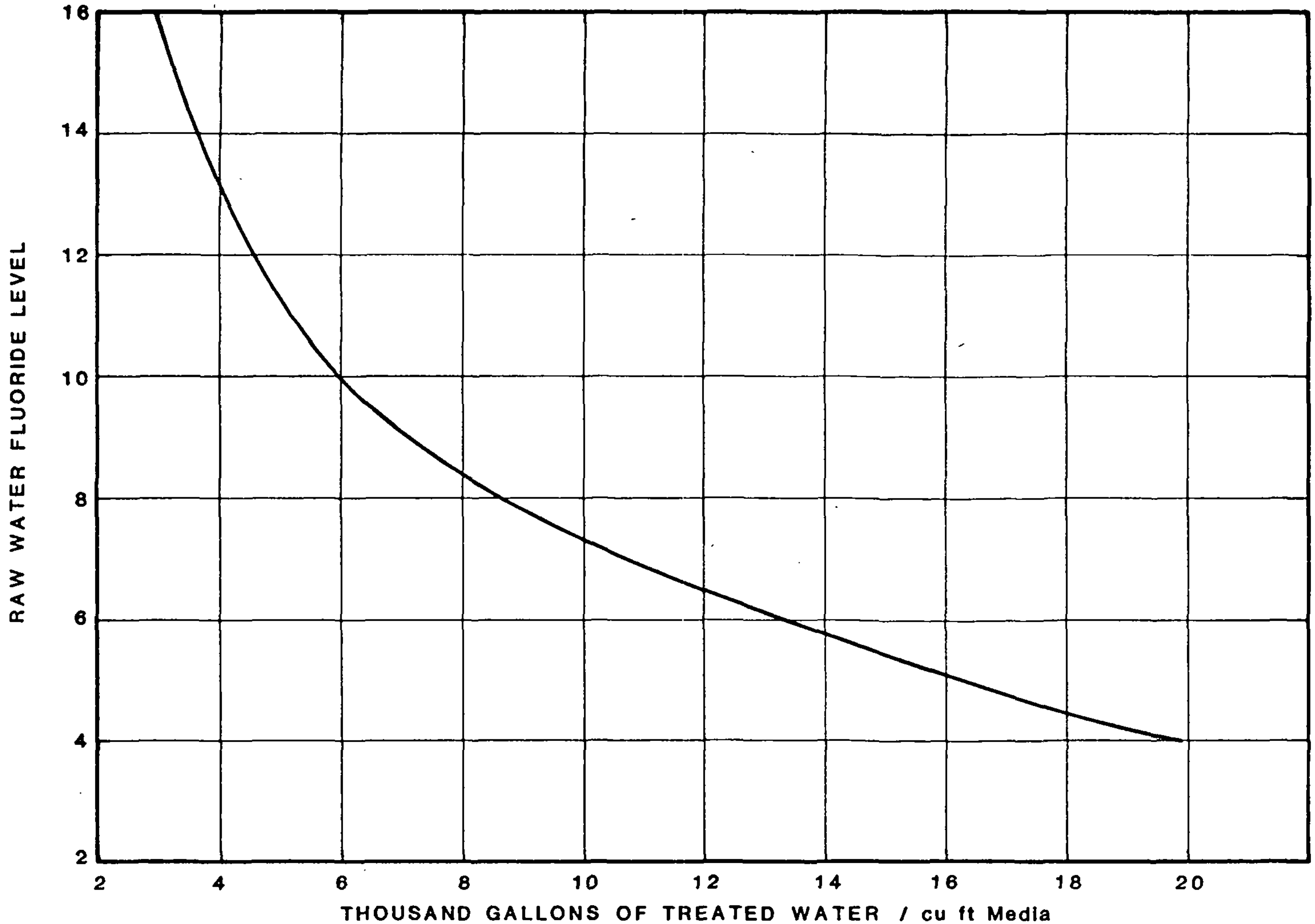


FIGURE 6-1 CURVE ILLUSTRATION RULE OF THUMB FOR VOLUME OF WATER TO BE TREATED PER CYCLE VS. RAW WATER FLUORIDE LEVEL

frequency of regeneration and the volume of water over which this cost is dispersed. This varies from site to site.

The caustic consumption for treated water pH adjustment is also a function of raw water alkalinity. The concentration of free CO_2 in the water after the initial pH adjustment with sulfuric acid will determine the caustic requirement. High CO_2 concentration (or community objection to addition of sodium to the water supply) could dictate the aeration method for pH adjustment. In general, when cost dictates the method, caustic pH adjustment is recommended when alkalinity is less than 100 mg/l and aeration is recommended when alkalinity is over 200 mg/l. In the alkalinity range 100-200 mg/l, a general recommendation is difficult; other factors such as storage tank elevation must be considered. If caustic is used to raise the pH of the treated water, the quantity will be small. The consumption requirement is again accurately determined by continuing the original titration required for acid to lower the pH to the treatment level of 5.5; then adding the 50 percent NaOH required to raise the pH to the desired level (7.5). The cost of caustic required is then determined by extending the caustic addition in mg/l to the weight required per 1,000 gallons and multiplying by the commercial rate for the caustic. The actual caustic cost will normally fall in the range of $0.02 to $0.12/1,000 gallons.

6.2.2 Operating Labor Costs

This area of operating labor cost is the most difficult to quantify. The operator is required to be dependable and competent. However, it is not a full time position, and the educational and experience requirements for this position does not dictate a high salaried position. It is impractical to establish this as a full-time position for a highly skilled operator. Depending on the size of the system and the other duties available for the operator, his time should be spread over several accounting categories. Except for days when regeneration takes place, the treatment plant requires 1-2 hours per day of operator attention. During regeneration, the operator is required to spend approximately 6-8 hours over a twelve hour period. On the routine operating days, he merely checks the system to see that pH is being controlled, takes and analyzes water samples, checks instrument (flow, temperature, pressure), and makes entries in daily logs. During the remainder of the time, he is able to operate and maintain other systems (distribution, pumps, storage, etc.), read meters or handle other municipal responsibilities (e.g. operate sewage treatment plant). The salary for a qualified individual for such a position will range from $12,000-$30,000 per year depending upon the size and economic conditions in the community. There should always be a second operator available to take over in case of an emergency, that is an individual well versed in the operation of the plant.

Using the example treatment plant presented in the design section, the cost of operational labor will be as follows: (it is assumed that the hours not used for treatment plant operation will be efficiently used on other duties).

Given

flow rate	=	600 gpm
annual average utilization	=	40%
number of regenerations per year	=	50
operator annual salary	=	$18,000
overhead and fringe benefits	=	30%
available man hours per year	=	2,000/man

Then:

number of hours on regeneration/year 50 x 8			400 hours
number of hours on routine operation/year (365-40)		=	472.5 hrs.
Total plant operator time			872.5 hrs.
Operator hourly rate - 18,000/2,000	-	$9.00/hr.	
30% (overhead and fringe benefits	-	$2.70/hr	
Operator Rate		$11.70/hr	

Total operator cost 872.5 hours x $11.70/hr. = $10,208

Total gallons water produced = .4(600 gpm) x 1440 min/day x 365 days/year = 126,144,000 gallons/year

Labor cost/1000 gallons $10,200/126,144 (1000 gallons) = $0.08/1000 gal

If the operator had no other responsibilities and his entire salary were expended against this treatment plant operation, the operating labor cost would become $0.18/1,000 gallons. As the reader can readily see, there are many variables which can be controlled in different ways. Depending on the motivation of the designer/planner/manager, the operating labor cost can be minimized or maximized over a very broad range. In the case of a very high production plant, the reader will see that the operating labor requirement is not significantly larger than that for a very small treatment plant. Therefore, depending on relative salaries, the resulting cost per 1,000 gallons can range from a few cents to a dollar. In proper perspective, the operating labor cost should always fall in the $0.03 to $0.10/1,000 gallon range.

6.2.3 Utility Cost

The utility cost is normally electric utility. However, there can also be telephone and natural gas (or oil). Telephone service to the treatment building is recommended as a safety precaution in case of accident as well as operator convenience. Cost for that service should be the minimum available monthly rate. Depending upon the local climate, the cost for heating can vary. The purpose of the building is to protect the equipment from elements (primarily freezing) not for operator comfort. Normally the treatment units act as heat sinks maintaining an insulated building at a temperature near that of the raw water. In cold climates, the building must have an auxiliary heat source to prevent freezing of pipes in the event that the water is not flowing. If the client determines that the treatment building is to serve additional functions, heating to a comfort temperature could be an additional required cost.

Electric power must be provided for the following functions:

1. chemical pumps
2. pH controls
3. caustic storage tank immersion heater
4. lighting
5. convenience receptacle
6. (optional) aeration unit blower
7. (optional) repressurization pump
8. extra load on well pump for regeneration/backwash wastewater, and loss of head through the treatment system

Items 1, 2, 4 and 5 are negligible. Item 3 is a function of the climate and the heat losses through the insulation. The designer must incorporate provisions to conserve energy for this function. Item 6 is a relatively small load (1-2 HP blower motor). Item 7 is potentially the biggest electrical load. This requirement only exists when aeration is used to adjust treated water pH, and the water must be pumped to an elevated storage tank. This electrical load can be equal to the original well pump motor load. However, when repressurization is a requirement, then the original well pump should be modified to reduce its discharge pressure capability to only that which is required to pump the raw water through treatment into the clearwell in lieu of the pressure to pump to the elevated storage tank. Then the net increase of electrical energy consumption is nearly negated. Item 8 amounts to 3-5 percent of the well pump electrical energy consumption.

The electrical utility rate also varies considerably from one geographic location to another. In, March 1983 rates vary from $0.03 to $0.12/KWH. The electrical utility cost will range from $0.005 to $0.02 per 1,000 gallons under normal conditions. Under abnormal conditions, it could be 5¢/1,000 gallons or higher.

6.2.4 <u>Replacement Treatment Media Cost</u>

The consumption of treatment media should be close to zero in a well cperated activated alumina fluoride removal water treatment plant. However, there are ways in which the media can be expended.

The most obvious loss of media occurs during backwash. Excessively long backwash periods will cause the granular particles to wear down and leave the bed. This is defined as attrition; it can be minimized. An excessive backwash rate can expand the treatment media out of the vessel resulting in a massive loss of media. Monitoring the backwash water will prevent that.

During regeneration and neutralization, excessively high and/or low pH exposure will attack the treatment media. If the pH of the regeneration solution exceeds 1.5 percent NaOH, the solution becomes increasingly aggressive to the activated alumina. Similarly, if the pH of the neutralization solution is lower than pH 2.0, a more drastic dissolving of the alumina takes place. Samples taken during the regeneration cycle should periodically be analyzed for aluminum.

A final way for the alumina to be lost is through the effluent underdrain (collection system) within the bed. If alumina grains ever appear in the treated effluent, the treatment unit should immediately be taken out of service for inspection (and repair) of the collection system.

Media replacement costs are extremely hard to predict. The only known instance of significant media replacement has occurred at a treatment plant where extensive backwash has been required to remove filtered solids from the media. The plant is also a high production plant requiring frequent extended backwashing.

A conservative bed replacement estimate is 10 percent per year. In our previous example where two 300 ft^3 beds are used, the media replacement will be:

$$.10(600\ ft^3) \times 50\ lb/ft^3 = 3,000\ lb/year$$

Assuming media cost to be $0.70/lb. (see Table 6-1 for current activated alumina costs), the annual cost will be $2,100.00/year and the cost per 1,000 gallons will be:

$2,100/126,144 (1,000 gallons) = $0.015/1,000 gallons

TABLE 6.1. PRICE FOR ALCOA F-1, 28-48 MESH ACTIVATED ALUMINA

Quantity	Price*
2,000-10,000 lbs.	$0.697/lb.
12,000-20,000 lbs.	0.594/lb.
22,000-38,000 lbs.	0.548/lb.
40,000 lbs. and over	0.516/lb.

* 100 pound bags, 2,000 pounds/pallet, FOB Bauxite, Arkansas

The projected cost for treatment media replacement is $0.005 to $0.03 per 1,000 gallons of treated water.

6.2.5 Replacement Parts and Miscellaneous Material Costs

This is a very small operational cost item. Replacement parts (e.g., chemical, pump diaphragms, seals and replacement pump heads) should must be kept in stock in the treatment plant, to prevent extended plant shut down in the event a part is required. Also included are consumables such as laboratory reagents (and glassware), record keeping supplies, etc. An operative allowance of $0.01/1,000 gallons of treated water is conservative.

6.3 OPERATING COST SUMMARY

The range of fluoride removal water treatment plant operating costs discussed above are summarized in Table 6.2. As has been pointed out, the range of costs is very broad.

TABLE 6.2. Operating Cost Tabulation

Operating cost items	Dollars/1000 gallons treated water min. $	max. $	average
Treatment Chemicals - acid	0.02	0.08	0.05
- caustic	0.02	0.12	0.05
Operating labor	0.03	0.10	0.06
Utility	0.005	0.05	0.01
Replacement Treatment Media	0.005	0.03	0.02
Replacement Part & Misc. Material	0.05	0.1	0.01
TOTAL	0.085	0.39	0.20

The designer and treatment plant operator are the keys to continued improvement in plant performance and reduction in operating costs. Their close liaison is necessary to achieve and maintain minimum operating cost performance.

APPENDIX A

SUMMARY OF SUBSYSTEMS INCLUDING COMPONENTS

The items that are designated as "optional" are not mandatory requirements. Some of those items may already be included in systems other than treatment and therefore, would be redundant. Other items, though desirable, are not mandatory. And, finally as in the case of backwash water and regeneration wastewater disposal, only one of the optional methods would be used.

For Schematic Flow Diagram, see Figure A-1.

1) Raw Water Influent Main (manifold)
   a) Flow control (optional)
   b) Flow measurement (optional)
   c) Temperature indicator (optional)
   d) Pressure indicator (optional)
   e) Pressure control (optional)
   f) Pressure relief (optional)
   g) Backflow preventer (optional)
   h) Sample piped to sample panel (optional)
   i) Isolation valve

2) Treated water effluent main (manifold)
   a) Caustic injection for pH adjustment (optional)
   b) pH measurement, indicator, alarm and fail-safe control
   c) Sample (after pH adjustment) piped to sample panel
   d) Pressure indicator (optional)
   e) Flow rate indicator (optional)
   f) Flow totalization (optional)
   g) Aeration subsystem (optional)
      i) Air blower (optional)
      ii) Clearwell (optional)
   h) Booster or repressurization pump (optional)
   i) Disinfection injection (optional)
   j) Isolation valve

3) Wastewater discharge main (manifold)
   a) Backflow preventer
   b) Process isolation valves

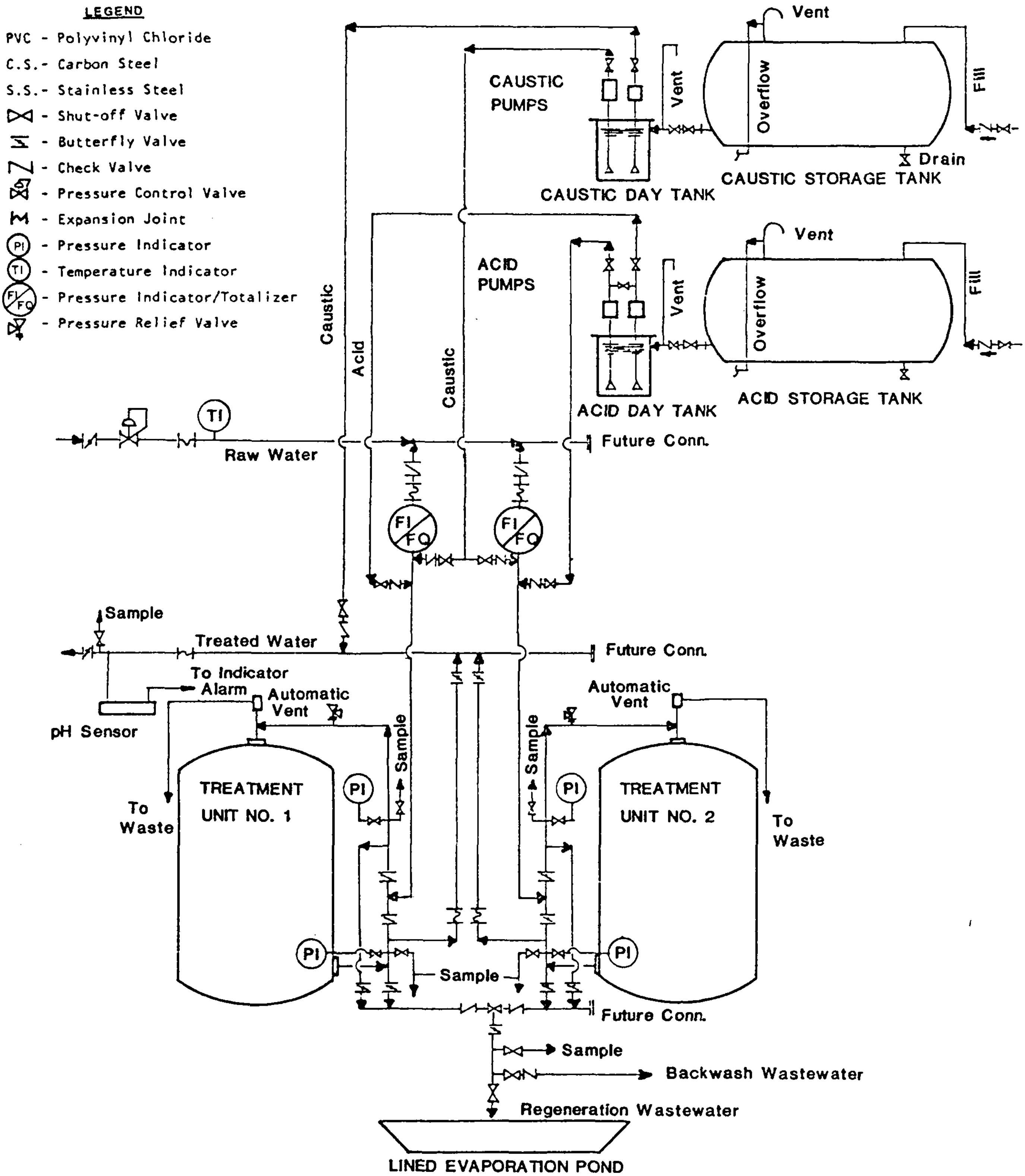


FIGURE A-1 SCHEMATIC FLOW DIAGRAM

c) Acid injection for pH adjustment (optional)
d) Coagulation chemical injection (optional)
c) Sample (after chemical injection) piped to sample panel

4) Treatment Unit Branch Piping
   a) Isolation valves (influent and effluent)
   b) Process control valves (manual or automatic)
   c) Acid injection (lower pH for treatment)
   d) Caustic injection (raise pH for regeneration)
   e) Pressure indicator (influent and effluent)
   f) Flow rate indicator
   g) Flow totalization
   h) Sample (influent after pH adjustment and effluent) piped to sample panel
   i) Connections to influent, effluent and wastewater discharge manifolds
   j) Pressure relief (optional)
   k) Air/vacuum valve

5) Treatment Unit
   a) Pressure vessel
   b) Treatment media
   c) Internal distribution and collection piping
   d) Operating platform and/or ladder (optional)

6) Sample Panel
   a) Manifolds
      i) Influent manifold (influent main sample and raw water samples from each treatment vessel after pH adjustment)
      ii) effluent manifold (effluent main sample after pH adjustment, treated water samples from each treatment vessel and wastewater manifold sample after pH adjustment and chemical injection)
      iii) pH indicator (influent sample manifold and effluent sample manifold)
      iv) sample collection spigots with drain
   b) Wet chemistry lab bench with equipment, glassware, reagents, etc.

7) Acid Storage and Feed Subsystem
   a) Emergency shower and eye wash
   b) Acid storage tank (outside treatment building)
      i) fill, discharge, drain, vent, and overflow piping
      ii) liquid level sensor (optional)
      iii) Desiccant air dryer in vent (optional)
      iv) weather protection (optional)
      v) diked containment area (optional)
   c) Acid day tank (inside treatment building)
      i) fill pipe float valve
      ii) drain valve
      iii) curbed containment area (optional)

d) Acid pumps
   i) treatment unit pH adjustment (one pump for each unit)
   ii) wastewater pH adjustment (optional)

e) Acid piping (interconnecting piping)
   i) between storage tank and day tank
   ii) between feed pumps and injection points
   iii) between feed pump and wastewater main injection point (optional)

   iv) backflow prevention

8) Caustic Storage and Feed Subsystem
   a) Emergency shower and eye wash
   b) Caustic storage tank (outside treatment building)
      i) fill, discharge, drain, vent, and overflow piping
      ii) liquid level sensor (optional)
      iii) immersion heater with temperature control
      iv) weather protection (optional)
      v) diked containment area (optional)
   c) Caustic day tank (inside treatment building)
      i) fill line float valve
      ii) drain valve
      iii) curbed containment area (optional)
   d) Caustic piping (interconnecting piping)
      i) between storage tank and day tank
      ii) between regeneration feed pump and injection points in treatment and branch piping
      iii) between feed pump and treated effluent main injection point (optional)
      iv) backflow prevention

9) Non-toxic Backwash Water Disposal System
   a) Surge tank (optional)
   b) Lined evaporation pond (optional)
   c) Unlined evaporation pond (optional)
   d) Sewer (optional)
   e) Drainage ditch (optional)
   f) Other discharge method (optional)

10) Toxic Regeneration Wastewater Disposal System
   a) Surge tank (optional)
   b) Lined evaporation pond (optional)
   c) Wastewater reclamation system (optional)
   d) Other discharge method (optional)

Appendix B

Treatment System Design Example

Given: g (flow rate) = 600 gpm
N (number of treatment vessels) = 2
Raw water fluoride level = 5.0 mg/l
Treated water fluoride level =1.0 mg/l
Treatment media fluoride removal capacity = 2,000 grains/ft^3
Pipe material - Type I schedule 40 PVC,
v pipe velocity = 5'/sec. (max.)
for higher velocities shock preventers are required to eliminate water hammer
P (Pressure) = 50 psig (max.)
T_a (Ambient temperature) = 95^oF (max.)
T_w (Water temperature) - 85^oF (max.)

I Vessel and Treatment Bed Design

Solve for: h (Treatment bed depth)
d (Treatment bed diameter)
V (Treatment bed volume)
N.Mw (Total weight of treatment media)
D (Vessel outside diameter)
H (Vessel overall height)

Reference: Figure 3-4

First, q/N = 600 gpm/2 treatment beds = 300 gpm/treatment bed
Then, using one ft^3 treatment media per gpm treatment flow we require 300 ft^3 treatment media per treatment bed or, V = 300 ft^3 = $\pi d^2 h/4$
Then, try h = 5'-0"
Then, d^2 = 4V = 4 x 300 ft^3/(5 ft) x π = 240 ft^2/π
Then, d = 8'-9", D must employ the next even multiple of 6" or D = 9'-0" > 8'-9"
Then, d = D-(1") = 9'-0" - (1") = 8'-11" > 5'-0" OK
Then, h = 5'-0" and d_H = 24" (standard dished head)
Then, V = $\pi d^2 h/4$ = π (8.92')$^2/\pi$ = (5')/4 = 312 ft^3
Then, N.Mw = N.V.Md = 2 x 312 ft^3 x (50 lb./ft^3) = 31,200 lb
Then, H = 1" + 2 (d_H) + (h/2) + (6") = 1" + 2(24") + 60" + 30" = 6" = 12'-1"

II Pipe Sizing

Solve for: A) Sizes of raw and treated water pipe mains
B) Sizes of treatment unit branch piping

A) Mains: $q = 600$ gpm
Try 6", v = 6.8'/sec. > 5'/sec., therefore NG
Try 8", v = 3.9'/sec. > 5'/sec., therefore OK
Use 8" schedule 40 PVC

B) Branches $q_B = q/2 = 300$ gpm
Try 4", v = 7.7'/sec. > 5'/sec., therefore NG
Try 6", v = 3.4'/sec. > 5'/sec., therefore OK
Use 6" schedule 40 PVC

Note: During backwash of one treatment bed the flow rate can increase up to 600 gpm. Backwash rate is not to exceed rate required for 50 percent treatment bed expansion. This rate is sensitive to raw water temperature. Lab bench tests determined that 9.5 gpm/ft backwash flow rate with water at 104°F expanded the specified bed material 50 percent. Since bed expansion will increase as water temperature decreases, an 8 gpm/ft^2 backwash rate for the 95°F water used in this example will expand the bed material 50 percent.

III Acid System Design

A) Storage Tank Size

Storage tank size is based upon logistical requirements which are a function of treatment plant acid consumption rate and tank truck deliveries of bulk acid. The tank truck can deliver up to 50,000 lbs. of 66° B' H_2SO_4. The density of this liquid is 15.5 lbs/gallon. Therefore, a delivery contains 3,250 gallons.

In this example the peak treatment flow is 600 gpm, and we shall assume that the acid consumption is 0.10 gallons/1,000 gallons treated water (an above average acid requirement). Then the acid consumption is 3.6 gallons/hour, and a tank truck load would supply a minimum of 900 hours of treatment operation. Acid consumption for raw water pH reduction, which is a function of total alkalinity and free carbon dioxide, is discussed in Appendix C.

A 5,000 gallon storage tank provides capacity for 1½ bulk tank truck loads of 66° B' H_2SO_4. Therefore, when half a truckload is consumed, there is a minimum of a 450 hour (18.75 day) acid storage available before the acid supply is expended. In practice it would probably be at least two times that minimum. At any rate, the 5,000 gallon storage capacity will easily maintain operation while awaiting delivery.

B) Day Tank Size

The storage tank supplies a polypropylene day tank located inside of the treatment building. A 100 gallon day tank will satisfy acid requirements for 1,000,000 gallons of treated water which exceeds the treatment flow for one day.

C) Acid Pump Size

The maximum acid feed rate required. for the treatment mode feed rate for each pump is: 300 gpm x 60 min/hr x 0.10 gallons acid/1,000 gallons water = 1.8 gph

The acid feed rate must be increased during the neutralization mode (see Section 5.6) to adjust raw water pH to 2.5. Positive displacement diaphragm type metering pumps with materials of construction suitable for 66 $^{\circ}$B' H_2SO_4 service rated at 5.0 gph and a 10:1 turndown rate are suitable for acid feed to the mixing tee where dilution takes place in the influent branch to each vessel.

IV Caustic System Design

A) Storage Tank Size

Given: Raw water fluoride - 5.0 mg/l
Treated water fluoride - 1.0 mg/l
Treatment media Fluoride capacity - 2,000 grains/ft^3
Density of 50 percent NaOH-12.6 lb/gal

Find: Frequency of Regeneration

Amount of fluoride removed = 5.0 - 1.0 = 4.0 mg/l

Converting mg/l to grains/gal multiply by .058 = (4.0) x (.058) = 0.23 grains/gal

Quantity of water treated/treatment run = 2,000 grains/ft^3 x 312 ft^3/0.23 grains/gal = 2,700,000 gal

During maximum treatment flow continuous operation minimum regeneration frequency would be six days per bed. Using the two bed system in this example, the maximum regeneration frequency could be as often as once every three days. The amount of 50 percent caustic soda required per regeneration is as follows: Weight of regeneration solution = 2 x (15 gallons 1 percent NaOH/ft^3 bed) x (312 ft^3 bed) x (8.4 lb/gal) = 78,600 lb

Weight of 50 percent NaOH/regeneration = 1,572/lbs = Volume of 50 percent NaOH/regeneration = 1,572 lbs/(12.6 lbs/gal) = 125 gallons

A tank truck 50 percent NaOH delivery contains 50,000 lbs or approximately 4,000 gallons, enough to supply 32 regenerations (neglecting caustic feed requirements for neutralization of treated water).

For sizing of the caustic storage tank in the example, we are using a 50 percent NaOH feed rate of .02 gallons/1,000 gallons of treated water. This requires 50 percent NaOH feed rate of 0.72 gph (or 17 gpd). When adding this maximum caustic feed rate for neutralization to the maximum required for regeneration (17 gpd + 125/3 days) = 76 gpd, if we employ a 5,000 gallon storage tank identical to that used for acid storage in this example, we find that a 40,000 gallon delivery allows a 1,000 gallon maximum supply in storage at time of delivery. The 1,000 gallons will supply the treatment plant for a minimum of 13 days during periods of maximum caustic consumption, which is adequate. Therefore, the 5,000 gallon caustic storage tank can be used.

In cases where the raw water fluoride is higher and/or the treatment flow rate is higher, the rate of caustic consumption will require larger storage capacity.

B) Day Tank Size

The tank a polypropylene day tank located inside of the treatment building. A 100 gallon day tank will satisfy caustic requirements for one of the two phases of the regeneration. This size day tank will require refilling during the upflow rinse after the upflow regeneration. A 150 gallon day tank will satisfy the entire regeneration plus the caustic required for neutralization of the treated water. Therefore, use the 150 gallon day tank.

C) Caustic Pump Sizing

A positive displacement diaphragm caustic feed pump with materials of construction suitable for 50 percent NaOH service, sized for a miximum flow of 2.5 gph with a 10:1 turndown ratio, will be satisfactory for the treated water neutralization caustic feed requirement (0.72 gph).

For the neutralization step a 2 gpm metering pump with materials of construction suitable for 50 percent NaOH service is satisfactory. Each regeneration step (upflow and then downflow) requires 62.5 gallons of 50 percent NaOH to be fed into the mixing tee where it is diluted to 1 percent NaOH. Each regeneration step is designed to last between 30 and 35 minutes.

V Lined Regeneration Wastewater Disposal Evaporation Pond Design

A) Assumptions:

1) Average treatment plant average utilization = 40 percent

2) Annual average net evaporation (less rainfall) rate = 6'- 0"

B) Find: Evaporation pond size

Total annual volume of water treated = 40 percent (600 gpm) = 240 gpm (240 gpm) (1,440 min/day) (365 days/year) = 126 x 10^6 gpy
Number of regenerations: 126 x 10^6 gpy treated water/(2.7 x 10^6 gal/regeneration) = 47 regenerations/year

Experience dictates that 300 gallons of wastewater per cubic foot of treatment media are produced per regeneration. Therefore, each regeneration yields 312 ft^3 x 300 gal/ft^3 = 93,600 gallons of wastewater.

The total wastewater produced per year is: (93,600 gallons/regeneration) x (47 regenerations year) = 4.4 x 10^6 gallons/year = 586,000 ft^3/year.
Using an average annual net evaporation of 6'-0" and deducting 1'-0" for deviation from average we have (6'-0")-(1'-0") = 5'-0" net minimum evaporation rate per year.

To determine the required pond areas we divide the total annual wastewater produced by the net evaporation.

Pond Area = 586,000 ft^3/5 ft = 117,200 ft^2

Pond Depth to be 8' (minimum)

APPENDIX C

DISCUSSION OF ACID CONSUMPTION REQUIREMENTS FOR pH ADJUSTMENT OF RAW WATER

The practical method described in the text which is used to determine the acid feed requirement for lowering the raw water pH to 5.5 is acid titration. However, this can also be accomplished theoretically when a raw water analysis is available and raw water samples are not. This method requires the pH, the total alkalinity (M as ppm $CaCO_3$), and/or the free carbon dioxide CO_2 as ppm) from the raw water analysis in addition to the graph illustrated in Figure C-1. If only two of the three raw water analysis items are available, the third is determined by the graph. The pH curves illustrated in Figure C-1 were developed from theoretical chemical formulae which integrate the relationship between pH, alkalinity and free CO_2. This theory is beyond the scope of this manual. Trial and error usage of these curves rapidly leads the designer to the acid feed requirement for the desired pH adjustment. The objective is to determine the amount of alkalinity reduction that is required to lower the pH the desired amount, and then to convert the alkalinity reduction to acid addition. The designer must be aware of the fact that the reduction in alkalinity coincides with the corresponding increase in free carbon dioxide. The following examples best illustrate this method:

Example 1:

Given: Raw Water pH = 8.0
Raw Water M = 220 ppm as $CaCO_3$
Raw Water CO_2= 4 ppm

Find: a) M and free CO_2 for pH adjusted to 5.5
b) $66^{\circ}B'$ H_2SO_4 required feed rate to adjust pH to 5.5

a) Try reducing M by 200 ppm (as $CaCO_3$) to 20 ppm (as $CaCO_3$).

Then, increase in free CO_2 (M multiplied by 0.88), 200 x 0.88 = 176 ppm

Then, total free CO_2 = 176 + 4 = 180 ppm

Then, using graph we find that the pH is 5.4 when:

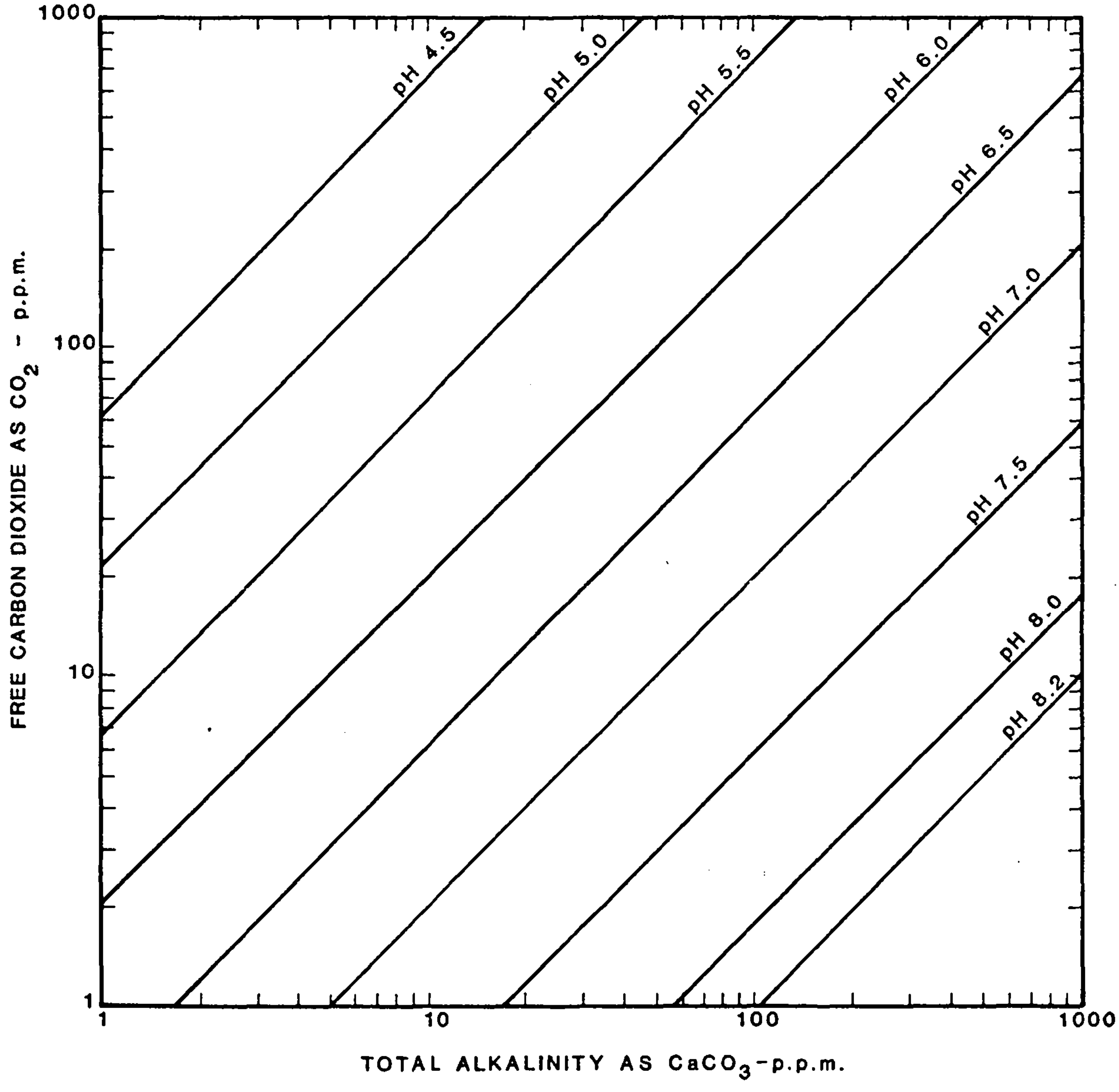


FIGURE C-1 GRAPH OF pH AS A FUNCTION OF TOTAL ALKALINITY AND FREE CARBON DIOXIDE

1) $M = 20$ ppm (as $CaCO_3$)

2) $CO_2 = 180$ ppm   Therefore, NG

Therefore, too much alkalinity was removed. Try reducing M by 196 ppm (as $CaCO_3$) to 24 ppm (as $CaCO_3$)

Then, increase in free $Co_2 = 196 \times 0.88 = 172.5$

Then, total free $CO_2 = 172.5 + 4 = 176.5$ ppm

Then, using graph we find that the adjusted raw water pH is 5.5 when:

1) $M = 24$ ppm $CaCO_3$

2) $CO_2 = 176.5$ ppm   Therefore, OK

b) For each 100 ppm (as $CaCO_3$) reduction of total alkalinity, 105 ppm $66^oB'$ sulfuric acid must be added. Therefore, reduce M by 196 ppm (as $CaCO_3$) by feeding 1.96×105 ppm = 205.8 ppm $66^oB'$ sulfuric acid to adjust raw water pH to 5.5. If we desire to find what acid feed rate would be required per thousand gallons of treated water, we find that:

$$\text{Feed rate} = (205.8 \times 10^{-6}\text{ppm}) \times (1{,}000 \text{ gal} \times 8.34 \text{ lb/gal})/(15.5 \text{ lb/gal}) = 0.11 \text{ gal } H_2SO_4/1{,}000 \text{ gal water}$$

Example 2:

Given: Raw Water M - 100 ppm (as $CaCO_3$)
Free CO_2 = 6 ppm

Find:
a) Raw Water pH
b) M and free CO_2 for pH adjusted to 5.5
c) $66^oB'$ H_2SO_4 required feed rate to adjust pH to 5.5

a) From graph we find raw water pH to be 7.5

b) Try reducing M by 80 ppm (as $CaCO_3$) to 20 ppm (as $CaCO_3$)

Then, increase in free $CO_2 = 80 \times 0.88 = 70.4$ ppm

Then, total free $CO_2 = 70.4 + 6 = 76.4$ ppm

Then, using the graph we find the adjusted pH to be 5.75 when:

1) $M = 20$ ppm (as $CaCO_3$)

2) CO_2 = 76.4 ppm Therefore, NG

Therefore, too little alkalinity was removed, try reducing M by 87 ppm (as $CaCO_3$) to 13 ppm (as $CaCO_3$).

Then, increase in free CO_2 = 76.5 + 6 = 82.5 ppm

Then, using the graph we find the adjusted pH to be 5.55 when:

1) M = 13 ppm (as $CaCO_3$)

2) CO_2 = 82.5 ppm Therefore, NG

Therefore, too little alkalinity was removed, try reducing M by 88 ppm (as $CaCO_3$) to 12 ppm (as $CaCO_3$)

Then, increase in free CO_2 = 88 x 0.88 = 77.5 ppm

Then, total free CO_2 = 77.5 + 6 = 83.5 ppm

Then, using the graph we find the adjusted <u>raw water pH to be 5.5</u> when:

1) <u>M = 12 ppm (as $CaCO_3$)</u>

2) <u>CO_2 = 83.5 ppm</u> <u>Therefore, OK</u>

c) Therefore, reduce M by 88 ppm (as $CaCO_3$) by feeding 0.88 x 105 = <u>92.4 ppm 66$^{\underline{o}}$B' sulfuric acid to adjust raw water pH to 5.5</u>

Acid feed rate = (92.4 x 10^{-6}ppm) x (1,000 gal x 8.34 lb/gal)/(15.5 lb/gal) = 0.05 gal H_2SO_4/1,000 gal water

APPENDIX D

TABULATIONS OF CAPITAL COST BREAKDOWNS FOR CENTRAL FLUORIDE REMOVAL WATER TREATMENT PLANTS BASED UPON FLOW RATE

TABLE D-1. TABULATION OF ESTIMATED CAPITAL COST* OF FLUORIDE REMOVAL CENTRAL WATER TREATMENT PLANTS BASED UPON TREATMENT FLOW RATE IN DOLLARS ROUNDED OFF TO THE NEAREST THOUSAND (Multiply by $1,000)

Treatment Flow Rate (gpm)	100	200	300	400	600	800	1000	1200	1400	1600	1800	2000
Process Equipment												
Treatment Vessels	14	16	21	25	33	40	45	50	60	70	80	90
Treatment Media	4	8	11	14	21	27	34	41	48	54	60	66
Process Piping, etc.	10	12	14	16	16	17	18	20	22	25	28	32
Instrument and Controls	6	6	7	7	8	9	9	9	10	12	12	14
Chemical Storage Tanks	10	10	21	21	21	25	25	25	27	27	27	27
Chemical Pumps, Piping, etc.	5	5	6	6	6	7	7	8	9	10	11	12
Subtotal	49	57	80	89	105	125	138	153	176	198	218	241
Process Equipment Installation												
Mechanical	25	27	30	33	36	39	43	48	54	60	65	70
Electrical	3	4	6	7	7	7	8	8	8	9	10	11
Painting and Miscellaneous	3	3	3	4	5	5	7	9	12	15	18	21
Subtotal	31	34	39	44	48	51	58	65	74	84	93	102
Misc. Installed Items												
Wastewater Pond	28	48	71	93	138	180	225	265	310	350	385	420
Building and Concrete	20	24	24	28	28	28	36	36	45	45	55	55
Site Work and Miscellaneous	8	8	9	10	11	12	14	16	19	22	25	28
Subtotal	56	80	104	131	177	220	275	317	374	417	465	503
Contingency 5%	7	9	11	13	17	20	23	27	31	35	39	42
Engineering Fees 10%	14	18	23	27	34	41	49	56	65	73	81	88
TOTAL	157	198	257	304	381	457	543	618	720	807	896	976

*March 1983 prices.

TABLE D-2. TABULATION OF ESTIMATED CAPITAL COST* OF MINIMUM FLUORIDE REMOVAL CENTRAL WATER TREATMENT PLANTS BASED UPON TREATMENT FLOW RATE IN DOLLARS ROUNDED OFF TO THE NEAREST THOUSAND (Multiply by $1,000)

Treatment Flow Rate (gpm)	100	200	300	400	600	800	1000	1200	1400	1600	1800	2000
Process Equipment												
Treatment Vessels	14	16	21	25	33	40	45	50	60	70	80	90
Treatment Media	4	8	11	14	21	27	34	41	48	54	60	66
Process Piping, etc.	10	12	14	16	16	17	18	20	22	25	28	32
Instrument and Controls	6	6	7	7	8	9	9	9	10	12	12	14
Chemical Storage Tanks	--	--	--	--	--	--	--	--	--	--	--	--
Chemical Pumps, Piping, etc.	5	5	6	6	6	7	7	8	9	10	11	12
Subtotal	39	47	59	68	84	100	113	128	149	171	191	214
Process Equipment Installation												
Mechanical	20	22	25	28	30	35	42	47	55	58	63	68
Electrical	2	3	4	5	5	5	5	6	6	7	8	9
Painting and Miscellaneous	3	3	3	3	4	4	4	5	6	7	9	11
Subtotal	25	28	32	36	39	44	51	58	67	72	80	88
Misc. Installed Items												
Wastewater Pond	--	--	--	--	--	--	--	--	--	--	--	--
Building and Concrete	2	2	3	3	3	4	4	5	5	5	6	7
Site Work and Miscellaneous	--	--	--	--	--	--	--	--	--	--	--	--
Subtotal	2	2	3	3	3	4	4	5	5	5	6	7
Contingency 5%	4	4	5	5	6	7	9	10	11	13	14	16
Engineering Fees 10%	7	8	9	11	13	15	17	20	23	26	29	32
TOTAL	77	89	108	123	145	168	194	221	255	287	320	357

*March 1983 prices.

APPENDIX E

ENGLISH TO METRIC CONVERSION TABLE

English	Multiply by	Metric
Inches (in)	0.0254	meter (m)
in^2	0.000645	m^2
in^3	0.000016	m^3
Feet (ft)	0.03048	m
ft^2	0.0929	m^2
ft^3	0.0283	m^3
Gallon (gal)	0.2642	liters (l)
gal	0.0038	m^3
gal	0.0038	kiloliter (kl)
Grains (gr)	0.0649	gam (g)
gr/ft^3	2.2919	g/m^3
pounds (lb)	0.4545	kilograms (kg)
lb/in^2 (psi)	0.00689	megapascals (MP)
lb/ft^2 (psf)	4.8922	kg/m^2
¢/1000 gal	0.2642	¢/1000 liters

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