OPTIMIZATION OF THE COAGULATION PROCESS AT THE CARVINS COVE WATER TREATMENT PLANT

by

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I. INTRODUCTION

An adequate supply of good quality water is an essential ingredient to both good public health and economic prosperity. Such a quality of water is seldomly available naturally and must be produced. Protection of the public health requires that the water be free of both toxic chemicals and microorganisms capable of causing disease. A desirable water supply requires that the final product shall be as low as possible in color, turbidity, and suspended solids, as cold as possible, and free from undesirable tastes and odors. The protection of property from staining and corrosion must also be addressed by those who supply the public with water. The reduced useful life span of waterworks appurtenances due to the corrosion action of a water has important economic consequences.

The proper design of a water treatment facility must address the nature of the raw water available and the purposes that the finished water will be used. A good design will reliably achieve each objective as economically as possible. The treatment processes that have historically been available include aeration, coagulation (usually with iron or aluminum salts), flocculation, sedimentation, filtration, and disinfection. Past practice has been to provide a separate unit for each treatment process. More recently, the practice of direct filtration with the use of synthetic, organic polyelectrolytes has eliminated some of the separate treatment processes (4,17).

The work described herein was conducted on a laboratory scale basis at the Carvins Cove water treatment plant in Roanoke, Virginia, during June and July, 1979. The Carvins Cove plant was built in 1947 and supplies most of the water required by the city of Roanoke. The finished water from the plant is of high quality, but the coagulation (prefiltration) step in the plant is somewhat unconventional, in that alum is added to the raw water without rapid mixing and prior to aeration. It was therefore felt that the coagulation operations should be studies to determine if a better coagulated water could be produced. Hence, the purpose of this investigation was to study and optimize the performance of treatment operations through to the sedimentation step at the Carvins Cove water treatment plant.

Each of the prefiltration operations was evaluated in terms of its own contribution to producing a finished product of the desired quality. The evaluation was accomplished by arranging the unit processes in various configurations in which the use of a particular unit process, the point of chemical application, and the type of coagulating agent was varied. The performance of each treatment configuration were then compared to determine which system was best.

II. LITERATURE REVIEW

Carvins Cove Water Treatment Plant

Although about three-fourths of the public water supplied in the United States is desired from underground sources, these systems supply water to only about one-fourth of those people served by public systems. Most large cities are dependent on surface water supplies (13). This is true of the city of Roanoke, although groundwater does supplement the surface water supply.

Roanoke has three sources of water supply: Crystal Springs, Falling Creek, and Carvins Cove. Crystal Springs yields about four million gallons of spring water per day. Treatment is limited to the addition of chlorine and fluoride to the water. Falling Creek and the flow from the Beaver Dam reservoir are impounded in a second reservoir. Falling Creek water receives complete treatment, consisting of coagulation, flocculation, sedimentation, filtration, and disinfection. In this study, only water from Carvins Cove was used.

The Carvins Cove reservoir contains approximately 24.6 million cubic meters (6.5 billion gallons) of water. (10) The Carvins Cove water treatment plant, shown in Figure 1, can produce 68,130 cubic meters (18.0 million gallons) of water per day. Water flows from the concrete dam by gravity through a 0.91 meter (36-inch) diameter pipe to the aeration basin which is equipped with spray-nozzle aerators. The aeration process was origionally added for the purpose of oxidizing iron, to permit its precipitation in the sedimentation basins. Aluminum sulfate is added to the raw water just prior to aeration. Lime and chlorine are then added to the aerated water which flows to the flocculation basins. These basins provide a detention time of 41 minutes at a rated capacity of 68,130 m^3/day (18.0 mgd) and are equipped with horizontal paddle agitators. The flocculation basin effluent is then permitted to settle in rectangular clarifiers for 2.7 hours at a flow of 68,130 m^3/day. The settled water is then applied to the rapid sand filters which are operated at a filtration rate of 0.08 $m^3/min/m^2$ (2 gpm/ft^2). The filter effluent is then discharged to the clearwell where chlorine and fluoride are added to the finished water. The quantities and costs of the various chemicals used at the water plant are presented in Table 1. The amounts shown are the average for June and July of 1979, during which time the study was conducted. The raw water quality for this time period is presented in Table 2. Daily water quality data is

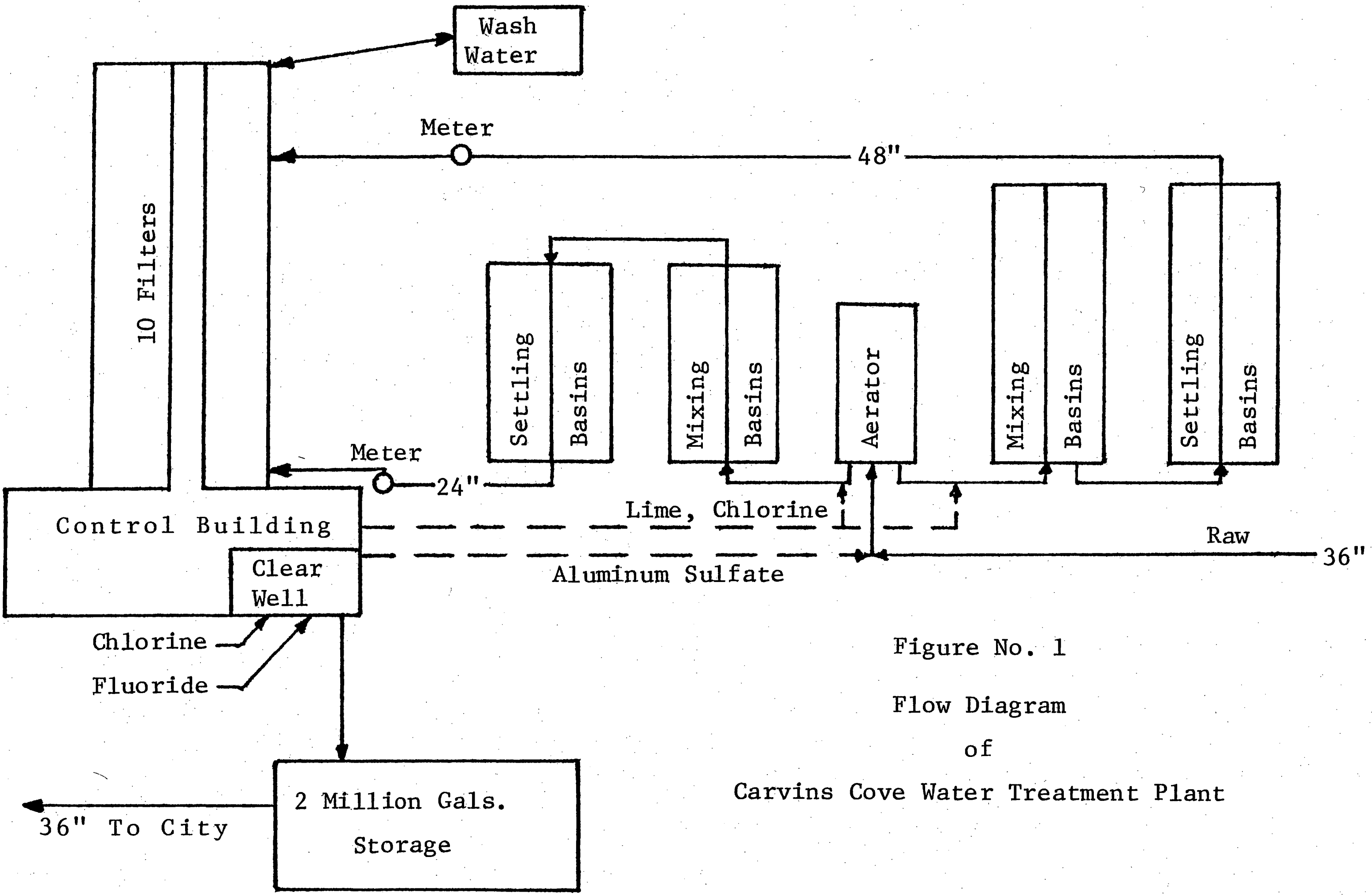

Figure No. 1 Flow Diagram of Carvins Cove Water Treatment Plant

Table 1

Chemicals Used At Carvins Cove Water Treatment Plant*

Name	Kilograms per thousand cubic meters of water treated	Cost per thousand cubic meters of water treated
Aluminum sulfate	9.1	$1.89
Lime	7.6	$0.47
Chlorine	2.9	$1.22
Fluoride	1.1	$0.39
Total	---	$3.97

*average amounts shown are for June and July, 1979.

Table 2

Average Values Of

Raw Water Quality At

Carvins Cove Water Treatment Plant*

Parameter	Amount
pH	7.2
Turbidity	3.1 NTU
Alkalinity	44 mg/l as $CaCO_3$
Temperature	18° C
Hardness - Calcium	38 mg/l as $CaCO_3$
Hardness - Total	54 mg/l as $CaCO_3$
Ferrous Iron	0.07 mg/l
Manganese	not detected
Color	10 APHA Units

*average amounts shown are for June and July, 1979.

available in Appendix A. The raw water was soft, lightly buffered and had a low turbidity level (average 3.1 NTU) during the time of this study.

Chemical Coagulation

The purpose of chemical coagulation is to condition particulates to encourage them to coalesce, thereby making them more easily removed by settling and granular filtration. When discussing the coagulation process, it is useful to distinguish between two separate and distinct steps: (a) Particle transport to bring about interparticle contacts, and (b) Particle destabilization to permit coalescence when contact occurs (19). Particle transport will be discussed later in this review of chemical coagulation. Prior to discussing particle destabilization, an understanding of the origin of particle charge and colloid stability is essential. Coagulation with aluminum (III), colloidal bridging, and aeration will also be discussed.

Origins Of Colloid Stability

The transport of the colloidal particles in an electric field is called electrophoresis (25). Colloids most commonly adopt a net charge by the process of isomorphous substitution, where the substitution of an aluminum species for silica in the clay lattice structure will result in a net negative charge.

Colloids may also adopt a net charge from the ionization of chemical groups or from the preferential adsorption of certain ions from the solution onto the colloid surface. Most colloids in water are hydrophilic (23) and develop a negative surface charge. An electric, double layer extends out from the colloid-liquid interface, consisting of the bound water layer and the diffuse layer. The stability of a colloid is a result of the repulsive electrical forces between the colloids. The zeta potential is a measure of the charge at the bound water layer. The amount of zeta potential is therefore an indication of the extent of particle stability that must be overcome to permit agglomeration of the particles.

Colloidal Destabilization

In an aqueous system, all hydrophilic colloids are subject to two opposing forces, namely stabilization by electrical forces, and destabilization by van der Waals forces. Destabilization of dispersed colloids is usually accomplished by reducing the potential energy resulting from electrostatic repulsion between the colloids (9). As coagulants are added to the water, counter ions are produced which destabilize a colloid by compressing the diffuse layer of charges that surrounds the particle (25,27). From the Gouy-Chapman model (18) for the distribution of ions in the diffuse layer, it is possible to calculate the electrical potential of the diffuse layer (6, 19). Stern later proposed an electrical double layer model that combined the Gouy-Chapman diffuse layer and the Helmholtz fixed layer (6). In the Stern-Guoy model, a surface layer of counter ions of the diffuse layer extend out into the bulk of the solution. As the diffuse layer is compressed, the repulsive charges between the colloids will be sufficiently reduced to permit van der Waals forces to cause coalescence of the colloids (21,25). Coagulation tends to occur slowly as the zeta potential increases to a range of -5 to -10mv (2) more rapidly as the zeta potential approaches zero. Aluminum sulfate is most commonly used for reduction of the repulsive charges between colloids. Long-chained, organic polyelectrolytes are also sometimes used and rely principally upon a bridging mechanism to cause agglomeration.

Coagulation With Aluminum (III)

The coagulation process incorporates reactions between: the colloid and coagulant, the colloid and the solvent (typically water), and the coagulant and the solvent. The impurities present in natural waters (including silica, proteins, color) may significantly affect reactions between particles and the coagulant, and thereby affect the flocculation mechanisms utilized during the treatment process. Coagulation with aluminum salts usually encompasses either adsorption of the soluble hydrolysis species of aluminum by a particle and subsequent colloidal destabilization, or the enmeshment of the colloidal suspension (sweep coagulation) by the precipitation of aluminum hydroxide.

Aluminum (III) salts may be used to destabilize colloidal particles. When metal cations are hydrated in water, a polymerization of the hydrolysis products occurs. Mattson (16) stated that it is primarily the hydrolysis products of the salts of aluminum, not the Al^{3+} ion, which are responsible for the electrical neutralization and flocculation of electronegative colloids. When a sufficient quantity of aluminum (III) salt is added to water, a hydroxo-alumino complex is formed. Brosset (5) suggested that $Al_6(OH)_{15}^{3+}$ (aqueous) as the most predominate species. However, Matijevic (15) and Stumm and morgan (23) found that the hydrolysis of aluminum is the pH range of 4 to 7 leads to the formation of a tetravalent aluminum complex. The most likely formula for the complex was postulated to be $Al_8(OH)_{20}^{4+}$. Several investigators have also reported that a wide variety of other chemical species are also important (24): $Al_2(OH)_2^{4+}$, $Al_2(OH)_5^{+}$, $Al_4(OH)_8^{4+}$, $Al_7(OH)_{17}^{4+}$, and $Al_{13}(OH)_{34}^{5+}$. These hydroxo-metal complexes are readily adsorbed at interfaces (14,27). Destabilization of colloidal dispersions can be accomplished by the soluble intermediates which are formed in the over-saturated solutions during the transition of the complexes to the precipitation of metal hydroxides (20,23). These hydrolysis products have a very strong destabilizing capability. Adsorption of these positive polymers can destabilize negatively charged colloids by charge neutralization (24,27), which may be measured as a reduction in zeta potential.

The rate of adsorption of the hydrolized aluminum species is a function of the pH, the coagulant concentration and the surface concentration of the solution (24). The pH of the solution will determine which of previously-mentioned hydrolysis products of aluminum will be most prelevant. During the hydrolysis reaction, the formation of various aluminum species results in the release of hydrogen ions into the solution. This increase in the hydrogen ion concentration is measured as a decrease in the pH of the solution. The alkalinity of the solution is therefore reduced by the addition of aluminum salts. Approximately 0.5 mg/l of alkalinity is destroyed for every 1.0 mg/l of aluminum sulfate added to the solution (27).

The surface area of the solids in the solution (usually indicated by measurement in terms of turbidity) will influence the amount of coagulant required to destabilize the solution. Various investigators (24) have found both direct and inverse relationships between coagulant concentration and the surface area of solids suspended in a water. When the coagulant dosage required is directly proportional to the surface area of the solids in the water, a stoichiometric relationship exists. When the coagulant dosage required and surface areas are independent of one another, a nonstoichiometric relationship exists.

Typical coagulation curve at a constant pH are presented in Figures 2 and 3 (24). These figures depict four different regions where coagulation is possible, either in terms of colloid concentration and coagulant dosage (Figure 2) or coagulant dosage and residual colloid concentration, or turbidity (Figure 3). Zone one depicts

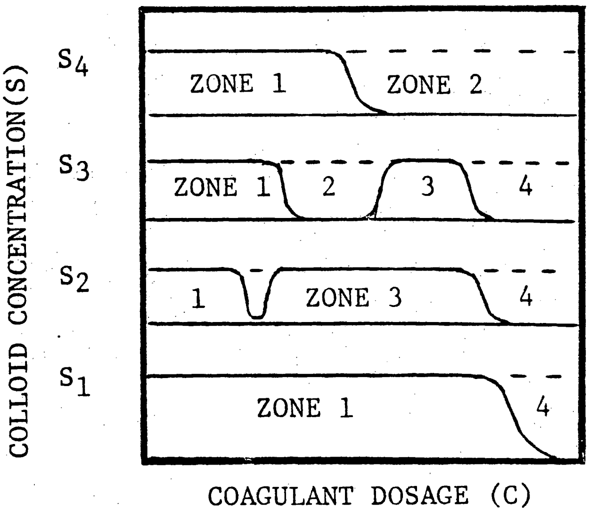

Figure 2: Regions of Aggregation of Colloidal Suspensions by Al(III) (adapted from 24)

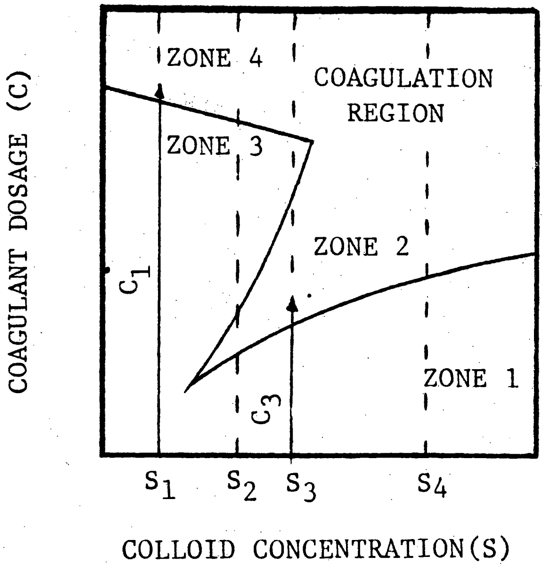

Figure 3: Regions of Aggregation of Colloidal Suspensions by Al(III) (adapted from 24)

the use of insufficient coagulant dosages to permit particle destabilization. In zone two, a stoichiometric relationship exists between the colloid concentration and the coagulant dosage where particle destabilization is obtained in the presence of higher colloid concentrations. Zone three indicates that with a further increase of the coagulant dosage, particle restablization and a corresponding increase in the colloid concentration (residual turbidity) occurs. In zone four, the solution is saturated with coagulant and the sweep coagulation mechanism is operative.

Figure 3 indicates that at low colloid concentrations high coagulant dosages will be required. Stumm and O'Melia (24) state that at low colloid concentrations an insufficient number of particles are present to provide the necessary contact opportunities within a reasonable time. The difficulty of coagulating cold, low turbidity surface waters is not uncommon to most water treatment plant operators. It is often necessary to add sufficient coagulant to operate in the sweep coagulation mode to form a settleable floc. An increase in particle surface area, which may be accomplished by adding colloids to the water, often permits the effective coagulation of low turbidity waters at lower coagulant dosages. Bentonite clay is often used to increase the turbidity of waters. This effect is graphically illustrated in Figure 2 as the colloid concentration is increased from zone four to zone two, where less coagulant is required.

Where sufficient alkalinity is present in the raw water to allow the aluminum sulfate to hydrolize, the addition of an alkali may be delayed. This delay would allow the various aluminum hydrolysis species to react at a lower pH, thereby encouraging the formation of more highly positive hydrolysis species (18). An alkali substance is often added to a water to replace the alkalinity destroyed by the hydrolysis of the aluminum salts and to make the water less corrosive. The addition of lime as an alkali in the flocculation process may also provide the increased particle surface area required for the coagulation of low turbidity waters. Lime is suggested as an alternative to soda ash for use as an alkali because it is less soluble, so the colloid concentration of the solution may be increased. Lime is also less expensive than soda ash. Final pH and alkalinity adjustment is normally practiced in the clearwell, following filtration.

The turbidity removal mechanism employed may be either coagulation by particle destabilization, sweep coagulation, or a combination of both. Coagulation practices of most water treatment plants lie within the region indicated as "AWWA Practice" in Figure 4. This zone defines a pH of the mixed solution varying from 5 to 8 and a alum dosage range of 10 mg/l to about 150 mg/l. Most surface water treatment plants in Virginia operate within this zone.

Colloidal Bridging

Particle destabilization using synthetic, long-chained, organic polyelectrolytes is not well characterized by the electric double layer model (19). La Mer and others (11,12,27) have developed a chemical bridging theory for the destabilization of colloidal dispersions using polymers. The chemical bridging model proposes that a polymer molecule can attach itself to the surface of the colloidal particle at one or more adsorption sites (6,19). The unattached portion of the polymer is then free to attach to another colloid in a similar manner. In this manner, a bridge is formed between the colloids, permitting agglomeration and eventual settling. The colloid may be restabilized by either excessive mixing or by an excessive polymer concentration (21).

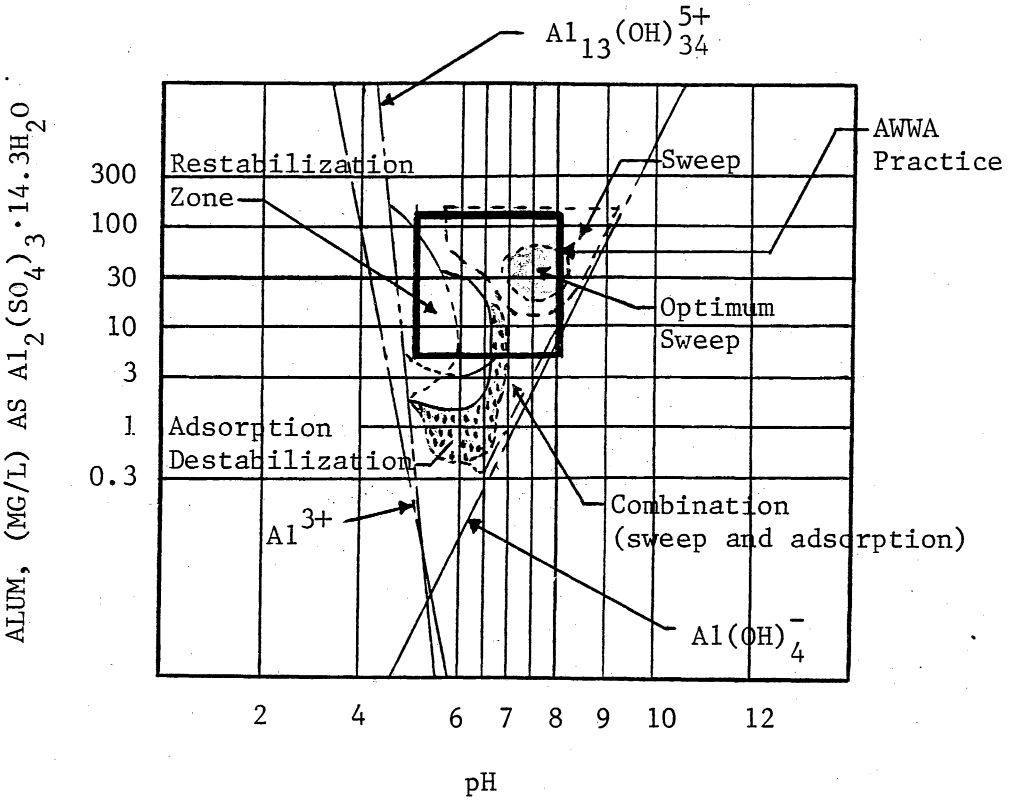

Figure 4: Coagulation Mechanisms of Al(III) Determined by Alum Dosage and pH (Adapted from 18)

This restabilization is due to the polymer wrapping about itself or occupying all of the available adsorption sites on a given colloid. The restabilized colloid does not necessarily have a reversed charge, as would likely be the case when using excess metallic salts.

Chemical reactions may also be responsible for polymer attachment to a colloidal surface. While electrostatic forces play a significant role in polymer-colloid attachment, adsorption of anionic polymers onto negatively charged colloids is not uncommon (3,11). The use of zeta potential as a coagulation control parameter for applying polymers is therefore questionable.

Particle Transport

A complete discussion of the kinetics of the coagulation process must include not only the hydrolysis reactions of the coagulant, but also consider the coagulation mechanisms involved.

Particle contact may be brought about by either Brownian motion (perikinetic flocculation) or fluid motion (orthokinetic flocculation) (19). Perikinetic flocculation has a very low velocity gradient (G) and depends upon the random motion of individual water molecules to cause colloidal collision. The rate of orthokinetic flocculation is dependent upon the velocity gradient and, hence, upon the energy put into the system. A lower velocity gradient is required during particle agglomeration (flocculation) to minimize shearing of the flocs previously formed. Work by Mills (18) indicates that the coagulation mechanism present determines the intensity of mixing required to hydrolyze the coagulant. The adsorption-destabilization reactions occur within microseconds while the hydrolysis products formed during sweep coagulation are formed in the order of 1 to 7 seconds (18). It is imperative that when the coagulation mechanism of adsorption-destabilization is employed, the coagulant must be immediately dispersed upon its addition to the raw water. It follows that the use of zeta potential as a means of controlling the coagulation process is applicable only where adsorption-destabilization is the primary coagulation mechanism.

Coagulation efficiency increases with an increase in particle contacts. An increase in both the velocity gradient (G) and the detention time (t) will serve to increase the total number of particle contact opportunities. The product Gt is often used as a design parameter, with typical values of 10^4 to 10^5 for alum coagulation systems (8,27). When synthetic organic polymers are used as primary coagulants, intense mixing (high Gt values) is not required as the only reaction occurring is polymer adsorption (19). In some instances, rapid mix of polymer may be replaced by flocculation. In any event, it is essential that the polymer be properly dispersed to allow the bridging mechanism to facilitate particle agglomeration and eventual settling.

Aeration

Aeration is a process whereby water is brought into intimate contact with air to achieve one of the following aims (7,8):

(1) Addition of oxygen to oxidize reduced iron and manganese species.

(2) Removal of carbon dioxide to reduce the corrosion potential of the water.

(3) Removal of other gases such as methane and hydrogen sulfide.

(4) Removal of volatile oils and taste and odor producing substances.

Many substances causing taste and odor problems are not sufficiently volatile to be completely removed by aeration alone. For example, the oils of algae are not highly volatile and, therefore, are not generally removed by aeration alone.

The removal of iron and manganese with aeration is pH dependent. The rate of iron oxidation above a pH of 7.0 will increase with an increase in pH. Above a pH of 8.5, manganese will rapidly oxidize. While higher pH values will encourage oxidation of iron and manganese, neutral to acidic pH values favor better floc formation during the coagulation-flocculation process with alum (24).

The carbon dioxide level of natural waters cannot be reduced to zero by aeration because carbon dioxide is present in the atmosphere and will partition into the aqueous phase in accordance with Henry's law.

III. EXPERIMENTAL METHODS AND MATERIALS

Source and Quality of Water

The raw water used for all laboratory experiments was obtained from the 0.91 meter (36-inch) diameter influent line. The raw water quality during the time period of the study was typical of that usually encountered. A copy of both the June and July water-quality reports are included in Appendix A. Average values of these water quality parameters for this time period are presented in Table 2.

Preparation of Alum and Polymer Solutions

Aluminum sulfate was used as the primary coagulant for the treatment configurations numbered 1 through 5 which are described in the following section. A cationic polymer was used for treatment process configurations 6 and 7. A standard ground reagent (coarse powder) alum of the form $Al_2(SO_4)_3 \cdot 18\ H_2O$ (alum) was used to prepare a 1.0 mg/ml alum stock solution every two weeks. The cationic polymer used to prepare a 1.0 mg/ml stock solution was CatFloc T, as manufactured by the Calgon Corporation.

Treatment Configurations

Seven different treatment process configurations were developed by varying the type of primary coagulant, point of coagulant addition, and the use of the unit treatment processes: aeration, rapid mix, flocculation, and settling. The seven different treatment configurations used during this study are presented in Table 3.

Treatment configurations 1 through 5 were developed primarily to study aeration and the effect of mixing on the coagulation process. Treatment configuration 1 characterized the present operating mode of the Carvins Cove water treatment plant. Treatment configuration 4 represented the unit configuration without aeration for conventional treatment while treatment configuration 5 typified conventional treatment with aeration. Treatment configuration numbers 2 and 3 were developed to determine the effect of aeration prior to coagulant addition, without rapid mixing, as the Carvins Cove facility had no rapid-mix facilities.

Treatment configurations 6 and 7 were developed to provide preliminary information for a direct filtration study. Reasons for selection of these process configurations will be discussed later.

Table 3

Treatment Configurations

Treatment Configuration Number	Order and Type Of Unit Operations*				
1	(a)	A		F	S
2		(a)		F	S
3	A	(a)		F	S
4		(a)	RM	F	S
5	A	(a)	RM	F	S
6	A	(p)	RM	F	S
7	A	(p)	RM		S

*Where; A = Aeration for 8.27 min

RM = Rapid Mix for 2 minutes, except in Configuration 7 where the water was rapidly mixed for 1 minute

F = Two Stage Flocculation, 10 minutes each stage

S = Settling for 20 minutes

(a) = Addition point of aluminum sulfate

(p) = Addition point of cationic polymer

Experimental Procedures

Treatment configurations 1 through 5 were conducted at four pH values: 6.5, 7.0, 7.5, and 8.0. Two trials were performed under each experimental condition and have been designated as "run number one" and "run number two." Each run consisted of adjusting the pH of the raw water, adding varying amounts of coagulant and simulating the operation of the appropriate treatment units as required for each treatment configuration. The range of alum dosages chosen was based upon preliminary tests where it was found that zeta potential reached a maximum value at a coagulant dose of 50 mg/l alum. The optimum coagulant dosage was therefore less than 50 mg/l alum. See Appendix C for graphs of zeta potential versus alum dosage.

The polymer dosages chosen were based upon previous work by McCormick (17). The pH of the raw water was adjusted to the desired value by the addition of either sulfuric acid or sodium hydroxide to approximately seven liters of continuously mixed raw water. Each of the six jars on the jar test apparatus was then filled with one liter of water.

The treatment procedures followed those outlined in the text for the advanced short school for Virginia water treat plant operators (1). Zeta potential measurements were made two minutes after the addition of the primary coagulant. Rapid mixing was performed for two minutes at 72 rpm, which was the highest speed possible with the jar test apparatus available. The typical velocity gradient (G) for a plant scale rapid mix is approximately 1,000 sec^{-1}, while the laboratory scale jar test apparatus provided a maximum G of 97 sec^{-1}. Two stage flocculation was provided using two-10 minute stirring intervals, the first of which was at 40 rpm, and the second at 24 rpm. Plant scale flocculators are generally operated to provide a minimum G of 10 sec^{-1} to promote floc particle growth and a maximum G of 75 sec^{-1} to prevent the shear of the floc particles. The laboratory scale jar test apparatus provided two-stage flocculation at G values of 19 sec^{-1} and 44 sec^{-1}. A quiescent settling period of 20 minutes followed. The speed and duration of mixing and settling time were as specified in the previously-mentioned text for water treatment plant operators (1). A portion of the clarified supernatant was then siphoned from each one-liter jar using a clean, clear plastic tubing. This water was tested for pH, alkalinity, and turbidity.

The spray aeration practiced at the Carvins Cove treatment plant was duplicated using diffused aeration. Bench scale aeration was provided using an air pump in conjunction with a six-way gang valve and six diffuser stones. On the basis of comparable CO_2 reductions, it was determined that the bench scale diffused aeration process would require operation for 8.33 minutes to duplicate the performance of the plant's spray aerators. Carbon dioxide concentrations were determined in accordance with Standard Methods (22). Calculations performed to determine the required period of aeration are presented in Appendix B.

Water Quality Characterization Tests

pH

The pH of both the raw water and the supernatant of the settled water was determined using a Hach Electronic pH meter. The meter was standardized with a pH 7 buffer solution.

Turbidity

The turbidity of both the raw water and the supernatant of the settled water was determined using a Hach model 2100A turbidimeter. The turbidimeter was standardized using either a 0.61 Nephelometric Turbidity Units (NTU) or 10.0 NTU standard suspension as supplied by the manufacturer.

Alkalinity

The alkalinity of both the raw water and the supernatant of the settled water was determined in accordance with Section 403 of Standard Methods (22).

Hardness

The hardness of the raw water was determined using the EDTA titrimetric method as described in Section 309B of Standard Methods (22). Both total hardness and calcium hardness were determined using the materials packaged by the Hach chemical company. ManVer was used for total hardness and CalVer was used for calcium hardness. All samples were titrated with 0.02 N TitraVer.

Zeta Potential

The zeta potential was determined using a meter manufactured by Zeta-Meter, Inc. The procedures used were those outlined in the Zeta-Meter Manual, ZM-77 (28).

The sample was microscopically viewed to determine the average time ten colloids took to traverse ten microdivisions where each microdivision is one micron in width. The average time was then used together with the applied voltage to determine the zeta potential.

IV. EXPERIMENTAL RESULTS

Presentation of Laboratory Data

The options available to the water treatment plant operator for varying the plant operation are usually very limited. A water treatment plant that obtains the raw water from a reservoir such as the Carvins Cove plant may vary the depth of the raw water intake. Varying the different chemical dosages may also assist in plant operation. The adjustment of pH coupled with a change in the coagulant dosage is one of the more effective control options available in plant operations.

Because coagulant dose to the raw water is the most relied upon means of controlling the coagulation process, the alum dosage was plotted against the settled turbidity level resulting from each treatment configuration. For the purpose of this study, settled turbidity is defined as the turbidity of the coagulated water, after settling. The effect of a differing initial pH upon the settled turbidity for each treatment configuration using alum is presented in Figures 5 through 8. In each configuration the initial raw water turbidity was approximately 3.0 NTU. Recall that

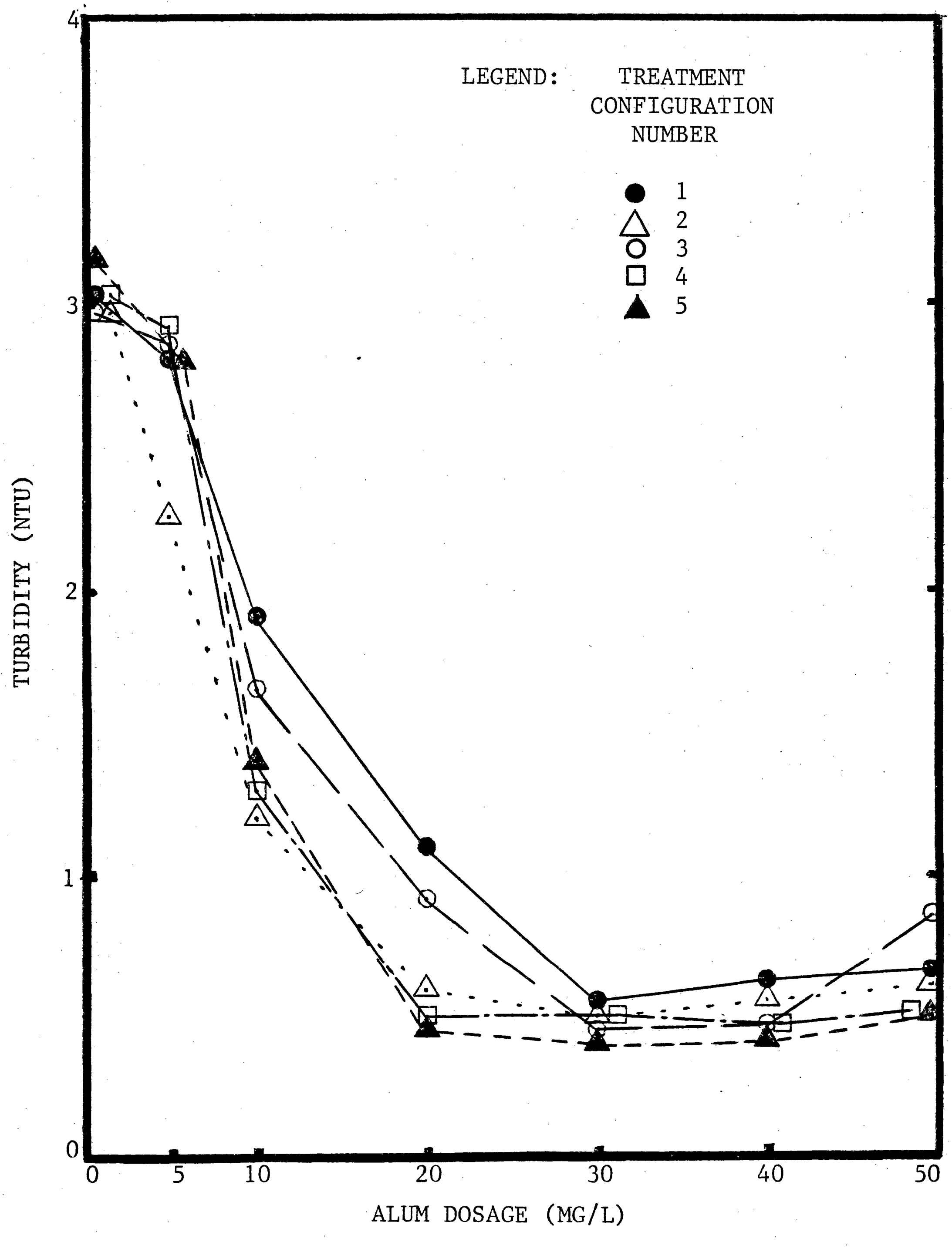

Figure 5 : Relationship of Settled Turbidity to Alum Dosage for Treatment Configurations 1 through 5, pH = 6.5 (See Table 3, p. 27, for treatment configuration)

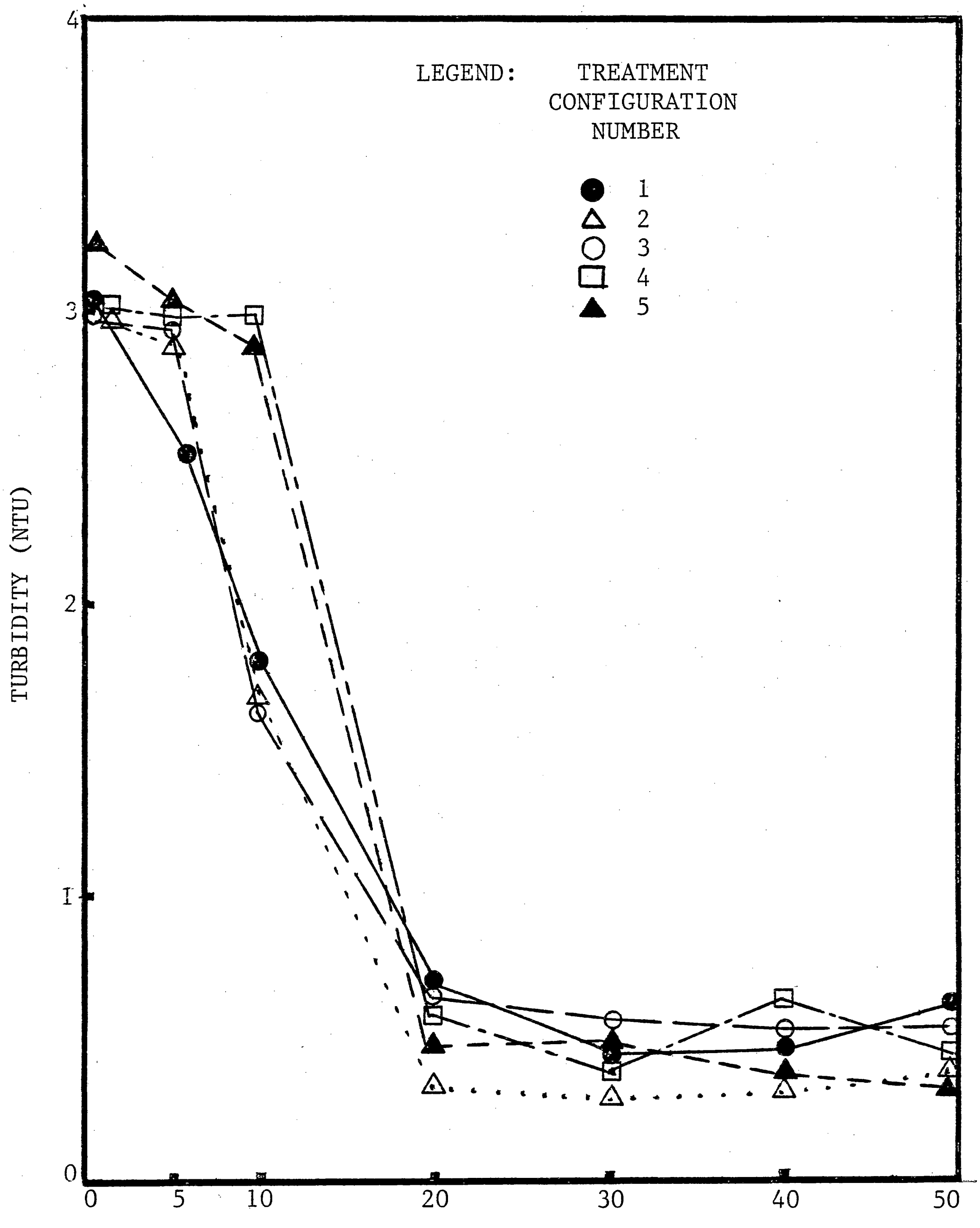

Figure 6: Relationship of Settled Turbidity to Alum Dosage for Treatment Configurations 1 through 5, pH = 7.0 (See Table 3, p. 27, for treatment configuration)

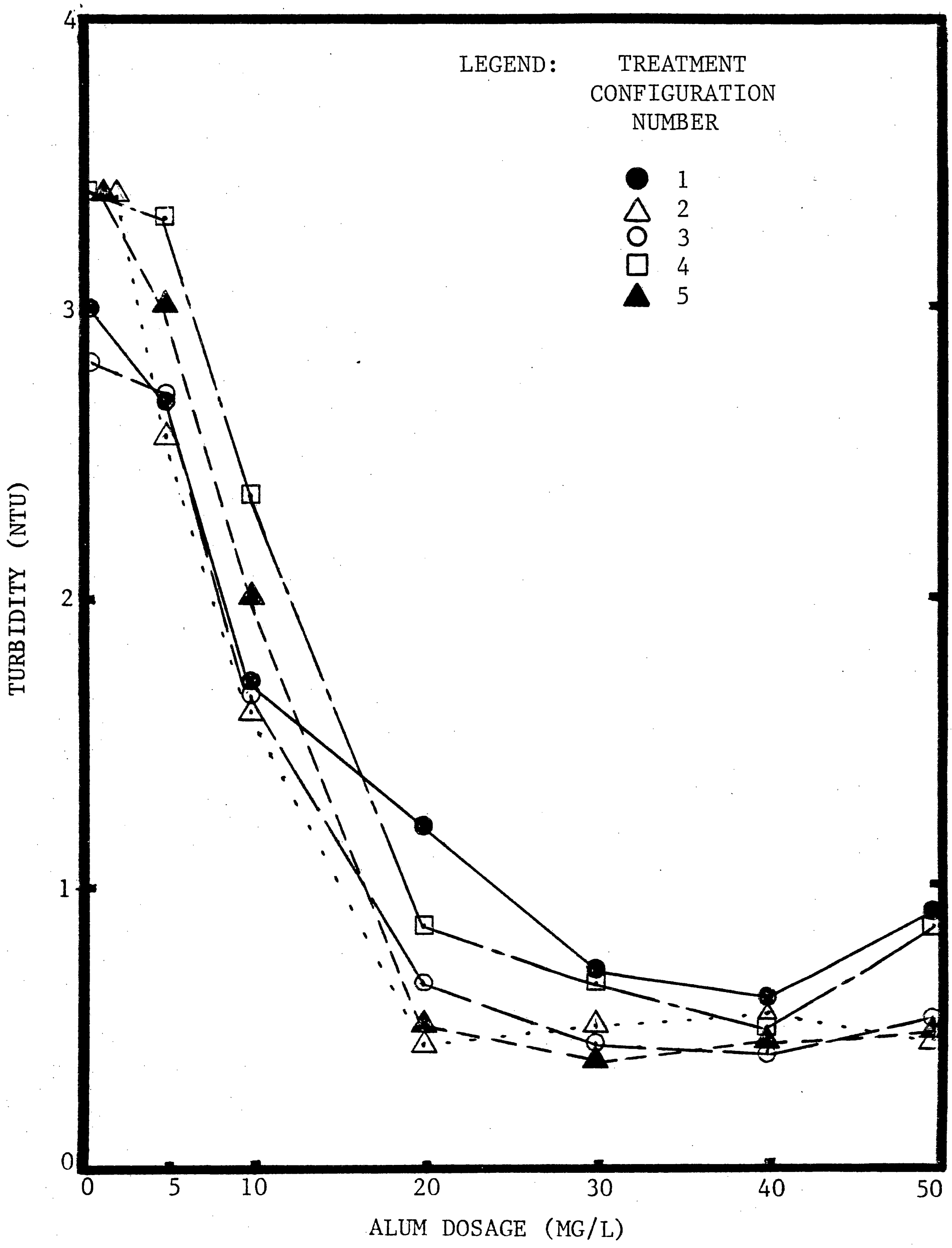

Figure 7 : Relationship of Settled Turbidity to Alum Dosage for Treatment Configurations 1 through 5, pH = 7.5 (See Table 3, p. 27, for treatment configuration)

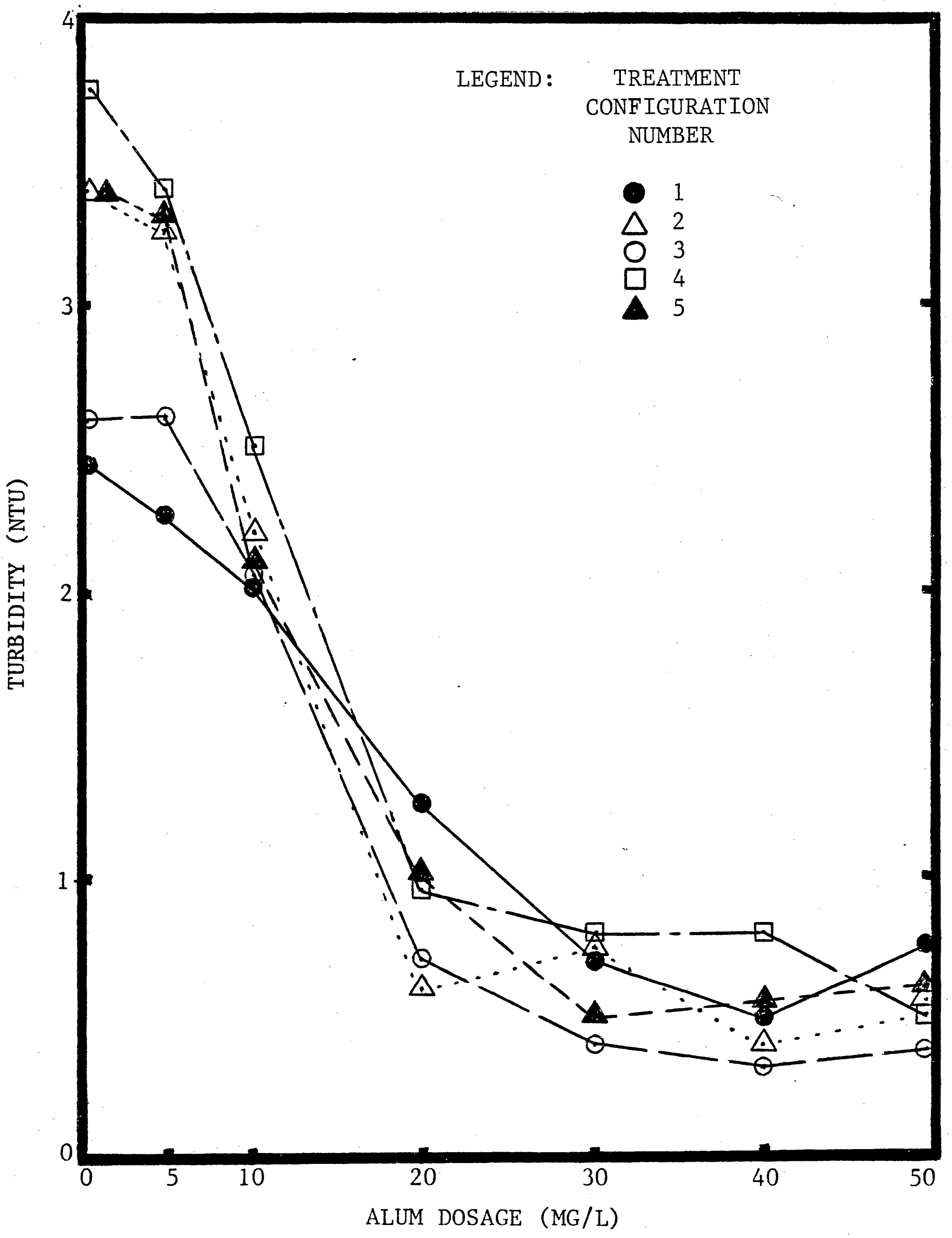

Figure 8 : Relationship of Settled Turbidity to Alum Dosage for Treatment Configurations 1 through 5, pH = 8.0 (See Table 3, p. 27, for treatment configuration)

treatment configuration 1 simulates the present operation of the Carvins Cove treatment plant. Figure 5 indicates that at an initial pH of 6.5, configuration 1 produced slightly higher settled turbidities than the other treatment configurations. The difference in the settled turbidities was more appreciable in the range of a 10 to 20 mg/1 alum dose, at which dosages the Carvins Cove plant typically operates. The optimum turbidity reduction was achieved with an alum dosage of 30 mg/1. Figure 6 compares the various treatment configurations with the raw water adjusted to a pH of 7.0. Recall that during the time period in which this study was conducted, the average raw water pH was 7.2. It is evident from Figure 6 that treatment configuration 1 produced the highest settled turbidities, while treatment configurations 2 through 5 each produced significantly lower settled turbidities. An alum dose of 20 mg/1 would appear optimum to produce a low settled turbidity. Figures 7 and 8 indicate that comparatively higher coagulant dosages of 20 to 30 mg/1 alum were required to produce the lowest settled turbidities for treatment configurations 1 through 5.

The relationship of both the zeta potential and settled turbidity to the alum dosage for treatment configuration 1 is presented in Figures 9 through 12. Upon examination of these figures, it is evident that to achieve a zero zeta potential, progressively more alum must be utilized as the raw water pH is increased. At a raw water pH of 6.5, 23 mg/l of alum was required to achieve a zeta potential of zero, while zero zeta potential was achieved with 32 mg/l of alum when added to a raw water with a pH of 8.0.

Similar figures for treatment configurations 2 through 5 are presented in Appendix C. A summary of the settled turbidity and the coagulant dosage required to achieve both a zeta potential of zero and greatest significant reduction in turbidity for treatment configurations 1 through 5 is presented in Table 4. The selection of zero zeta potential is arbitrarily chosen for comparative purposes only, to serve as an indicator of coagulant effectiveness. Although coagulation usually occurs at a zeta potential of -5 to -10 mv., the use of zero zeta potential is valid as Figures 9 through 12 and Appendix C indicate that the amount of coagulant required to effect a similar increase

TABLE 4

Coagulant Dose Required to Achieve Zero Zeta Potential (pZ = 0) and Lowest Settled Turbidity Levels

Treatment Configuration Number	Initial pH	Settled Turbidity at pZ=0 (NTU)	Coagulant Dosage at pZ=0 (mg/1)	Lowest Settled Turbidity (NTU)	Coagulant Dosage at Lowest Turbidity (mg/1)
1	6.5	0.8	23	0.5	30
	7.0	0.5	28	0.5	40
	7.5	0.7	30	0.6	40
	8.0	0.6	32	0.5	40
2	6.5	0.6	20	0.5	30
	7.0	0.3	23	0.3	30
	7.5	0.4	21	0.4	20
	8.0	0.6	23	0.4	40
3	6.5	1.0	18	0.4	30
	7.0	0.6	24	0.5	30
	7.5	0.6	23	0.4	30
	8.0	0.5	24	0.3	40
4	6.5	0.5	21	0.5	30
	7.0	0.6	20	0.5	30
	7.5	0.7	23	0.5	40
	8.0	0.8	25	0.5	50
5	6.5	0.5	18	0.4	30
	7.0	0.6	18	0.3	40
	7.5	0.5	22	0.4	40
	8.0	0.8	23	0.5	30

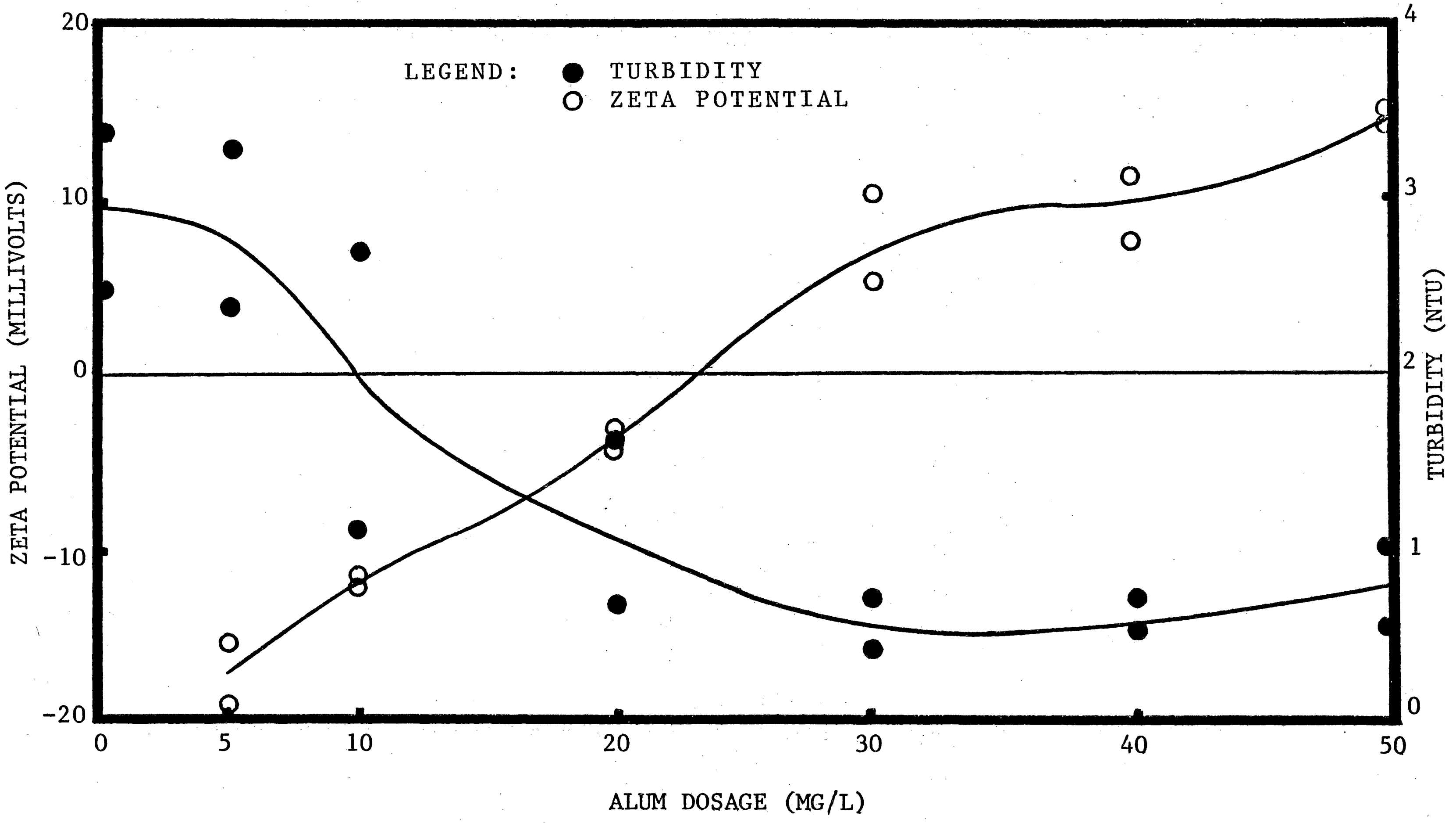

Figure 9: Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 1, pH = 6.5 (See Table 3, p. 27, for treatment configurations)

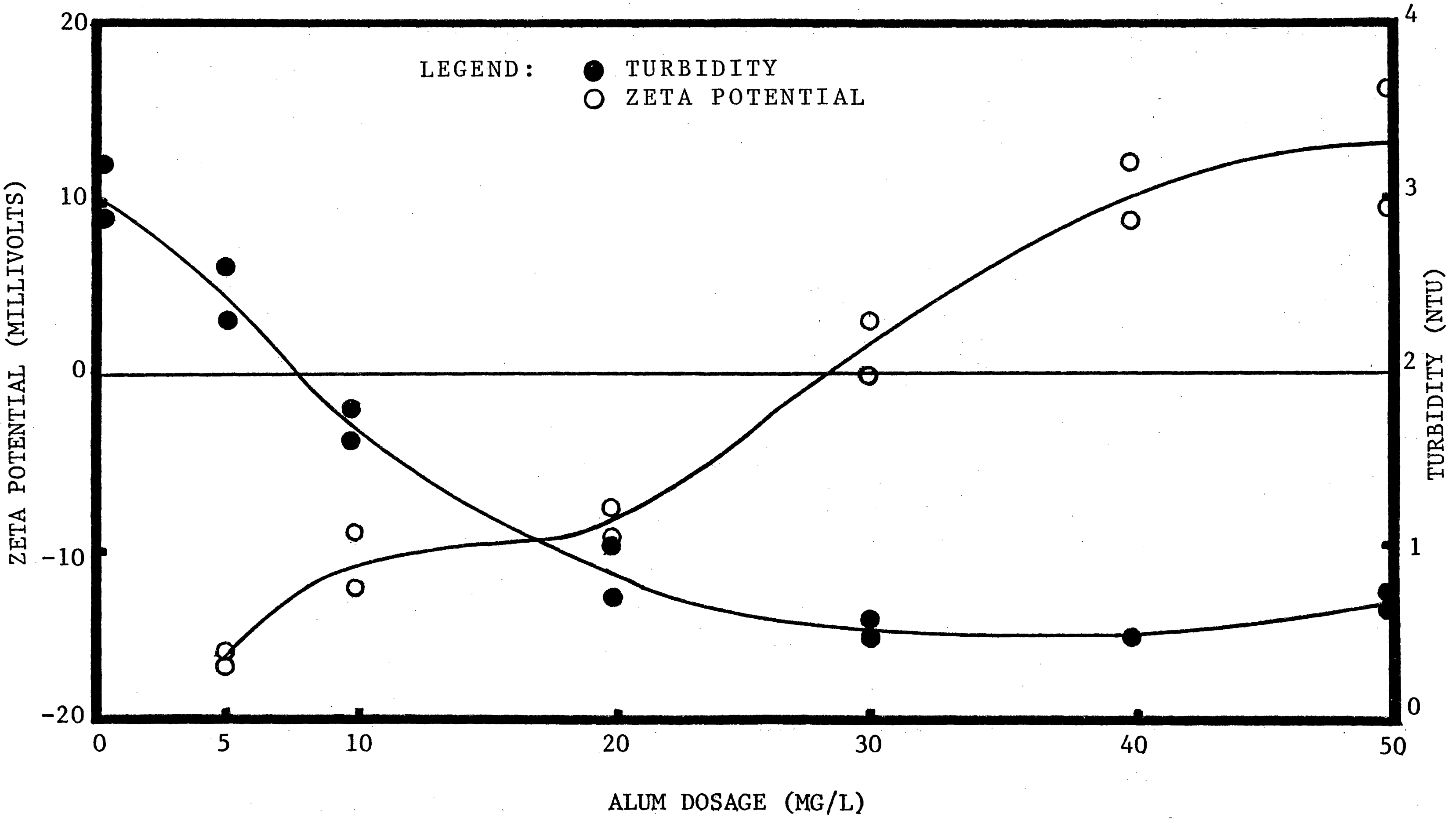

Figure 10: Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 1, pH = 7.0 (See Table 3, p. 27, for treatment configurations)

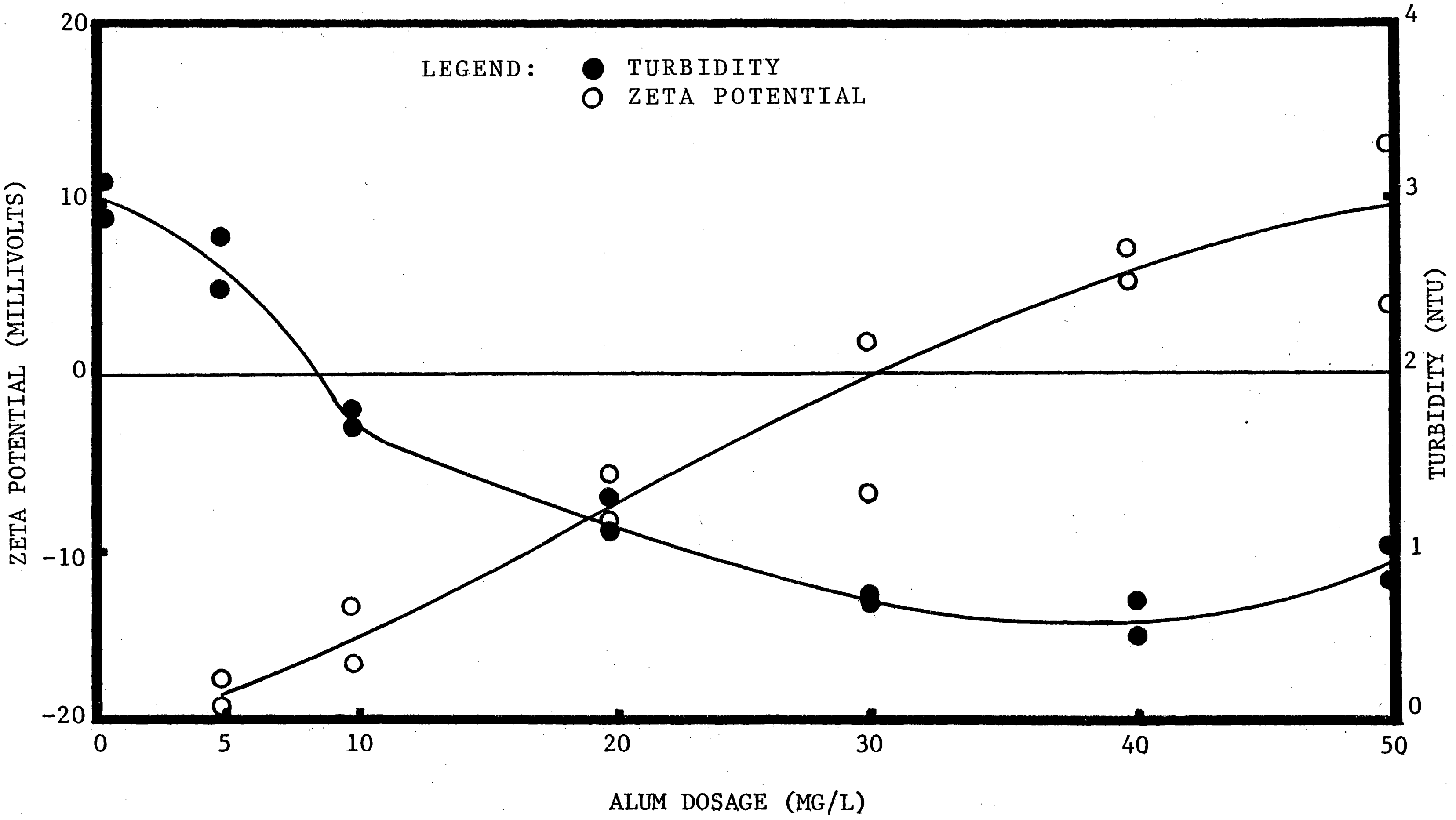

Figure 11: Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 1, pH = 7.5 (See Table 3, p. 27, for treatment configurations)

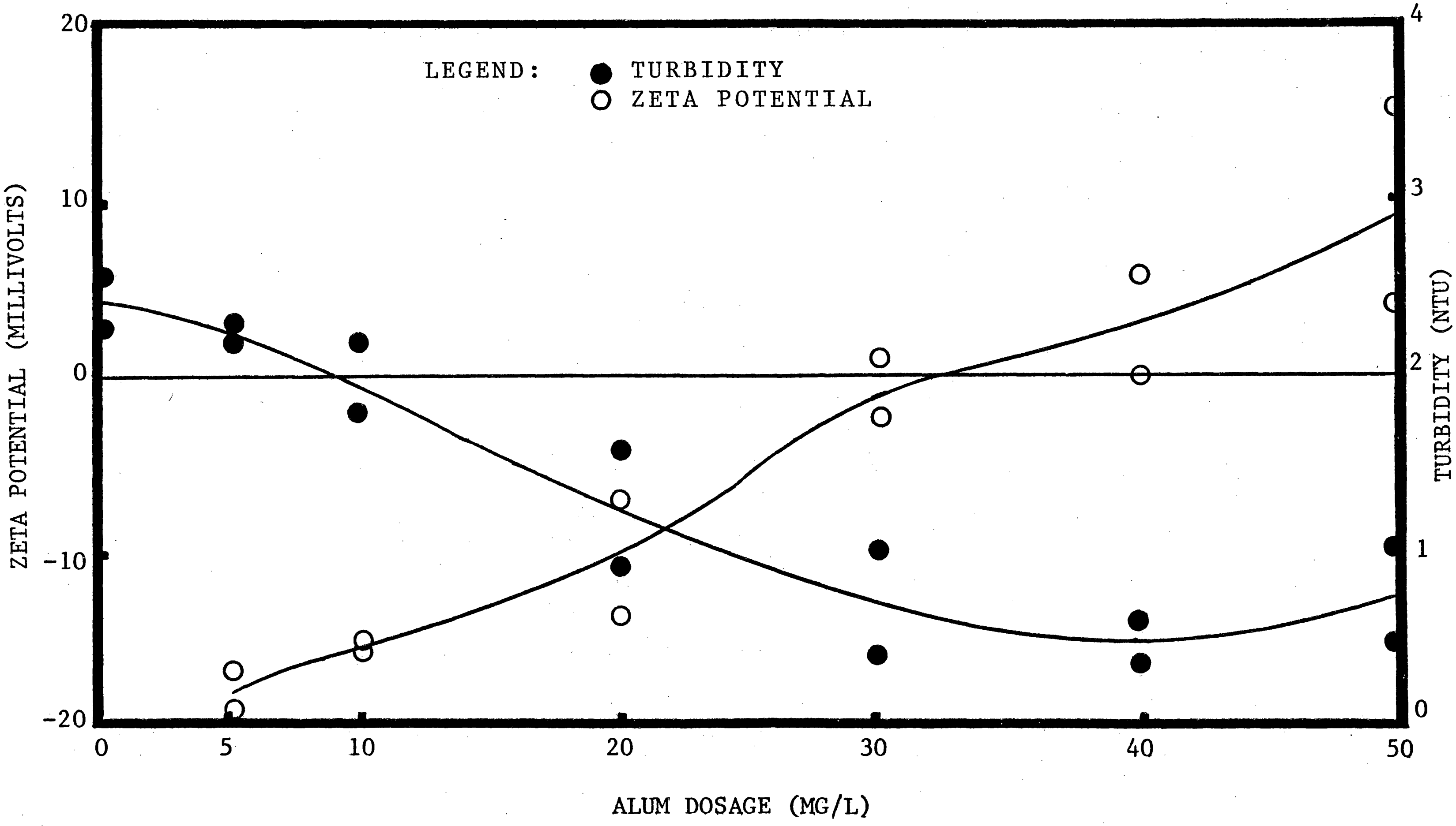

Figure 12: Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 1, pH = 8.0 (See Table 3, p. 27, for treatment configurations)

in the zeta potential remains fairly consistent from one configuration to the next. For example, the results of using polymer as the primary coagulant for treatment configurations 6 and 7 are presented in Figures 13 and 14, respectively. These figures indicate that both the settled turbidity and the zeta potential increased as the polymer dosage was increased.

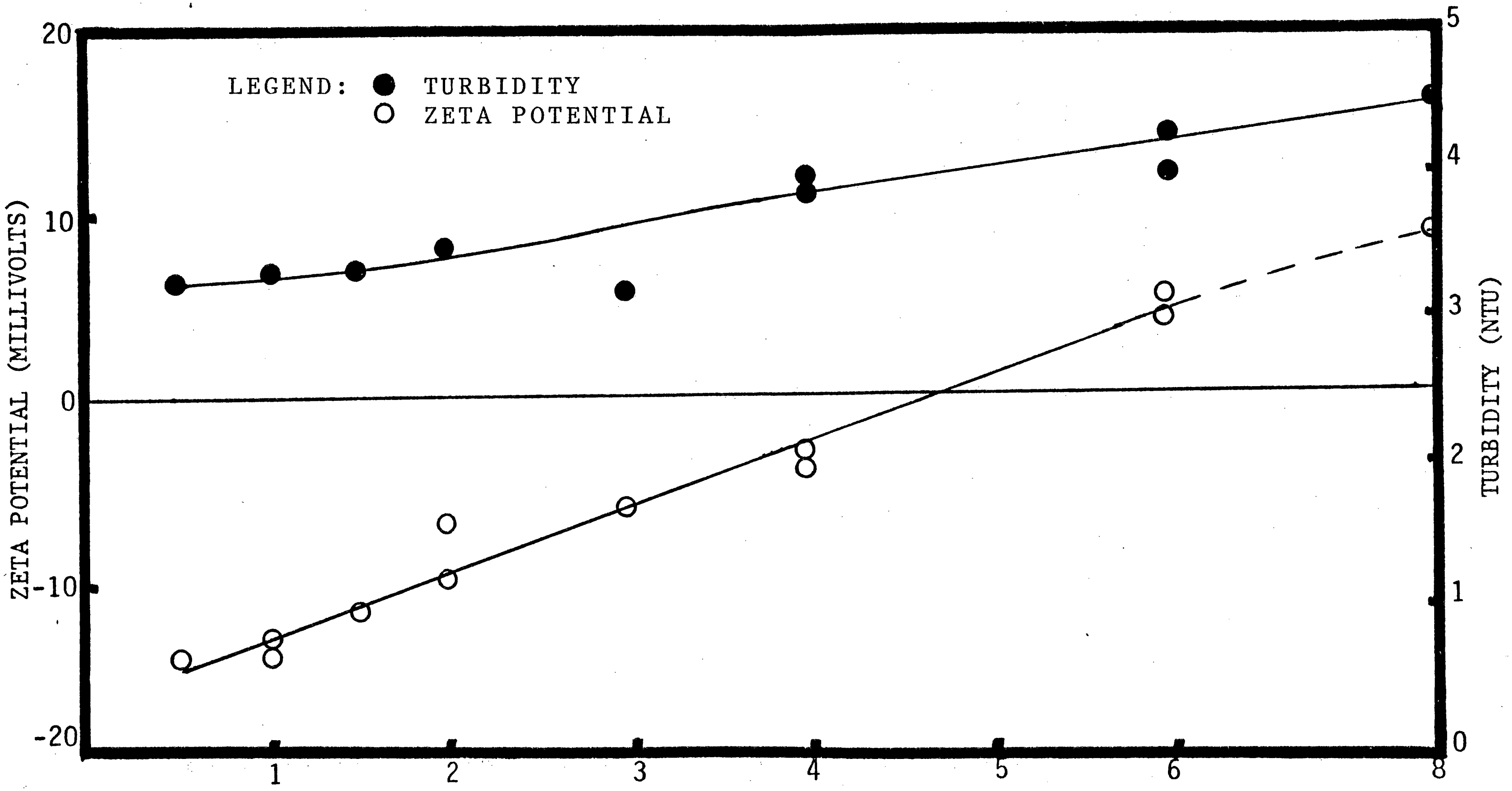

Figure 13: Relationship of Zeta Potential and Turbidity to Polymer Dosage for Treatment Configuration No. 6, pH = 7.6 (See Table 3, p. 27, for treatment configurations)

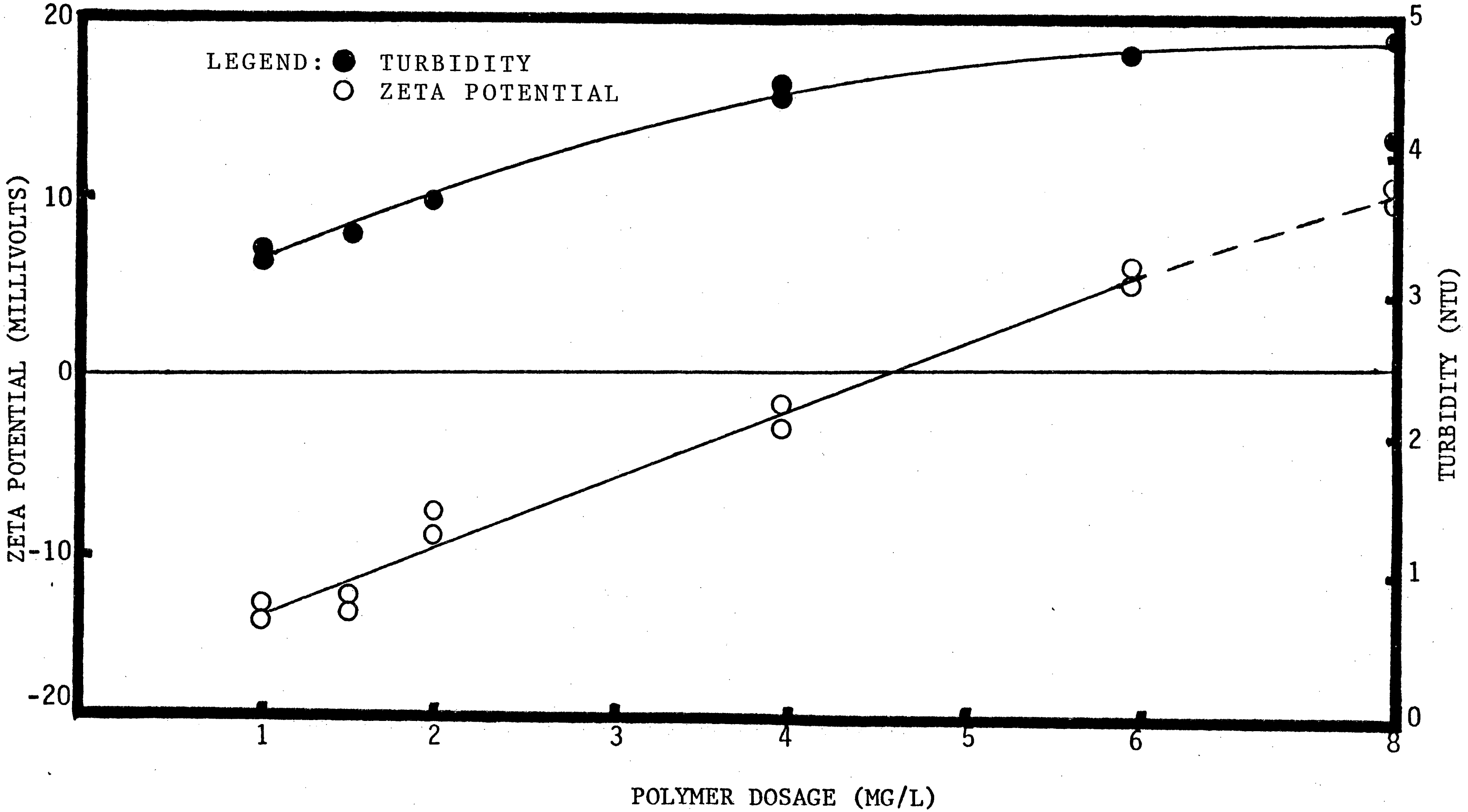

Figure 14: Relationship of Zeta Potential and Turbidity to Polymer Dosage for Treatment Configuration No, 7, pH = 7.6 (See Table 3, p. 27, for treatment configurations)

V. DISCUSSION OF RESULTS

Turbidity Reduction

The relationship of coagulant dosage to reduction in turbidity was evaluated for treatment configurations 1 through 5, at each of the four initial pH levels tested. Both the effect of varying the degree of mixing of the coagulant with the water and the aeration of the raw water were evaluated.

In Figures 5 through 8 the effectiveness of the various treatment configurations may be compared with one another at each of the four initial pH levels tested. Figure 5 compares the treatment configurations at an initial pH of 6.5. With the exception of treatment configuration 1 (which represents the operation of the Carvins Cove facility) there does not appear to be a great deal of difference in the settled turbidity from one configuration to the next. From Table 4 it is apparent that at an initial pH of 6.5, treatment configuration 1 requires a greater coagulant dosage than any other configuration to obtain a zeta potential of zero milli-volts. Each of the five treatment configurations effectively achieved settled turbidities of approximately 0.5 NTU with a coagulant dosage of 30 mg/1.

At this dosage, the zeta potential varied between approximately +6 and +8 millivolts for configurations 1 through 5. Figure 6 indicates that configuration number 1 provided settled turbidities which were about 1 to 2 NTU greater than the settled turbidities produced by treatment configurations 2 through 5. The most significant reduction in the settled turbidity was accomplished at a coagulant dose of 20 mg/1, where the zeta potential varied from approximately -8 to 0 millivolts.

Figure 7 further indicates that at an initial pH of 7.5, treatment configuration 1 is the least effective means of reducing the trubidity. A coagulant dose of 20 mg/1 provided the greatest turbidity reductions in treatment configurations 2, 3, 4, and 5. At a coagulant dosage of 20 mg/1, the zeta potential varied from approximately -3 to 0 millivolts. In configuration 1, a coagulant dose of 30 mg/1 was required to reduce the settled turbidity to 0.7 NTU, where the zeta potential was approximately -2 millivolts.

Figure 8 indicates that at an initial pH level of 8.0, treatment configurations 1 through 5 achieved the greatest turbidity reductions (to 0.3 to 0.7 NTU) at coagulant dosages greater than 30 mg/l. At this coagulant dosage, the zeta potential ranged from approximately -2 to +8 millivolts. The increase in the amount of alum required to achieve the lowest settled turbidity possible is consistent with the previously mentioned work by Mills (18) and Stumm (24) which stated that when alum is allowed to react at a lower pH, more highly positive species are formed and more efficient coagulation is encouraged. The effect of higher pH levels on the coagulant dosage required to achieve a zeta potential of zero millivolts is illustrated in Table 4. In each treatment configuration, the amount of coagulant required to reduce the zeta potential to zero millivolts was found to increase with an increase in the initial pH level of the raw water. This, of course, is due to the lower pH of the water where more highly positive hydrolysis species are produced.

To determine the effect of adding a rapid mix unit to the existing Carvins Cove facility, treatment configurations 2 through 5 were tested. Aeration of the raw water was deleted from both configuration numbers 2 and 4 to provide the basis for a valid comparison of the test results. Configuration 2 consisted of coagulant addition, followed by two-stage flocculation and settling.

Configuration 4 provided rapid mixing upon alum addition, followed by two-stage flocculation and settling. Alum was added immediately prior to rapid mixing in configuration 4. Both configuration numbers 3 and 5 employed aeration prior to coagulant addition, although configuration 5 included rapid mixing of the coagulant while configuration 3 did not include rapid mixing.

During the previous analysis of Figures 5 through 8, it was noted that at comparable coagulant dosages, both configurations 2 and 4 produced approximately the same settled turbidity. Table 4 indicates that for treatment configurations 2 and 4, both the settled turbidities and the corresponding coagulant dosages required to obtain a zeta potential of zero millivolts were essentially the same. Analysis of Figures 5 through 8 indicates that at comparable coagulant dosages, both configurations 3 and 5 produced approximately the same settled turbidity. From Table 4, it is apparent that similar coagulant dosages are required to achieve a zeta potential of zero millivolts in both configurations. Based upon the similarity of these test results, it may be stated that the rapid mixing of the coagulant with the raw water did not result in any significant benefits. Based upon the previously discussed work of Mills (18), the predominant coagulation mechanism in use was therefore not that of adsorption-destabilization, but that of enmeshment or sweep coagulation. Further analysis of Figure 5 indicates that at an initial raw water pH of 6.5, configurations 2, 4 and 5 produce slightly lower settled turbidities than configurations 1 and 5. Recall that a rapid mix was used in configurations 4 and 5 only.

Figure 4 indicates that at a pH of 6.5, the adsorption-destablization mechanism is the predominant coagulation mechanism when using an alum dose in the range of approximately 5 to 20 mg/1 alum. Figure 4 presents the alum dosage in terms of $Al_2(SO_4)_3 \cdot 14.3$ H_2O, while in this study, alum dosages were in the form of $Al_2(SO_4)_3 \cdot 18\ H_2O$. The alum dosages in this study of 5, 10 and 20 mg/1 are therefore expressed as alum dosages of 4.5, 9, and 18 mg/1, respectively, in Figure 4.

The slightly better turbidity removal achieved with treatment configurations 4 and 5 may indicate that when coagulating waters at a pH of 6.5 and at alum dosages of 5 to 20 mg/1, the use of a rapid mix unit may contribute to improved coagulation efficiency. This was to be expected, as at an initial pH level of 6.5, the most significant reduction in the settled turbidity for configurations 4 and 5 was achieved with an increase of the zeta potential of -14 to -2 millivolts and -16 to -5 millivolts, respectively. These ranges in zeta potential compare favorably with the desired zeta potential range of -5 to -10 millivolts or less previously cited (2).

Much of the experimental work was conducted either in the region of sweep coagulation or a combination of adsorption-destabilization and sweep coagulation. Both of these regions are generally characterized by a pH of 7.0 to 8.0 and an alum dose of 5 to 50 mg/l. Recall that the hydrolysis products of aluminum salts are formed over a longer period of time when sweep coagulation is the prevailing mechanism. It, therefore, follows that the provision of intense mixing would not significantly affect the overall performance of the flocculation-clarification process when operating at higher pH levels and higher alum dosages.

The low colloid concentration of the raw water dictated the use of the enmeshment mechanism to achieve the turbidity reductions desired. Recall that operation in zone four of Figures 2 and 3 requires a high coagulant dosage to achieve a significant reduction in turbidity. Zone two of Figures 2 and 3 indicates that the addition of additional turbidity (perhaps in the form of bentonite clay) to the raw water would permit the use of a lower coagulant dosage. The use of a lower coagulant dosage would change the predominate coagulation mechanism from that of enmeshment or sweep coagulation, to adsorption-destabilization. It, therefore, follows that unless the raw water turbidity is increased, the use of rapid mixing and zeta potential is inappropriate.

Figures 5 through 8 indicate that treatment configuration 1 provided the poorest reduction in turbidity when compared with all other treatment configurations using alum. Recall that only in configuration 1 was alum added to the raw water prior to aeration. The poor turbidity reduction of configuration 1 may be partially due to a shearing of the alum floc formed during the aeration process. The shearing of the floc would tend to reduce the floc size, resulting in a floc with poorer settling characteristics and a corresponding increase in the settled turbidity. Although the Carvins Cove facility is operating in this manner, the finished water produced is of acceptable quality, primarily due to reliance upon the filters to reduce the turbidity below the

1.0 NTU level required for potable water. Despite this mode of operation, filters at the Carvins Cove facility are typically operated 60 to 100 hours prior to backwashing.

Polymer As A Primary Coagulant

A cationic polymer was used as the primary coagulant for treatment configuration numbers 6 and 7. The relationship of zeta potential and turbidity to polymer dosage for treatment configuration numbers 6 and 7 is presented in Figures 13 and 14, respectively. A zeta potential of zero was achieved with a polymer dosage of 4.7 mg/l for both treatment configurations. Increasing amounts of polymer increased the turbidity after settling. The turbidity increased from 3.3 to 4.5 NTU in treatment configuration number 6 with the addition of 6 mg/l of polymer. The turbidity also increased from 3.3 to 4.9 NTU in treatment configuration number 7 when 6 mg/l polymer was added. The increase in turbidity may have been due to overmixing the polymer. As previously discussed, excessive mixing of a polymer may cause the polymer to occupy all of the adsorption sites on the colloid or fold about a colloid, thereby preventing the polymer from forming a settleable floc.

However, it is more likely that the low turbidity of the raw water was responsible for the poor performance of the polymer in that the low colloid concentration did not provide the opportunity for the polymer to form a bridge between the colloids. Although a zeta potential of zero was achieved with the addition of the polymer, zeta potential was not a good indicator of how the polymer will perform. Because the performance of the polymer was poor as a primary coagulant, only those treatment process configurations using alum (numbers 1 through 5) were considered in recommendations to the operators of the Carvins Cove water treatment facility.

VI. SUMMARY AND CONCLUSIONS

The present operating mode of the Carvins Cove facility provides a high quality potable water. The use of additional coagulant to achieve greater turbidity removals prior to filtration is not recommended because long filter runs are now routinely possible. From the results of the laboratory work performed at the Carvins Cove water treatment plant, the following conclusions were drawn:

1. The present operating mode of the Carvins Cove water treatment plant appeared to be the least efficient of the configurations considered. Marginal improvements in turbidity removals were accomplished when alum was added after aeration rather than before aeration.
2. The addition of a rapid mix unit at the Carvins Cove facility probably would not significantly improve the performance of the coagulation process, because other means of turbulence induction already exist.
3. The aeration step was not required to achieve effective coagulation. The aeration process should be retained at Carvins Cove, however, due

to its capacity to oxidize iron and aid in the control of taste and odor problems.

4. Turbidity levels in the raw water at Carvins Cove were not effectively reduced when the cationic polymer CatFloc T, was used as the primary coagulant. It was believed that the initial low level of turbidity was primarily responsible for the poor performance of the polymer, CatFloc T.

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APPENDICES

APPENDIX A

CARVINS COVE WATER TREATMENT PLANT

MONTHLY OPERATING REPORTS
FOR THE MONTHS OF
JUNE AND JULY, 1979

CARVINS COVE PLANT MONTHLY REPORT

Month of JUNE 1979

Day	Total Gallons	Plant Use	Delivered Gallons	Filters Washed	CHEMICALS USED Ferrisul Alum Lbs.	Lime Lbs.	Carbon Lbs.	Calgon. Lbs.	Fluoride Lbs.	Chlorine Lbs.	Ammonia Lbs.	F° Water Temp.	Residual Chlorine Fin.	Turbidity Raw	Turbidity Fin.	Color Raw	Color Fin.	Alkalinity Raw	Alkalinity Fin.	Finished Water Soap Hard	Finished Water pH	Manganese Raw	Manganese Basin	Manganese Fin.	Iron Raw	Iron Basin	Iron Fin.	SPC 1cc 35°C 24 Hrs. Raw	SPC Filter	SPC Fin.	E-Coli 35°C 5/10cc Raw	E-Coli Filter	E-Coli Fin.	BGB Raw	BGB Filter
1	8 405 000	111 000	8 297 000	1	424	448	X	X	51	190	X	56	1.3	1.9	.25	10	0	47	52	62	7.5	0	X	0	.07	X	.03	32	15	5	0 2	0 0	0 0	0 0	
2	11 655 000	201 000	11 454 000	2	779	751	X	X	88	265	X	56	1.3	1.9	.25	10	0	47	52	62	7.5	0	X	0	.07	X	.03	25	65	13	0 2	0 0	0 0	0 1	
3	7 722 000	196 000	7 526 000	2	473	480	X	X	55	175	X	56	1.3	—	.26																				
4	11 322 000	21 000	11 301 000	0	724	754	X	X	78	250	X	56	1.3	1.9	.26	10	0	46	50	62	7.5	0	X	0	.06	X	.03	20	6	2	0 2	0 0	0 0	0 1	
5	10 968 000	181 000	10 787 000	2	735	726	X	X	70	280	X	56	1.3	1.7	.28	10	0	47	51	60	7.6	0	X	0	.06	X	.03	15	10	0	0 5	0 3	0 0	2 2	0 0
6	12 048 000	101 000	11 947 000	1	809	772	X	X	89	285	X	56	1.3	1.6	.39	10	0	46	51	60	7.8	0	X	0	.07	X	.03	22	21	1	0 2	0 3	0 0	1 1	0 0
7	12 048 000	171 000	11 877 000	2	795	778	X	X	77	285	X	57	1.3	1.6	.29	10	0	47	50	60	7.7	0	X	0	.07	X	.03	35	65	3	0 3	0 4	0 0	1 1	2 2
8	9 989 000	186 000	9 803 000	2	725	697	X	X	85	275	X	57	1.3	1.6	.32	10	0	46	49	60	7.7	0	X	0	.06	X	.02	31	32	5	0 1	0 0	0 0	0 0	
9	10 657 000	171 000	10 486 000	2	711	698	X	X	75	250	X	57	1.3	1.6	.32	10	0	46	49	60	7.7	0	X	0	.06	X	.02	45	15	2	0 1	0 0	0 0	0 0	
10	7 618 000	106 000	7 512 000	1	478	464	X	X	56	190	X	57	1.3	—	.31																				
11	11 672 000	121 000	11 551 000	1	784	744	X	X	100	305	X	57	1.3	1.9	.29	10	0	47	49	58	7.7	0	X	0	.06	X	.03	60	40	0	0 5	0 0	0 0	2 3	
12	9 367 000	276 000	9 091 000	3	590	588	X	X	92	230	X	57	1.3	1.9	.22	10	0	46	50	60	7.7	0	X	0	.06	X	.02	55	22	0	1 3	0 1	0 0	1 1	0 0
13	11 801 000	191 000	11 610 000	2	758	777	X	X	113	280	X	58	1.3	2.1	.31	10	0	46	51	60	7.6	0	X	0	.06	X	.02	86	60	0	0 5	0 2	0 0	3 4	0 0
14	11 610 000	21 000	11 589 000	0	760	743	X	X	113	290	X	58	1.3	2.4	.31	10	0	46	50	60	7.6	0	X	0	.07	X	.02	110	70	5	0 5	0 3	0 0	0 0	0 0
15	12 092 000	301 000	11 791 000	3	796	781	X	X	117	295	X	59	1.3	2.2	.27	10	0	46	50	60	7.5	0	X	0	.07	X	.03	115	70	0	0 2	0 1	0 0	0 2	0 1
Subtotal	158 977 000	2 355 000	156 622 000	24	10,341	10,201			1,259	3,845				—																					
16	9 574 000	111 000	9 463 000	1	627	611	X	X	102	250	X	59	1.3	2.2	.26	10	0	45	50	60	7.5	0	X	0	.07	X	.03	170	110	10	0 5	0 0	0 0	2 4	
17	9 157 000	201 000	8 956 000	2	597	583	X	X	95	190	X	59	1.3	—	.30																				
18	8 679 000	191 000	8 488 000	2	536	554	X	X	74	205	X	59	1.3	2.8	.36	10	0	45	42	54	7.4	0	X	0	.07	X	.07	115	40	2	1 5	0 2	0 1	2 2	0 0
19	11 605 000	91 000	11 514 000	1	767	751	X	X	68	295	X	59	1.3	2.3	.36	10	0	44	47	60	7.6	0	X	0	.03	X	.03	120	40	3	0 4	0 0	0 0	0 0	
20	10 385 000	21 000	10 364 000	0	669	664	X	X	88	245	X	59	1.3	2.5	.34	10	0	45	48	56	7.5	0	X	0	.06	X	.03	220	20	3	5 0	2 0	0 0	4 4	0 0
21	8 700 000	201 000	8 499 000	2	543	506	X	X	64	215	X	59	1.3	2.7	.34	10	0	46	48	58	7.7	0	X	0	.07	X	.04	TNTC	28	7	0 5	0 1	0 0	0 5	0 0
22	11 468 000	106 000	11 362 000	1	768	796	X	X	89	225	X	59	1.3	2.6	.34	10	0	46	49	60	7.6	0	X	0	.06	X	.02	TNTC	38	2	0 5	0 0	0 0	2 4	
23	9 138 000	191 000	8 947 000	2	520	521	X	X	59	195	X	59	1.3	2.6	.34	10	0	46	49	60	7.6	0	X	0	.06	X	.02	TNTC	TNTC	2	0 3	0 0	0 0	3 +	
24	9 677 000	171 000	9 506 000	2	637	628	X	X	76	245	X	59	1.3	—	.36																				
25	8 346 000	21 000	8 325 000	0	525	533	X	X	67	215	X	59	1.3	3.3	.31	10	0	46	50	60	7.5	0	X	0	.06	X	.02	164	20	0	0 5	1 5	0 0	0 1	0 0
26	11 343 000	111 000	11 232 000	1	727	711	X	X	107	285	X	59	1.3	2.2	.32	10	0	46	50	60	7.5	0	X	0	.06	X	.02	75	129	2	1 5	0 5	0 0	2 2	2 2
27	10 718 000	251 000	10 467 000	3	705	688	X	X	97	255	X	59	1.3	2.6	.34	10	0	47	51	60	7.6	0	X	0	.07	X	.02	96	1	1	0 5	0 0	0 0	5 —	
28	10 656 000	21 000	10 635 000	0	786	672	X	X	103	260	X	59	1.3	2.4	.30	10	0	46	50	60	7.6	0	X	0	.06	X	.02	70	37	3	1 5	0 4	0 0	1 2	0 0
29	9 969 000	311 000	9 658 000	3	753	646	X	X	98	240	X	59	1.3	2.3	.26	10	0	44	48	60	7.5	0	X	0	.07	X	.03	79	34	1	0 4	0 0	0 0	1 3	
30	7 431 000	101 000	7 330 000	1	506	443	X	X	68	170	X	59	1.3	2.3	.26	10	0	44	48	60	7.5	0	X	0	.07	X	.03	79	35	3	0 3	0 1	0 0	1 3	1 —
31																																			
Subtotal	146 846 000	2 100 000	144 746 000	21	9,666	9307			1,255	3490																									
TOTAL	305 823 000	4 455 000	301 368 000	45	29007	19,508			2514	7335																									

REMARKS: WASH WATER - 13,825,000

CARVINS COVE PLANT MONTHLY REPORT

Month of JULY 1978

Day	Total Gallons	Plant Use	Delivered Gallons	Filters Washed	CHEMICALS USED Ferrisul Alum	Lime	Carbon	Calgon.	Fluoride	Chlorine	Ammonia	F°	Residual Chlorine	Turbidity		Color		Alkalinity		Finished Water		Manganese			Iron			SPC 1cc 35°C 24 Hrs.			E-Coli 35°C 5/10cc			BGB	
					Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Water Temp.	Fin.	Raw	Fin.	Raw	Fin.	Raw	Fin.	Soap Hard	pH	Raw	Basin	Fin.	Raw	Basin	Fin.	Raw	Filter	Fin.	Raw	Filter	Fin.	Raw	Filter
1	7 742 000	206 000	7 536 000	2	546	462	X	X	84	170	X	59	1.3	—	.28																				
2	10 991 000	91 000	10 900 000	1	727	618	X	X	88	270	X	59	1.3	2.7	.24	10	0	46	48	60	7.5	0	X	0	.07	X	.03	62	34	1	1 5	0 3	0 0	0 3	0 2
3	8 179 000	186 000	7 993 000	2	603	517	X	X	84	200	X	60	1.3	2.5	.25	10	0	46	48	60	7.4	0	X	0	.07	X	.03	47	5	0	0 1	0 0	0 0	1 —	
4	9 241 000	106 000	9 135 000	1	663	584	X	X	90	210	X	60	1.3	—	.27																				
5	8 596 000	121 000	8 475 000	1	612	536	X	X	87	210	X	60	1.3	2.6	.27	10	0	45	49	62	7.5	0	X	0	.07	X	.03	29	29	1	0 5	0 3	0 0	0 1	0 0
6	10 989 000	246 000	10 743 000	3	833	705	X	X	103	280	X	60	1.3	2.9	.21	10	0	45	50	60	7.7	0	X	0	.07	X	.03	34	1	3	0 4	0 0	0 0	0 1	
7	8 013 000	101 000	7 912 000	1	565	508	X	X	85	190	X	60	1.3	2.9	.24	10	0	45	50	60	7.7	0	X	0	.07	X	.03	74	2	1	0 3	0 1	0 0	1 2	0 0
8	10 406 000	201 000	10 205 000	2	747	656	X	X	97	245	X	60	1.3	—	.22																				
9	8 408 000	121 000	8 287 000	1	612	481	X	X	78	200	X	60	1.3	3.2	.27	10	0	46	50	60	7.8	0	X	0	.07	X	.03	65	2	0	0 5	0 4	0 0	0 3	0 1
10	11 031 000	186 000	10 845 000	2	1,021	720	X	X	90	275	X	60	1.3	3.0	.26	10	0	46	50	60	7.8	0	X	0	.06	X	.02	46	1	1	0 5	0 2	0 0	0 0	0 0
11	10 875 000	276 000	10 599 000	3	1,018	695	X	X	115	265	X	61	1.3	2.6	.22	10	0	45	48	58	7.7	0	X	0	.07	X	.03	65	11	1	1 5	0 5	0 0	3 3	2 2
12	10 615 000	191 000	10 424 000	2	985	670	X	X	108	250	X	64	1.3	2.8	.27	10	0	46	48	58	7.7	0	X	0	.07	X	.03	3	2	0	0 4	0 2	0 0	0 3	0 0
13	10 656 006	106 000	10 550 000	1	1,001	681	X	X	106	270	X	64	1.3	2.0	.33	10	0	42	44	56	7.7	0	X	0	.06	X	.04	30	50	2	0 4	0 1	0 0	4 —	0 1
14	9 907 000	106 000	9 801 000	1	893	620	X	X	99	250	X	65	1.3	2.4	.36	10	0	43	44	56	7.6	0	X	0	.07	X	.04	15	40	3	0 2	0 1	0 0	1 2	0 1
15	7 826 000	21 000	7 805 000	0	697	485	X	X	62	200	X	65	1.3	—	.27																				
Subtotal	143 475 000	2 265 000	141 210 000	23	11,523	8,938			1,376	3,485				—																					
16	11 488 000	281 000	11 207 000	3	1,059	715	X	X	121	280	X	65	1.3	2.6	.36	10	0	44	45	56	7.6	0	X	0	.07	X	.05	30	80	4	3 5	0 4	0 0	0 2	0 0
17	11 426 000	111 000	11 315 000	1	1,089	739	X	X	105	290	X	65	1.3	2.1	.33	10	0	42	45	56	7.6	0	X	0	.09	X	.06	70	5	0	0 2	0 0	0 0	0 2	
18	10 137 000	21 000	10 116 006	0	923	641	X	X	84	280	X	66	1.3	1.9	.29	10	0	43	45	60	7.9	0	X	0	.08	X	.05	35	TNTC	1	0 5	0 2	0 0	1 5	0 1
19	10 968 000	206 000	10 762 000	2	983	699	X	X	90	280	X	66	1.3	2.3	.29	10	0	41	45	56	7.9	0	X	0	.09	X	.05	80	3	0	2 5	0 0	0 0	2 5	
20	8 159 000	111 000	8 048 000	1	726	506	X	X	76	220	X	66	1.3	2.1	.34	10	0	43	43	60	7.9	0	X	0	.07	X	.05	60	TNTC	1	0 4	0 0	0 0	3 3	
21	10 614 000	176 000	10 438 000	2	996	686	X	X	86	270	X	66	1.3	2.2	.34	10	0	42	42	66	7.9	0	X	0	.07	X	.05	50	15	10	0 5	0 0	0 0	5 —	
22	7 161 000	121 000	7 040 000	1	641	473	X	X	65	190	X	66	1.3	—	.27																				
23	10 906 000	106 000	10 800 000	1	1017	686	X	X	92	285	X	66	1.3	2.8	.33	10	0	45	48	58	7.9	0	X	0	.08	X	.02	50	TNTC	0	0 5	0 4	0 0	4 4	0 1
24	8 409 000	21 000	8 388 000	0	759	529	X	X	95	210	X	66	1.3	2.7	.31	10	0	44	45	56	7.9	0	X	0	.08	X	.05	30	10	2	0 4	1 2	0 0	0 2	1 1
25	12 030 000	146 000	11 884 000	2	1089	724	X	X	122	300	X	66	1.3	3.1	.33	10	0	43	46	56	7.9	0	X	0	.08	X	.03	48	17	1	0 4	0 1	0 0	3 3	0 0
26	10 261 000	21 000	10 240 000	0	964	663	X	X	113	255	X	67	1.3	2.9	.39	10	0	42	45	56	7.9	0	X	0	.07	X	.03	50	TNTC	210	4 5	0 1	0 0	4 4	0 1
27	8 950 000	181 000	8 769 000	2	804	562	X	X	97	240	X	67	1.3	3.0	.38	10	0	45	45	54	7.8	0	X	0	.08	X	.02	16	50	4	0 5	0 0	0 0	0 4	
28	10 823 000	181 000	10 642 000	2	1031	708	X	X	103	265	X	67	1.3	2.7	.32	10	0	43	46	58	7.9	0	X	0	.07	X	.02	80	TNTC	0	0 5	0 2	0 0	5 —	0 2
29	7 222 000	21 000	7 201 000	0	632	457	X	X	80	200	X	67	1.3	—	.26																				
30	11 488 000	191 000	11 297 000	2	1099	734	X	X	111	305	X	67	1.3	3.4	.31	10	0	47	46	60	7.8	0	X	0	.07	X	.03	60	57	0	0 5	0 3	0 0	3 3	0 0
31	10 157 000	171 000	9 986 000	2	953	657	X	X	109	270	X	66	1.3	3.0	.34	10	0	45	46	60	7.8	0	X	0	.07	X	.02	182	24	0	0 5	0 2	0 0	0 3	2 —
Subtotal	160 199 000	2 066 000	158 133 000	21	14,765	19,179			1,549	4,140																									
TOTAL	303 674 000	4 331 000	299 343 000	44	26,288	19,117			2,925	7,625																									

REMARKS:

APPENDIX B

Determination of Aeration Period for Laboratory Scale Diffused Aeration

Plant Scale

Raw water CO_2 content = 6 mg/l

Spray-aerated water CO_2 content = 3 mg/l

Lab Scale

CO_2 level after 3 minutes of diffused aeration = 3 mg/l

Air pump capacity = $8,470 \frac{\text{ml air}}{\text{minute}}$

Therefore:

Air volume pumped in three minutes = 3 x 8,470 = 25,411 ml.

Diffused aeration sample volume = 2,175 ml

Hence, for a one liter sample:

$$\frac{25,411 \text{ ml air}}{2,174 \text{ ml sample}} = \frac{x \text{ ml air}}{1,000 \text{ ml sample}}$$

x = 11,700 ml air per liter

Therefore,

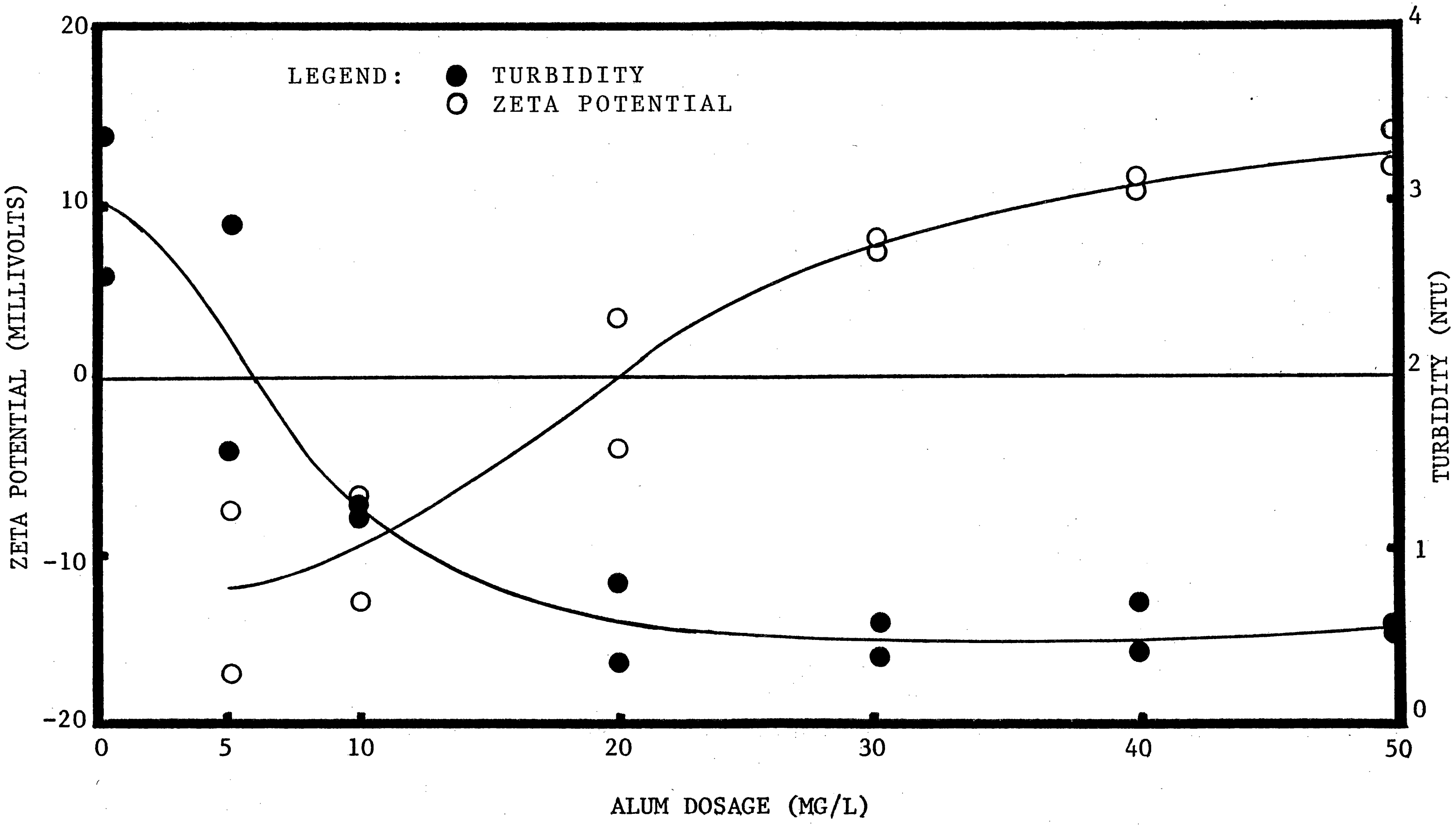
Volume of air for 6-one liter jars = 6 x 11,700 = 70,100 ml

Hence, the time required to pump 70,100 ml air is:

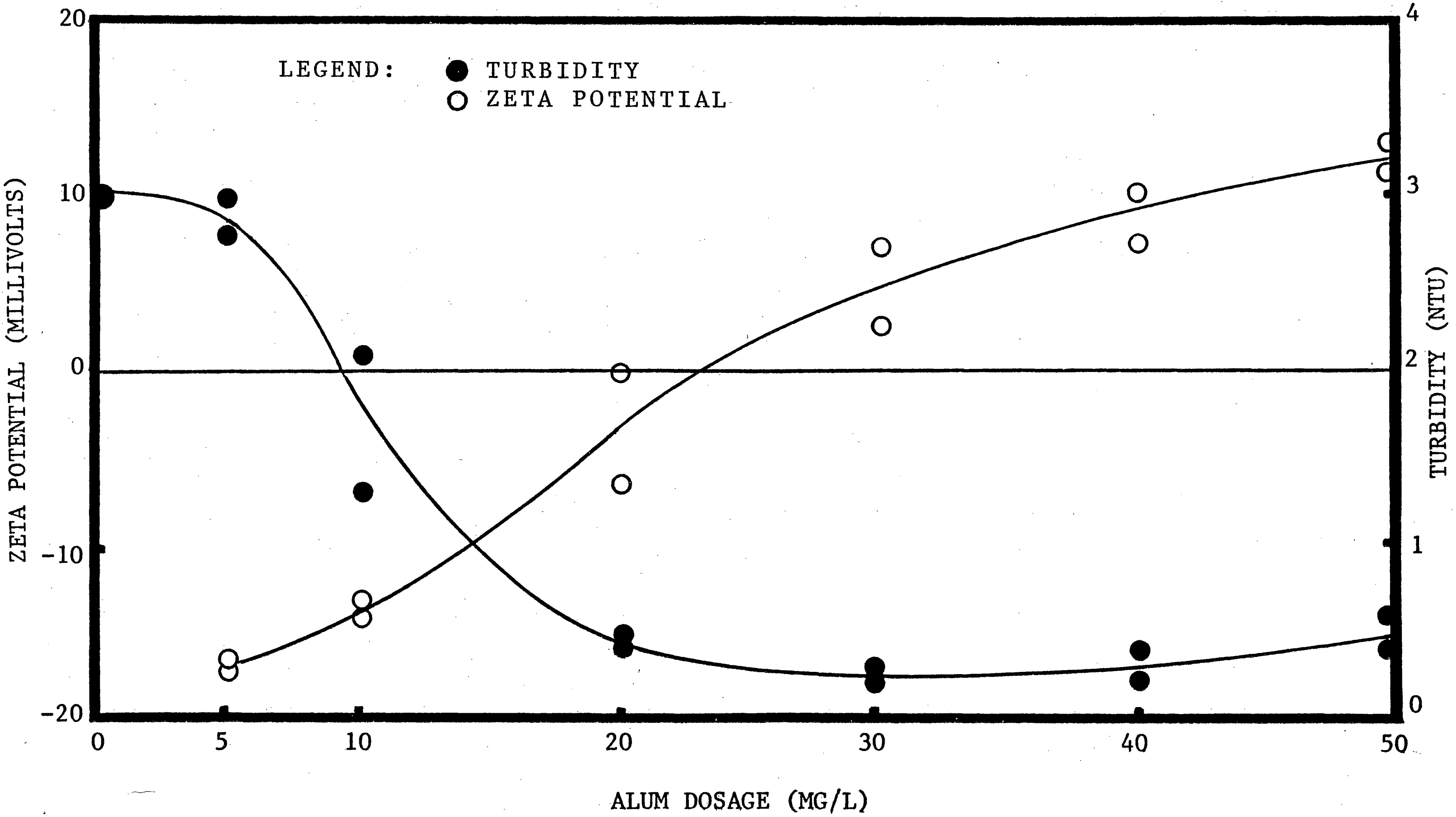
$$\frac{70,100 \text{ ml}}{8,470 \frac{\text{ml}}{\text{min}}} = \text{8.27 minutes or about 8 minutes and 20 seconds}$$

APPENDIX C

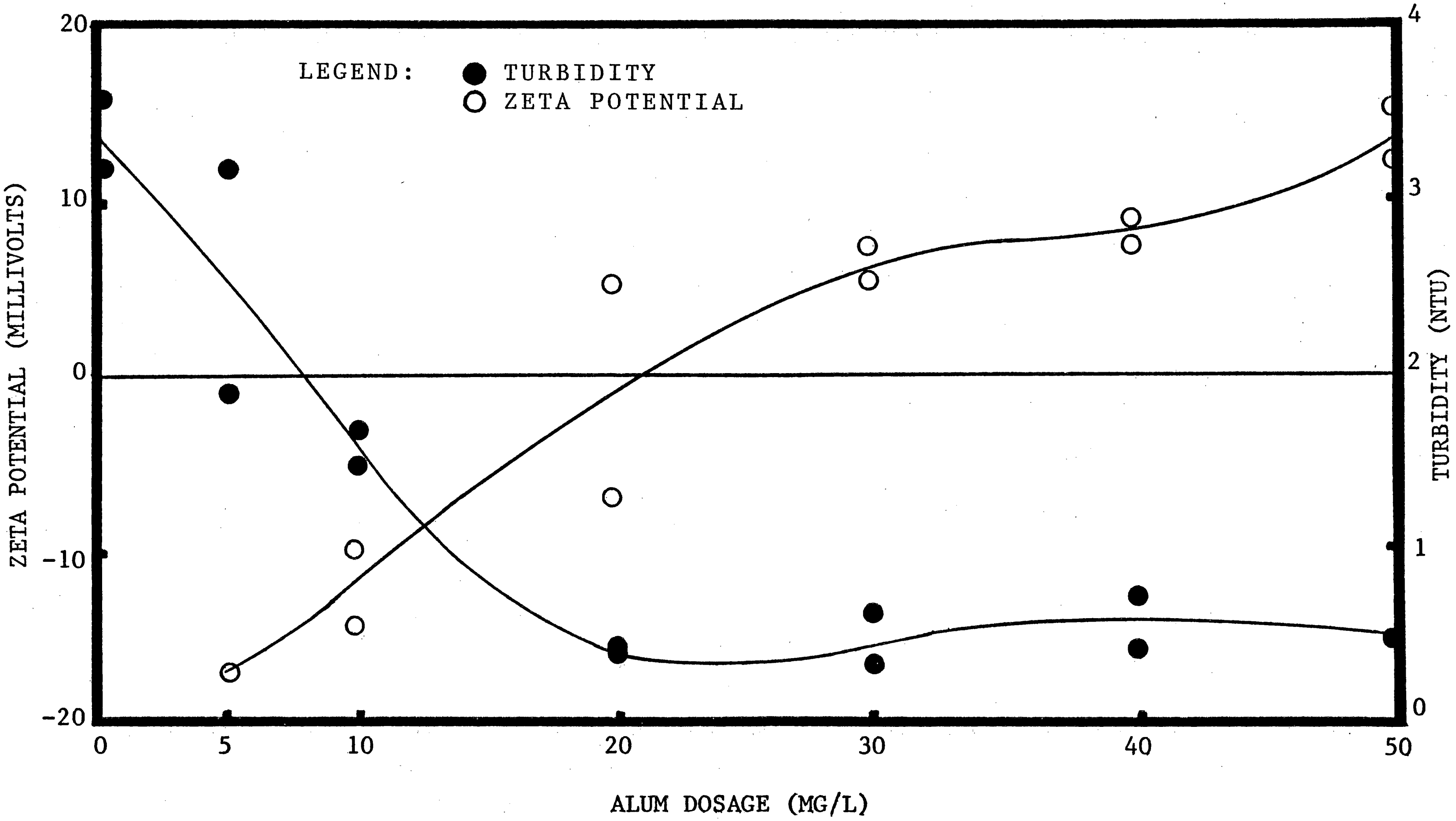
GRAPHICAL PRESENTATION OF THE RELATIONSHIP OF ZETA POTENTIAL AND TURBIDITY TO COAGULANT DOSAGE FOR TREATMENT CONFIGURATIONS 2 THROUGH 5 AT INITIAL pH LEVELS OF 6.5, 7.0, 7.5, and 8.0



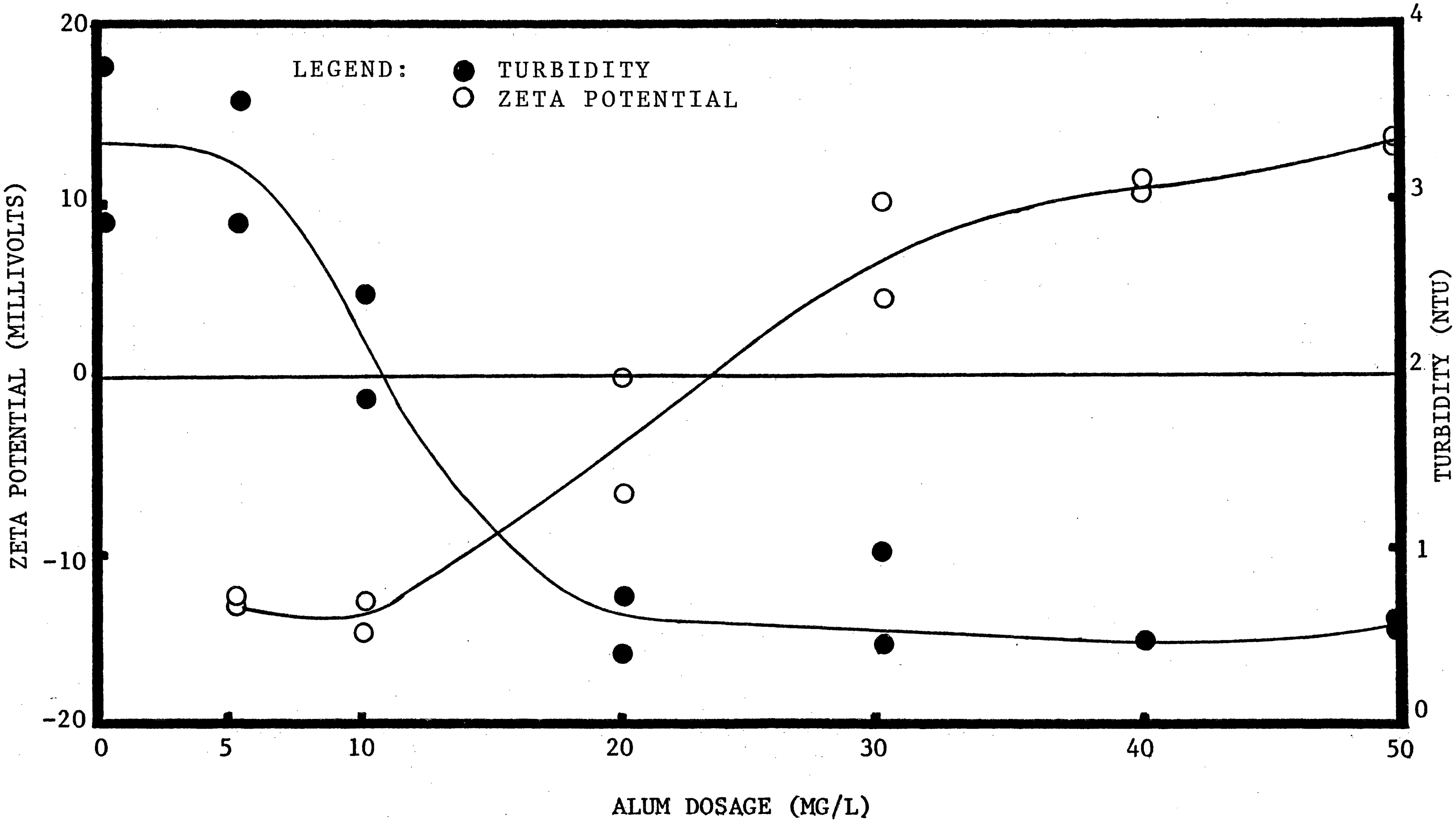
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 2, pH = 6.5



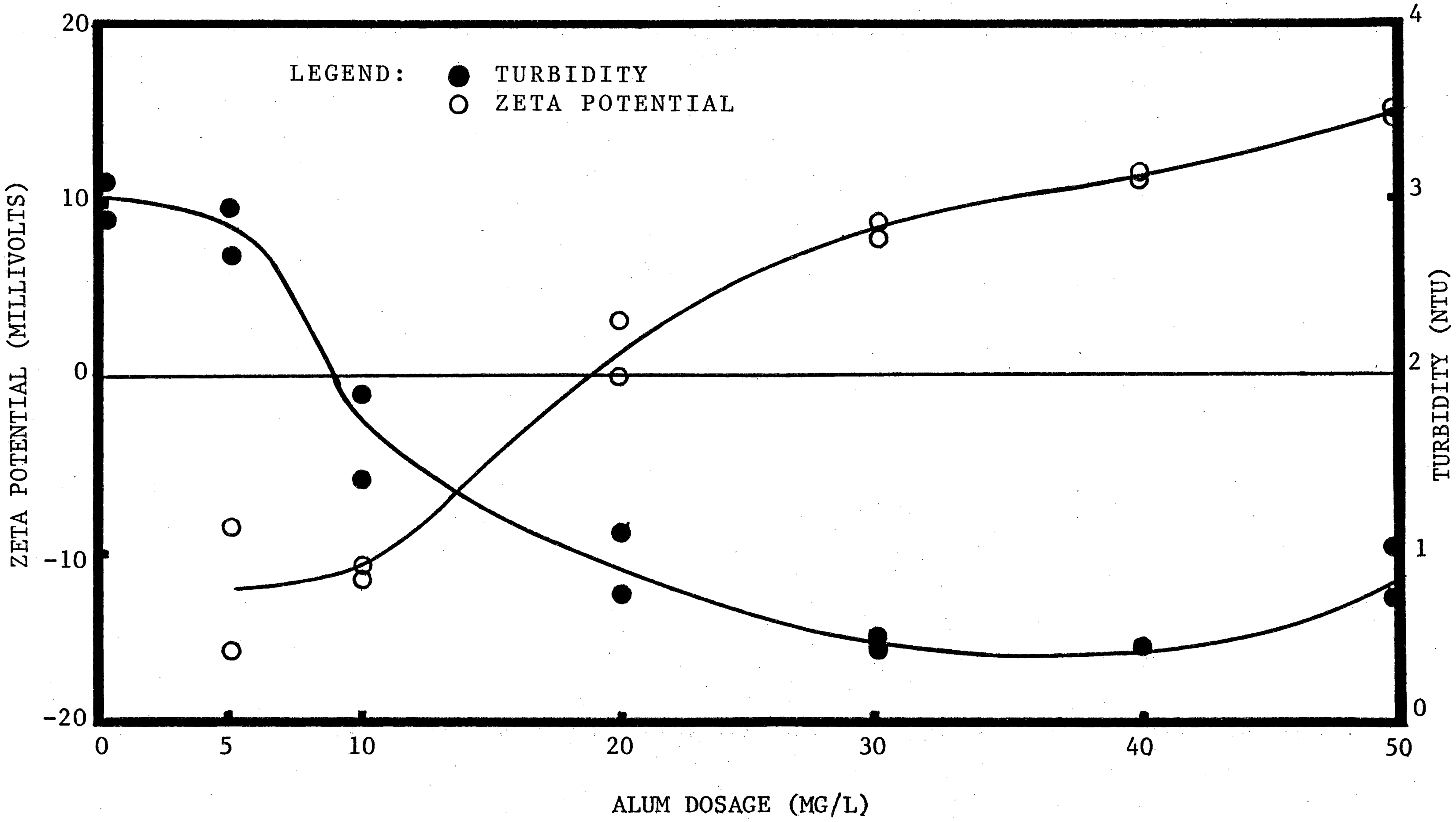
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 2, pH = 7.0



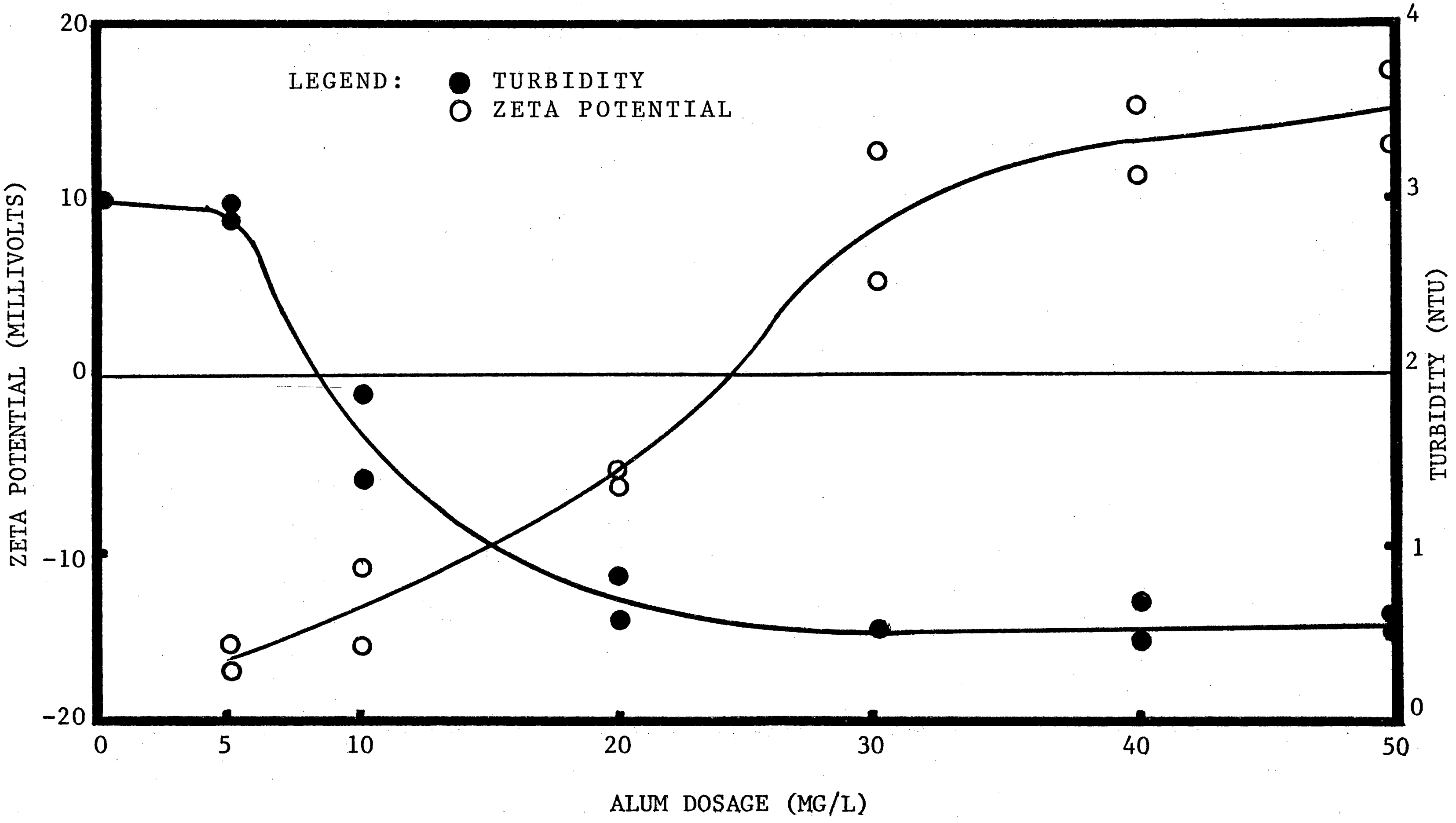
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 2, pH = 7.5



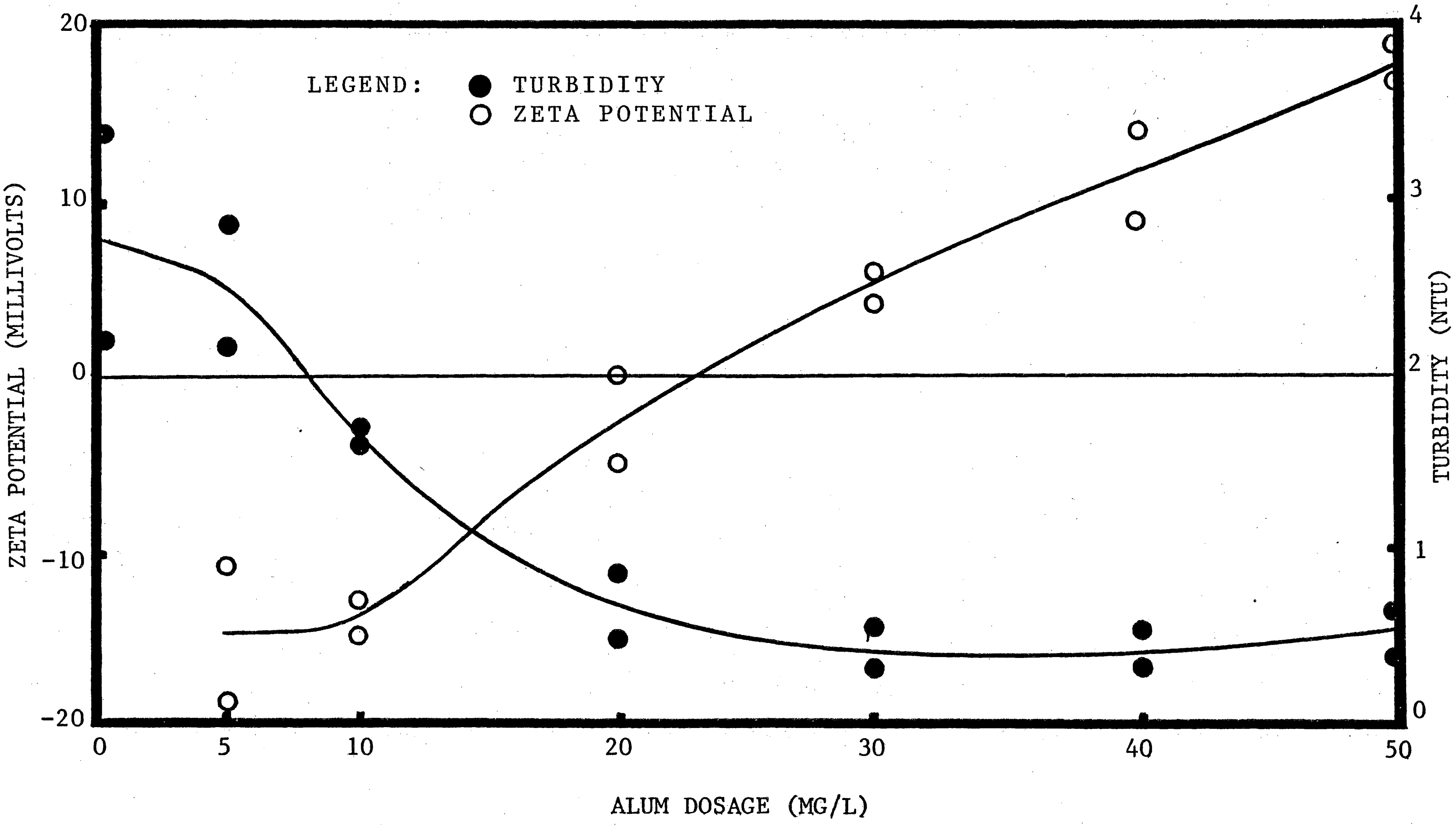
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 2, pH = 8.0



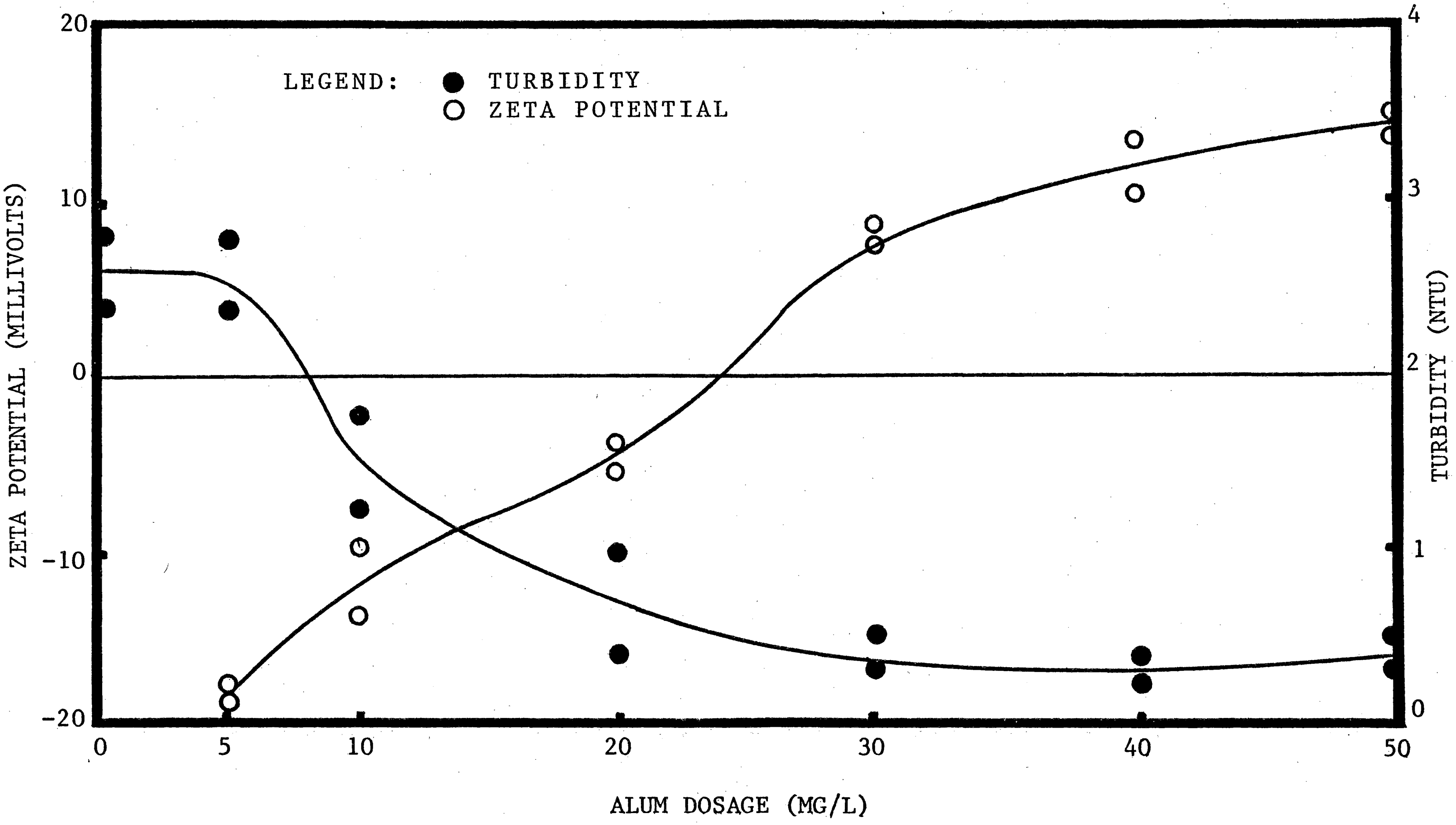
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 3, pH = 6.5



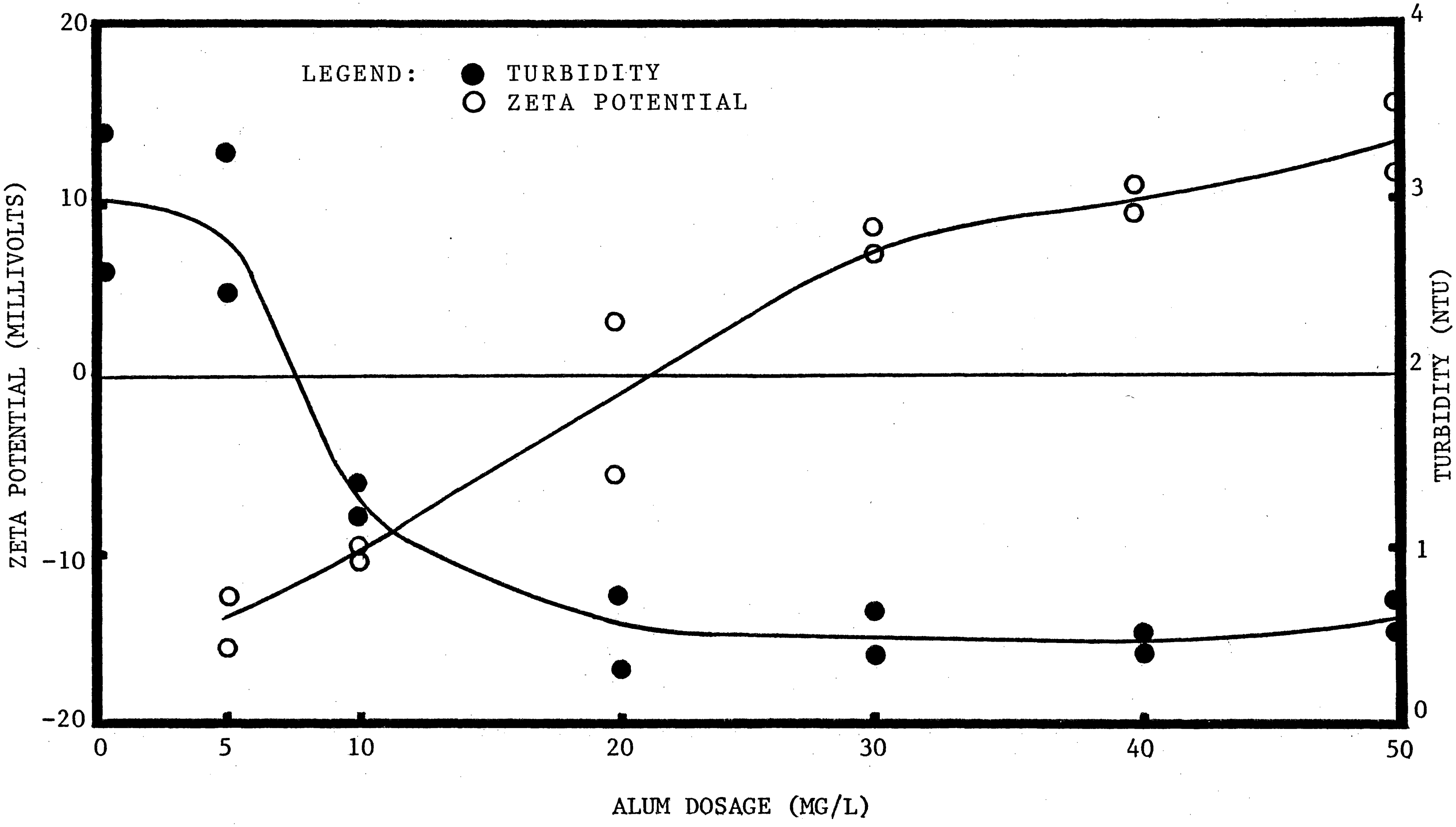
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 3, pH = 7.0



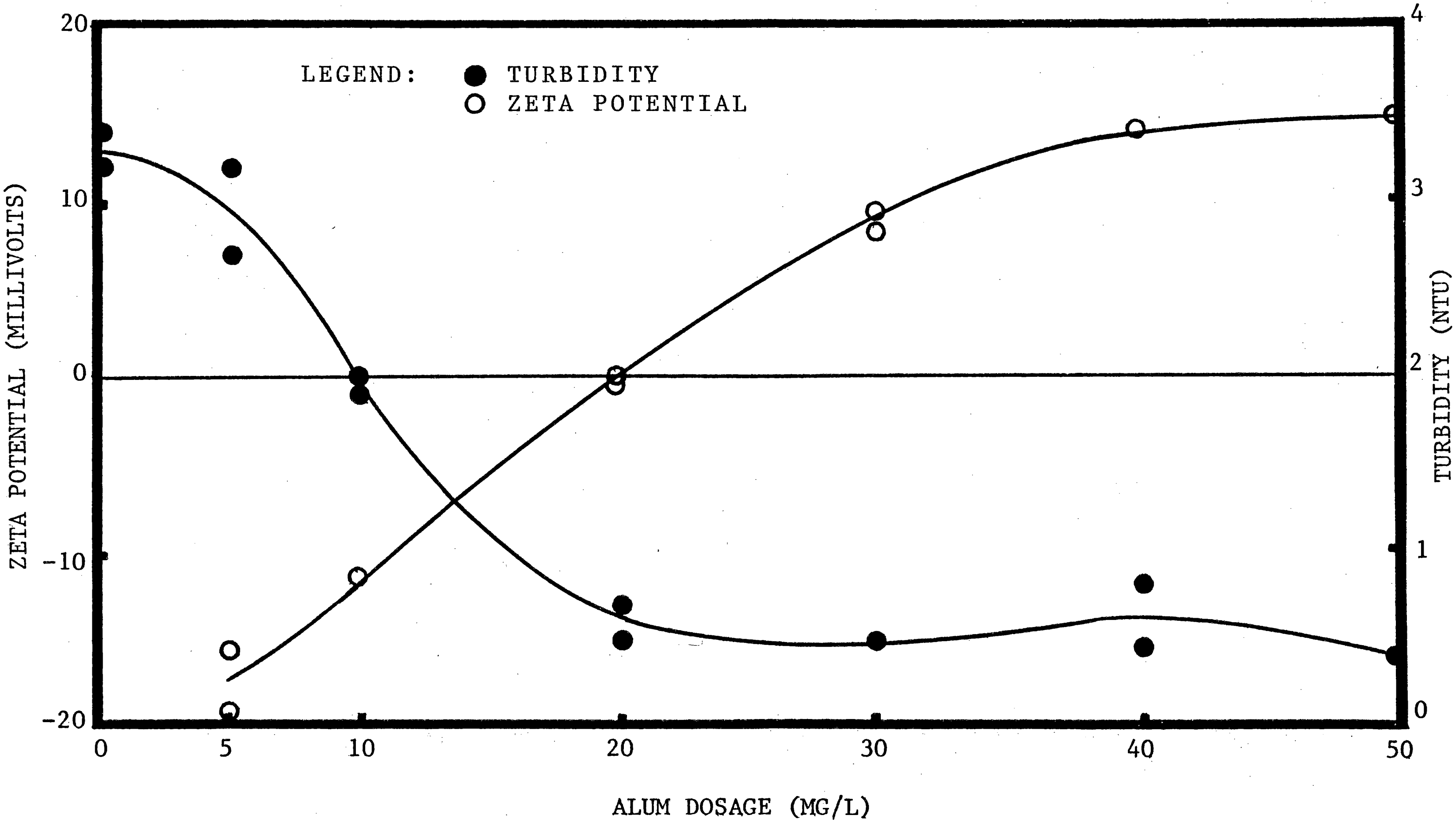
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 3, pH = 7.5



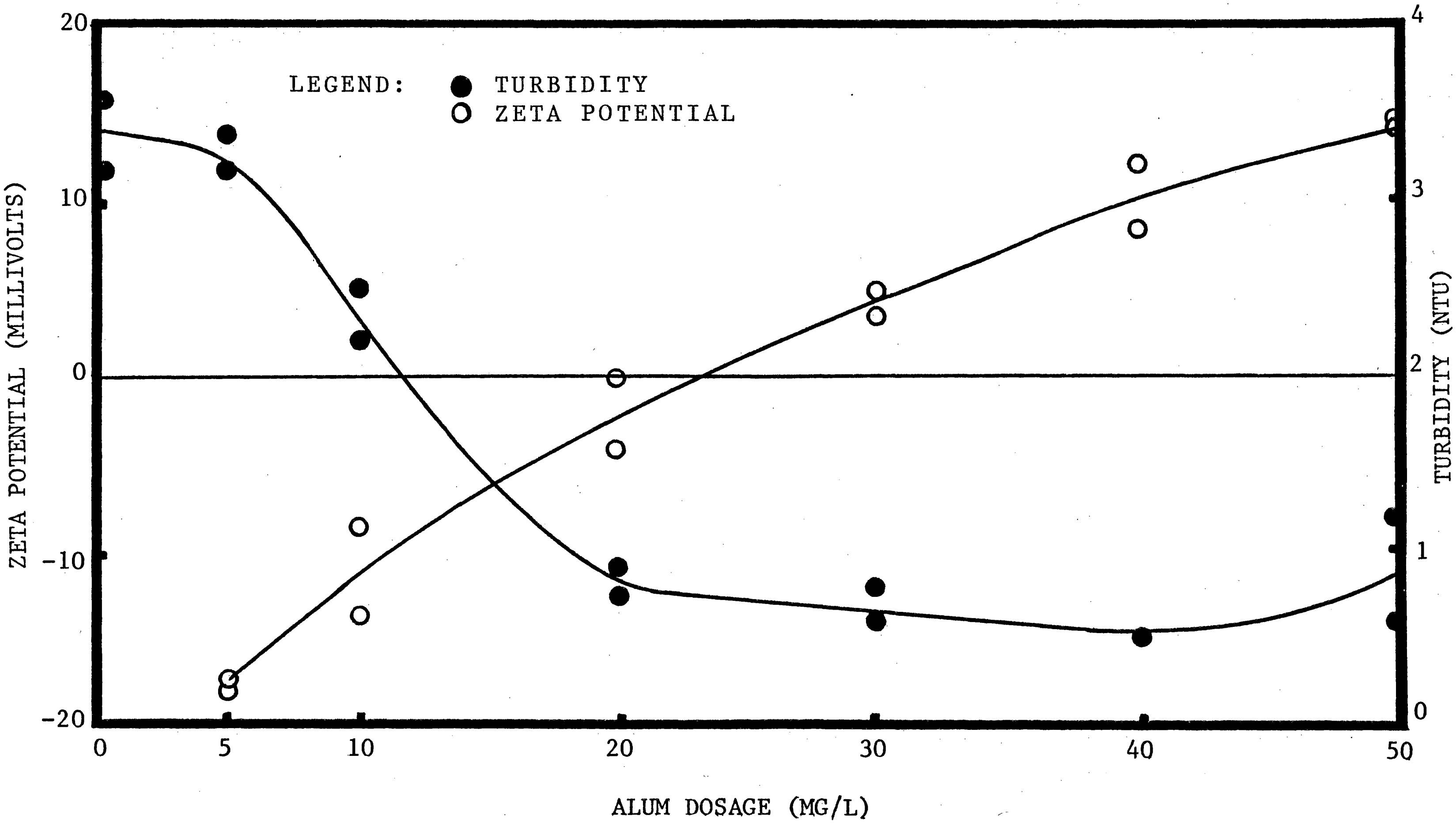
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 3, pH = 8.0



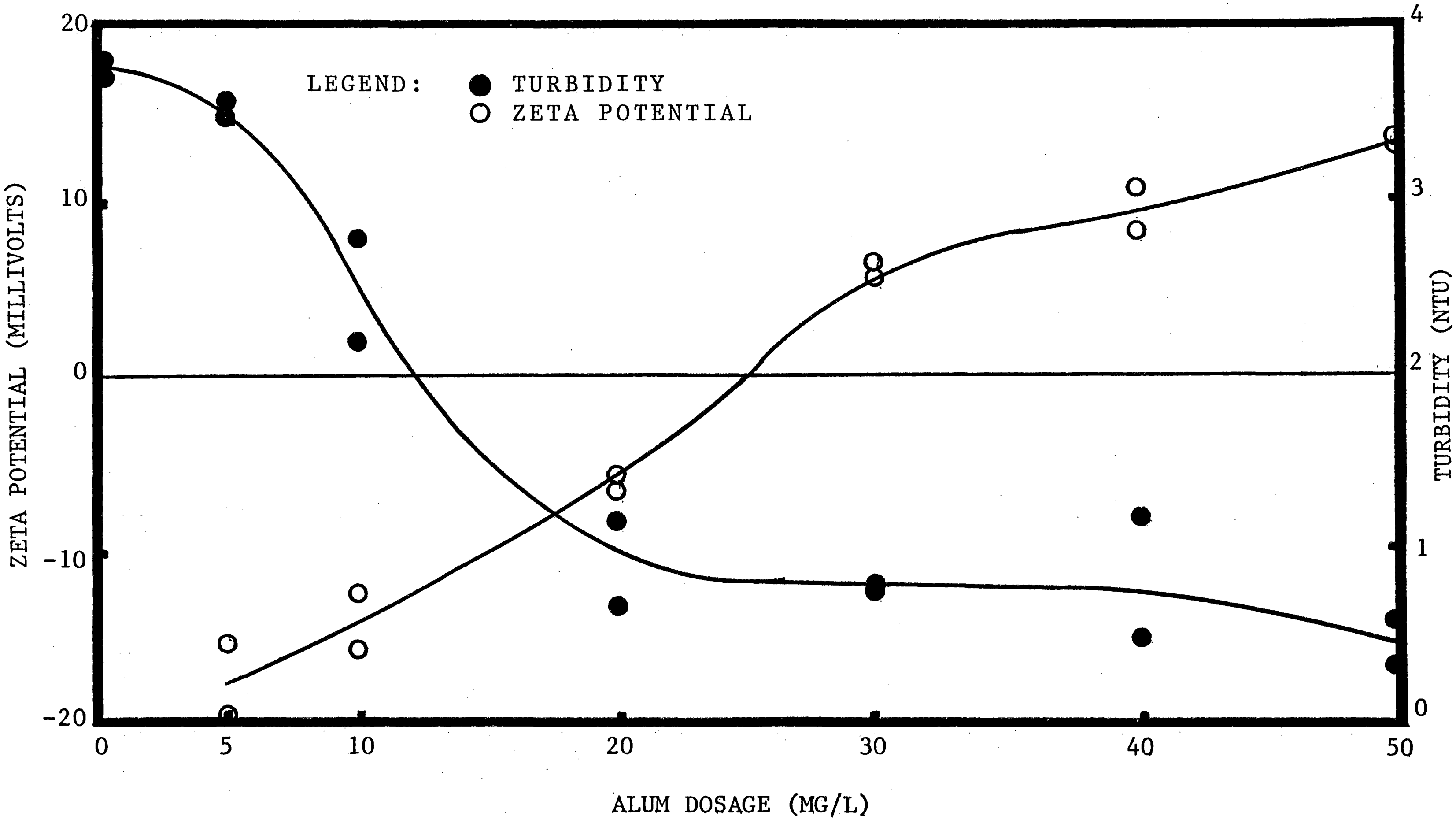
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 4, pH = 6.5



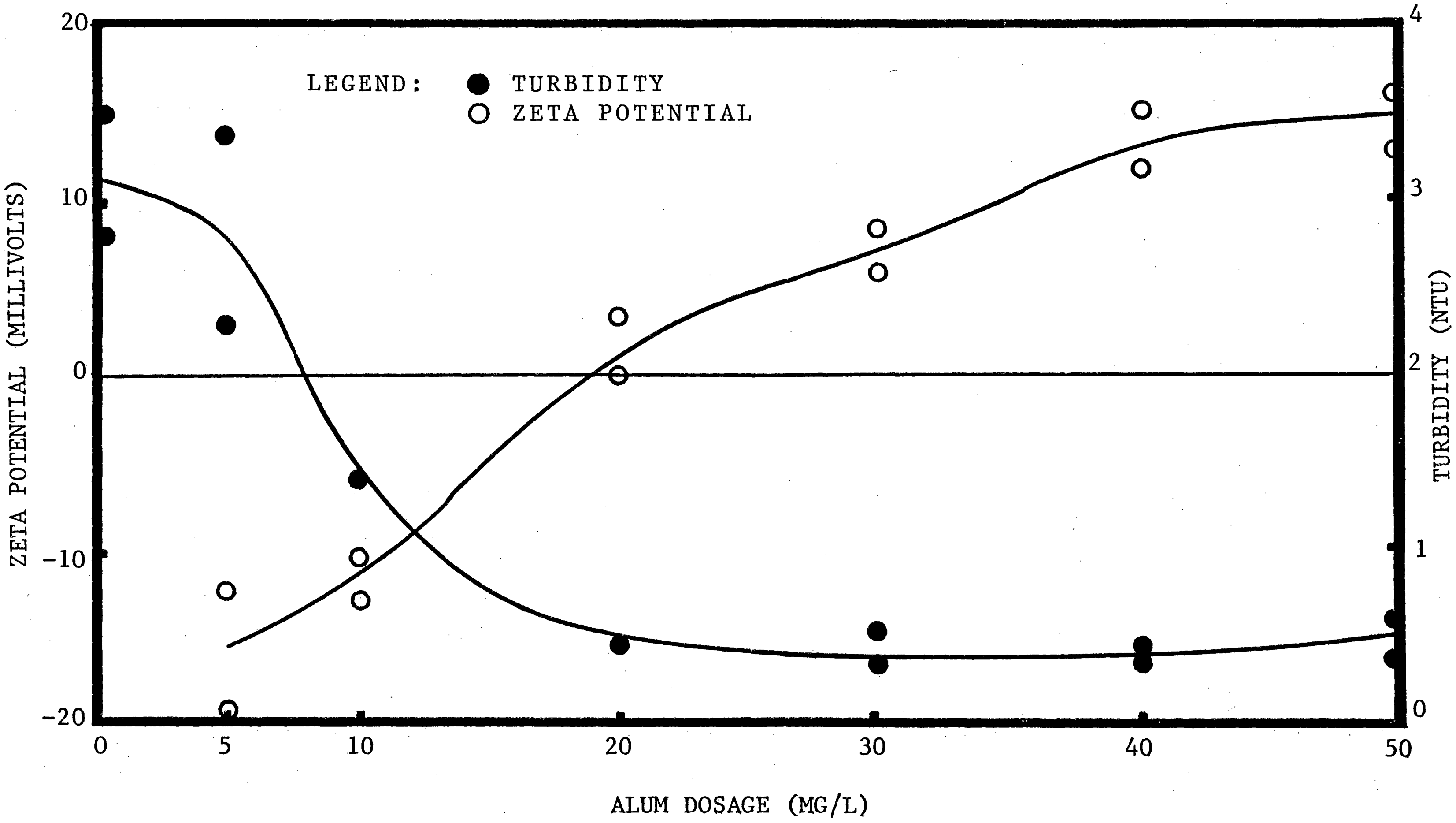
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 4, pH = 7.0



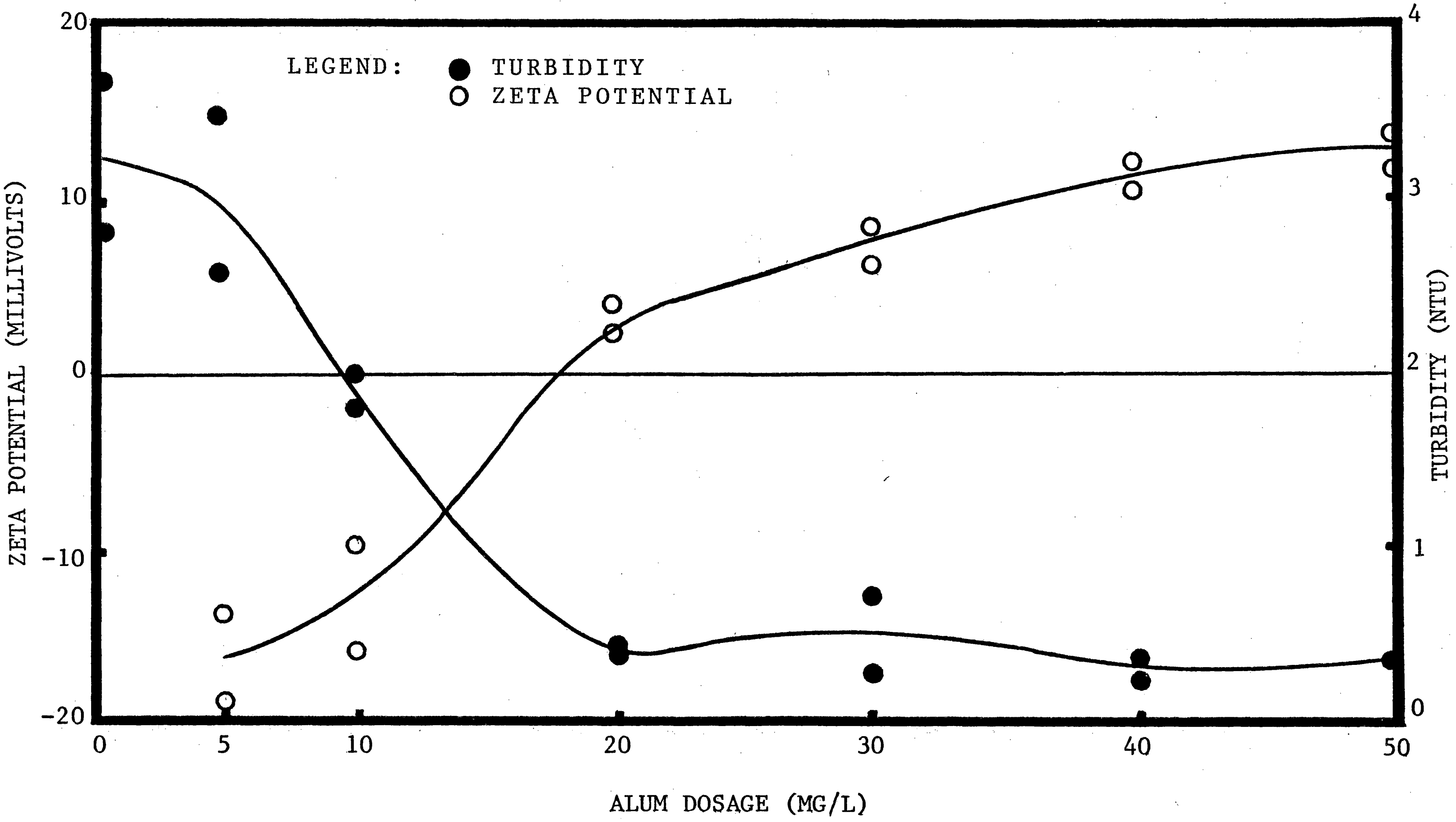
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 4, pH = 7.5



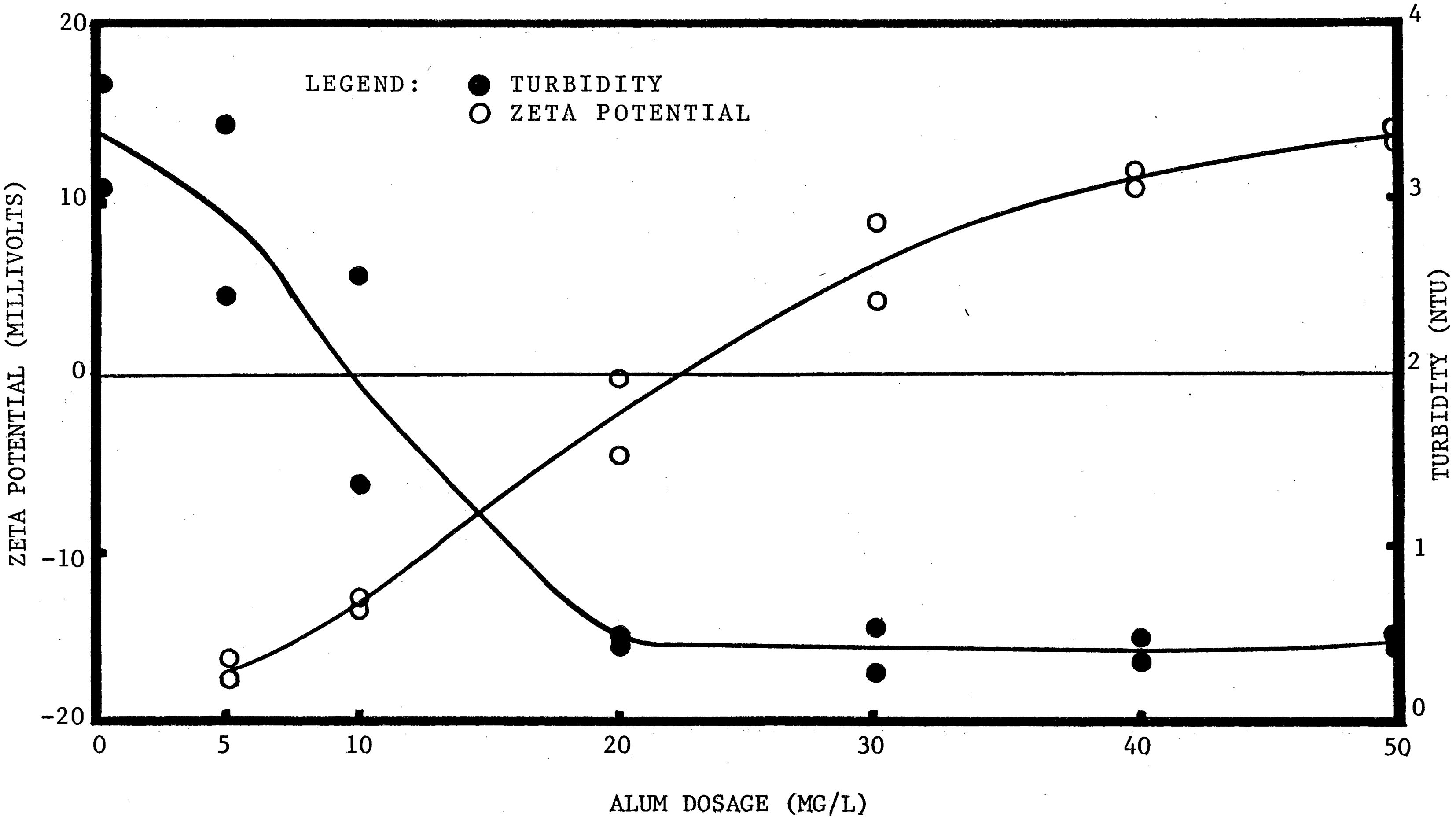
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 4, pH = 8.0



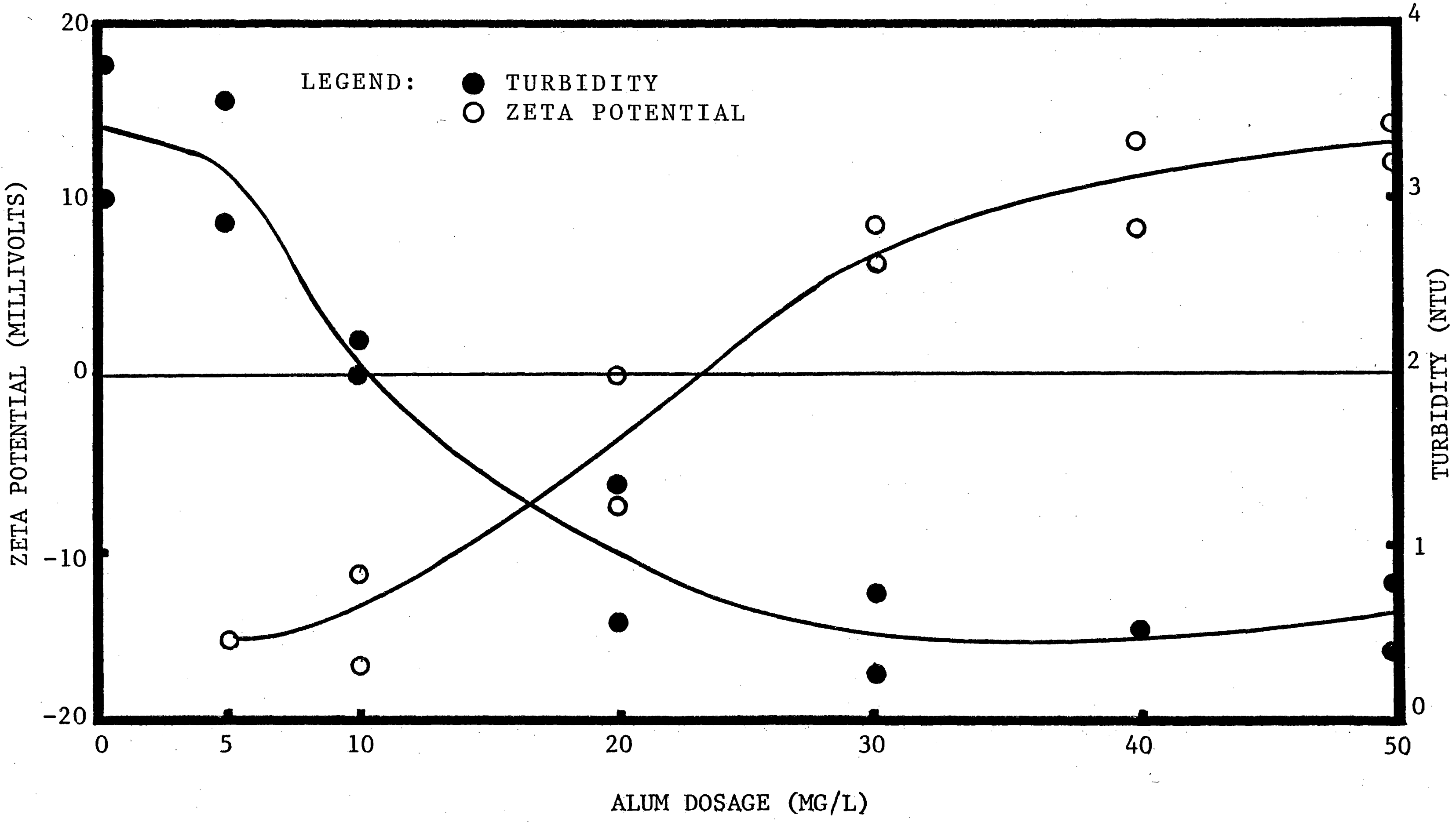
Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 5, pH = 6.5



Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 5, pH = 7.0



Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 5, pH = 7.5



Relationship of Zeta Potential and Turbidity to Alum Dosage for Treatment Configuration No. 5, pH = 8.0

APPENDIX D

RESULTS OF LABORATORY ANALYSIS FOR TESTS OF TREATMENT CONFIGURATIONS 1 THROUGH 7

TREATMENT PROCESS CONFIGURATION NO. 1

Raw Water Characteristics:

pH = 6.5	pH = 6.5
Alkalinity = 24.5 mg/l	Alkalinity = 38 mg/l
Turbidity = 2.5 NTU	Turbidity = 3.4 NTU

	Run No. 1						Run No. 2					
Jar No.	1	2	3	4	5	6	1	2	3	4	5	6
Alum Dose (mg/l)	5	10	20	30	40	50	5	10	20	30	40	50
Alkalinity (mg/l as $CaCO_3$)	26	22	18	13	9	7	34	32	27	22	19	14
Turbidity (NTU)	2.4	1.1	0.6	0.4	0.5	0.5	3.3	2.7	1.6	0.7	0.7	1.0
pH	6.4	6.2	5.0	5.9	5.8	5.8	6.5	6.4	6.3	6.3	6.1	6.1
pZ (millivolts)	-19.3	-12.4	-4.5	10.7	11.2	14.6	-15.7	-12.1	-3.2	5.3	7.7	15.2

TREATMENT PROCESS CONFIGURATION NO. 1

Raw Water Characteristics:

	Run No. 1	Run No. 2
pH	7.0	7.0
Alkalinity	33.5 mg/1	32 mg/1
Turbidity	2.9 NTU	3.2 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	34	31.5	27.5	22	18.5	15
Turbidity (NTU)	2.3	1.8	0.96	0.66	0.47	0.64
pH	7.0	7.0	6.8	6.8	6.5	6.3
pZ (millivolts)	-17.0	-12.3	-7.8	0	8.8	9.6

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	30	27	23	16.5	12.5	12
Turbidity (NTU)	2.6	1.6	0.70	0.49	0.49	0.76
pH	7.0	6.8	6.7	6.7	6.5	6.5
pZ (millivolts)	-16.1	-9.2	-9.5	3.1	12.1	16.6

TREATMENT PROCESS CONFIGURATION NO. 1

Raw Water Characteristics:

pH = 7.5

Alkalinity = 36.5 mg/1

Turbidity = 3.1 NTU

<u>Run No. 1</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	38	35	31	27	22	19
Turbidity (NTU)	2.8	1.6	1.1	0.73	0.70	1.0
pH	7.5	7.4	7.3	7.0	7.0	6.9
pZ (millivolts)	-19.3	-16.8	-8.4	-6.9	5.3	3.9

pH = 7.5

Alkalinity = 42 mg/1

Turbidity = 2.9 NTU

<u>Run No. 2</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	41	39	36	29	26	23
Turbidity (NTU)	2.5	1.8	1.3	0.68	0.50	0.81
pH	7.5	7.4	7.2	7.0	6.9	6.9
pZ (millivolts)	-17.8	-13.4	-5.8	2.0	7.2	13.4

TREATMENT PROCESS CONFIGURATION NO. 1

Raw Water Characteristics:

pH = 8.0

Alkalinity = 42.5 mg/1

Turbidity = 2.3 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	39.5	37	31	26	23
Turbidity (NTU)	2.3	2.2	1.6	0.98	0.62	1.0
pH	7.6	7.4	7.3	7.0	7.2	7.0
pZ (millivolts)	-17.0	-15.9	-14.1	-2.2	0	3.8

pH = 8.0

Alkalinity = 44 mg/1

Turbidity = 2.6 NTU

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	44	42.5	37.5	32	27	23
Turbidity (NTU)	2.2	1.8	0.91	0.40	0.35	0.45
pH	7.6	7.4	7.2	7.0	7.3	7.2
pZ (millivolts)	-19.2	-15.1	-7.1	1.0	5.9	15.6

TREATMENT PROCESS CONFIGURATION NO. 2

Raw Water Characteristics:

	Run No. 1	Run No. 2
pH	6.5	6.5
Alkalinity	26 mg/1	36 mg/1
Turbidity	2.6 NTU	3.4 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	24.5	22	18	14	10	6.5
Turbidity (NTU)	1.6	1.2	0.34	0.38	0.45	0.60
pH	6.5	6.5	6.3	6.1	5.8	5.6
pZ (millivolts)	-7.6	-6.9	3.8	8.1	11.4	12.0

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	34	30	27	24	22	20
Turbidity (NTU)	2.9	1.3	0.83	0.57	0.72	0.54
pH	6.5	6.4	6.3	6.2	6.0	5.8
pZ (millivolts)	-17.0	-12.9	-4.1	7.4	10.9	14.3

TREATMENT PROCESS CONFIGURATION NO. 2

Raw Water Characteristics:

pH = 7.0

Alkalinity = 40 mg/1

Turbidity = 3.0 NTU

<u>Run No. 1</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	38	37	34	28.5	24	21
Turbidity (NTU)	3.0	1.3	0.51	0.27	0.23	0.38
pH	6.9	6.9	6.8	6.5	6.4	6.2
pZ (millivolts)	-16.6	-13.4	0	2.6	10.5	13.4

pH = 7.0

Alkalinity = 40 mg/1

Turbidity = 3.0 NTU

<u>Run No. 2</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	38	36	31	26	22	19
Turbidity (NTU)	2.8	2.1	0.42	0.35	0.43	0.57
pH	7.3	7.3	7.1	7.0	6.8	6.8
pZ (millivolts)	-17.3	-14.4	-6.4	2.9	7.3	11.5

TREATMENT PROCESS CONFIGURATION NO. 2

Raw Water Characteristics:

pH = 7.5

Alkalinity = 42 mg/l

Turbidity = 3.2 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/l)	5	10	20	30	40	50
Alkalinity (mg/l as $CaCO_3$)	40	37	30	32	24	20
Turbidity (NTU)	1.9	1.5	0.40	0.35	0.44	0.40
pH	7.2	7.0	6.8	6.5	6.5	6.3
pZ (millivolts)	-17.0	-10.0	5.2	7.3	7.7	15.7

pH = 7.5

Alkalinity = 43 mg/l

Turbidity = 3.6 NTU

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/l)	5	10	20	30	40	50
Alkalinity (mg/l as $CaCO_3$)	41	39	35	30	27	24
Turbidity (NTU)	3.2	1.7	0.45	0.65	0.73	0.45
pH	7.4	7.3	7.2	7.0	6.9	6.7
pZ (millivolts)	-21.2	-14.2	-7.0	5.6	9.1	12.2

TREATMENT PROCESS CONFIGURATION NO. 2

Raw Water Characteristics:

pH = 8.0

Alkalinity = 43 mg/1

Turbidity = 2.9 NTU

pH = 8.0

Alkalinity = 45 mg/1

Turbidity = 3.8 NTU

<u>Run No. 1</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	40	37	34	26.5	21
Turbidity (NTU)	2.9	1.9	0.41	0.96	0.45	0.58
pH	7.4	7.1	7.0	6.7	6.5	6.2
pZ (millivolts)	-13.0	-13.0	-6.6	4.7	10.4	13.6

<u>Run No. 2</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	41	36	31	27	23
Turbidity (NTU)	3.6	2.5	0.76	0.44	0.41	0.55
pH	7.5	7.4	7.2	7.0	6.8	6.7
pZ (millivolts)	-13.0	-14.7	0	10.0	11.2	13.0

TREATMENT PROCESS CONFIGURATION NO. 3

Raw Water Characteristics:

pH = 6.5

Alkalinity = 28.5 mg/l

Turbidity = 2.9 NTU

pH = 6.5

Alkalinity = 31 mg/l

Turbidity = 3.1 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/l)	5	10	20	30	40	50
Alkalinity (mg/l as $CaCO_3$)	26	23.5	19	14	11	8
Turbidity (NTU)	2.7	1.4	0.75	0.43	0.43	0.70
pH	6.5	6.3	6.0	5.8	5.5	5.4
pZ (millivolts)	-8.7	-11.9	3.2	8.8	11.6	15.1

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/l)	5	10	20	30	40	50
Alkalinity (mg/l as $CaCO_3$)	32	29	24.5	20	16	13
Turbidity (NTU)	3.0	1.9	1.1	0.52	0.45	1.0
pH	6.5	6.3	6.2	6.1	5.9	5.7
pZ (millivolts)	-15.9	-11.2	0	7.8	11.1	15.3

TREATMENT PROCESS CONFIGURATION NO. 3

Raw Water Characteristics:

	Run No. 1	Run No. 2
pH	7.0	7.0
Alkalinity	40.5 mg/1	39 mg/1
Turbidity	3.0 NTU	3.0 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	41	38.5	34	28	23.5	20
Turbidity (NTU)	3.0	1.4	0.57	0.55	0.71	0.51
pH	7.0	6.9	6.8	6.6	6.2	6.1
pZ (millivolts)	-15.7	-11.1	-5.9	13.1	15.5	17.7

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	39	32	33.5	29	24	19
Turbidity (NTU)	2.9	1.9	0.85	0.55	0.47	0.65
pH	7.0	6.9	6.7	6.4	6.3	6.2
pZ (millivolts)	-17.0	-15.7	-6.5	5.5	11.8	13.0

TREATMENT PROCESS CONFIGURATION NO. 3

Raw Water Characteristics:

pH = 7.5	pH = 7.5
Alkalinity = 44 mg/1	Alkalinity = 41 mg/1
Turbidity = 2.2 NTU	Turbidity = 3.4 NTU

<u>Run No. 1</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	39.5	34	30	26	21.5
Turbidity (NTU)	2.2	1.6	0.47	0.27	0.32	0.36
pH	7.2	7.0	6.8	6.6	6.4	6.2
pZ (millivolts)	-11.0	-12.9	0	4.3	14.2	17.0

<u>Run No. 2</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	42	40	36	31	27	24
Turbidity (NTU)	2.9	1.7	0.86	0.56	0.54	0.66
pH	7.3	7.2	6.8	6.6	6.5	6.4
pZ (millivolts)	-18.9	-15.1	-5.2	6.0	9.0	19.2

TREATMENT PROCESS CONFIGURATION NO. 3

Raw Water Characteristics:

pH = 8.0

Alkalinity = 45 mg/1

Turbidity = 2.4 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	44	41	36.5	31	28	22.5
Turbidity (NTU)	2.4	1.25	0.38	0.30	0.24	0.30
pH	7.3	7.2	6.8	6.8	6.4	6.2
pZ (millivolts)	-17.9	-9.8	-4.0	8.7	13.4	15.0

pH = 8.0

Alkalinity = 45 mg/1

Turbidity = 2.8 NTU

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	42	36	31	26.5	21.5
Turbidity (NTU)	2.8	1.8	0.98	0.50	0.43	0.46
pH	7.4	7.1	6.9	6.7	6.6	6.4
pZ (millivolts)	-18.9	-13.7	-5.7	7.4	10.3	13.5

TREATMENT PROCESS CONFIGURATION NO. 4

Raw Water Characteristics:

pH = 6.5

Alkalinity = 27 mg/l

Turbidity = 2.6 NTU

<u>Run No. 1</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/l)	5	10	20	30	40	50
Alkalinity (mg/l as $CaCO_3$)	26.5	23	19	14.5	11	8.5
Turbidity (NTU)	2.5	1.2	0.27	0.41	0.41	0.71
pH	6.5	6.4	6.4	6.2	6.2	5.8
pZ (millivolts)	-12.5	-9.7	3.1	8.6	9.5	11.5

pH = 6.5

Alkalinity = 36 mg/l

Turbidity = 3.4 NTU

<u>Run No. 2</u>

Jar No.	1	2	3	4	5	6
Alum Dose (mg/l)	5	10	20	30	40	50
Alkalinity (mg/l as $CaCO_3$)	32	30	25	20	17	13
Turbidity (NTU)	3.3	1.4	0.75	0.65	0.52	0.53
pH	6.5	6.5	6.3	6.2	6.2	6.1
pZ (millivolts)	-15.8	-10.9	-5.9	7.2	8.9	15.8

TREATMENT PROCESS CONFIGURATION NO. 4

Raw Water Characteristics:

pH = 7.0

Alkalinity = 41 mg/1

Turbidity = 3.2 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	40	60	80
Alkalinity (mg/1 as $CaCO_3$)	39	37	32	21	14	8
Turbidity (NTU)	3.2	1.9	.50	.41	.52	.51
pH	7.0	6.8	6.6	6.7	6.4	5.6
pZ (millivolts)	-15.7	-20.0	0	9.6	11.2	11.5

pH = 7.0

Alkalinity = 38.5 mg/1

Turbidity = 3.4 NTU

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	38.5	35	31	26	21	18
Turbidity (NTU)	2.7	2.0	0.72	0.45	0.80	0.40
pH	6.9	6.8	6.6	6.4	6.2	6.0
pZ (millivolts)	-19.2	-11.2	0	8.5	14.5	14.9

TREATMENT PROCESS CONFIGURATION NO. 4

Raw Water Characteristics:

pH = 7.5

Alkalinity = 39 mg/1

Turbidity = 3.2 NTU

pH = 7.5

Alkalinity = 44 mg/1

Turbidity = 3.6 NTU

	Run No. 1						Run No. 2					
Jar No.	1	2	3	4	5	6	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	40	37	32	27	23.5	19	43	41	34	30	27	24
Turbidity (NTU)	3.4	2.2	.90	.80	.50	.61	3.2	2.5	0.76	0.56	0.50	1.2
pH	7.0	6.8	7.0	7.0	6.8	6.8	7.3	7.2	7.1	6.9	6.8	6.7
pZ (millivolts)	-18.1	-8.6	-4.2	4.9	12.3	14.0	-17.3	-13.8	0	3.5	8.5	14.4

TREATMENT PROCESS CONFIGURATION NO. 4

Raw Water Characteristics:

	Run No. 1	Run No. 2
pH	8.0	8.0
Alkalinity	44 mg/1	45 mg/1
Turbidity	3.7 NTU	3.8 NTU

	Run No. 1						Run No. 2					
Jar No.	1	2	3	4	5	6	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	42	36	26	26.5	18	43	42	37	33	29	26
Turbidity (NTU)	3.6	2.2	1.2	0.8	0.40	0.60	3.5	2.8	0.68	0.75	1.21	0.33
pH	7.0	7.0	7.2	6.5	6.4	6.2	7.5	7.5	7.3	7.1	6.9	6.9
pZ (millivolts)	-15.7	-12.5	-5.6	6.6	10.9	13.8	-19.8	-15.8	-6.9	5.7	8.4	13.4

TREATMENT PROCESS CONFIGURATION NO. 5

Raw Water Characteristics:

pH = 6.5

Alkalinity = 30 mg/1

Turbidity = 2.8 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	30	27	23	18.5	14.5	11
Turbidity (NTU)	2.3	1.4	0.45	0.53	0.45	0.62
pH	6.4	6.1	5.9	5.7	5.4	5.2
pZ (millivolts)	-20.2	-15.1	-10.1	8.6	15.2	16.2

pH = 6.5

Alkalinity = 35 mg/1

Turbidity = 3.5 NTU

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	33.5	31	27	22	18	15
Turbidity (NTU)	3.4	1.4	0.45	0.33	0.35	0.38
pH	6.4	6.3	6.1	5.9	5.7	5.5
pZ (millivolts)	-12.7	10.6	0	5.9	12.0	13.0

TREATMENT PROCESS CONFIGURATION NO. 5

Raw Water Characteristics:

pH = 7.0
Alkalinity = 38 mg/1
Turbidity = 2.8 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	38	36	30.5	26	21.5	18
Turbidity (NTU)	2.6	1.8	0.41	0.75	0.41	0.34
pH	7.0	6.9	6.8	6.5	6.3	6.1
pZ (millivolts)	-19.0	-16.1	0	8.7	10.6	11.9

pH = 7.0
Alkalinity = 40 mg/1
Turbidity = 3.7 NTU

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	37	34	31	26	22	18
Turbidity (NTU)	3.5	2.0	0.63	0.30	0.25	0.37
pH	7.0	6.9	6.7	6.4	6.3	6.1
pZ (millivolts)	-14.2	-10.0	0	6.6	12.3	14.0

TREATMENT PROCESS CONFIGURATION NO. 5

Raw Water Characteristics:

pH = 7.5

Alkalinity = 43.5 mg/1

Turbidity = 3.1 NTU

Run No. 1

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	44	40	35	30	25	21
Turbidity (NTU)	2.5	1.4	0.50	0.28	0.35	0.42
pH	7.4	7.2	6.9	6.6	6.4	6.2
pZ (millivolts)	-16.3	-12.9	0	4.4	11.9	13.4

pH = 7.5

Alkalinity = 45 mg/1

Turbidity = 3.7 NTU

Run No. 2

Jar No.	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	40	35	31	27	24
Turbidity (NTU)	3.5	2.6	0.44	0.55	0.50	0.50
pH	7.4	7.3	7.2	7.1	6.8	6.7
pZ (millivolts)	-17.9	-13.5	-4.6	9.1	11.0	14.2

TREATMENT PROCESS CONFIGURATION NO. 5

Raw Water Characteristics:

pH = 8.0

Alkalinity = 43 mg/1

Turbidity = 3.0 NTU

pH = 8.0

Alkalinity = 47 mg/1

Turbidity = 3.8 NTU

	Run No. 1							Run No. 2					
Jar No.	1	2	3	4	5	6	1	1	2	3	4	5	6
Alum Dose (mg/1)	5	10	20	30	40	50		5	10	20	30	40	50
Alkalinity (mg/1 as $CaCO_3$)	43	42	37	31.5	26	21		45	43	38	33	28	25
Turbidity (NTU)	2.9	2.0	1.4	0.30	0.58	0.81		3.6	2.2	0.56	0.75	0.51	0.37
pH	7.6	7.2	6.9	6.6	6.4	6.2		7.6	7.4	7.2	7.1	6.9	6.8
pZ (millivolts)	-23.7	-16.6	-7.7	6.5	8.3	12.1		-15.2	-11.4	0	8.9	13.7	14.7

TREATMENT PROCESS CONFIGURATION NO. 6

Raw Water Characteristics:

pH = 7.6

Alkalinity = 42 mg/1

Turbidity = 2.8 NTU

<u>Run No. 1</u>

Jar No.	1	2	3	4	5	6	7
Polymer Dose (mg/1)	0.5	1.0	1.5	2.0	3.0	4.0	6.0
Alkalinity (mg/1 as $CaCO_3$)	42	42	42	42	42	42	42
Turbidity (NTU)	3.3	3.3	3.4	3.6	3.2	3.9	4.0
pH	7.6	7.6	7.6	7.6	7.6	7.6	7.6
pZ (millivolts)	-14.4	-14.4	-11.9	-6.8	-6.2	-4.3	5.4

pH = 7.6

Alkalinity = 42 mg/1

Turbidity = 2.9 NTU

<u>Run No. 2</u>

Jar No.	1	2	3	4	5	6
Polymer Dose (mg/1)	1.0	1.5	2.0	4.0	6.0	8.0
Alkalinity (mg/1 as $CaCO_3$)	42	42	42	42	42	42
Turbidity (NTU)	3.4	3.4	3.6	4.0	4.3	4.5
pH	7.6	7.6	7.6	7.6	7.6	7.6
pZ (millivolts)	-13.0	-12.1	-10.0	-3.0	4.1	9.3

TREATMENT PROCESS CONFIGURATION NO. 7

Raw Water Characteristics:

pH = 7.6

Alkalinity = 42 mg/1

Turbidity = 2.8 NTU

pH = 7.6

Alkalinity = 42 mg/1

Turbidity = 2.8 NTU

	Run No. 1						Run No. 2					
Jar No.	1	2	3	4	5	6	1	2	3	4	5	6
Polymer Dose (mg/1)	1.0	1.5	2.0	4.0	6.0	8.0	1.0	1.5	2.0	4.0	6.0	8.0
Alkalinity (mg/1 as $CaCO_3$)	42	42	42	42	42	42	42	42	42	42	42	42
Turbidity (NTU)	3.4	3.5	3.7	4.5	4.7	4.2	3.3	3.5	3.7	4.4	4.7	4.9
pH	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
pZ (millivolts)	-14.2	-12.5	-8.0	-3.2	5.0	9.0	-13.2	-13.3	-9.1	-2.0	5.9	10.3

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OPTIMIZATION OF THE COAGULATION PROCESS AT THE CARVINS COVE WATER TREATMENT PLANT

by

Terence Edward Knight

(ABSTRACT)

The overall process of water treatment is a compilation of various unit processes including: aeration, disinfection, the mixing of chemicals, flocculation, sedimentation, and filtration. The arrangement of these various unit processes into different treatment configurations provided the basis for laboratory-scale experimentation in which the zeta potential, turbidity, alkalinity, and pH were monitored to determine the optiminium operating mode for the Carvins Cove water treatment plant in Virginia during June and July, 1979.

Results indicated that none of the treatment configurations tested produced significantly different results. Marginal improvement in turbidity removal was accomplished when alum was added after aeration rather than before aeration. The use of aeration did not significantly affect the coagulation process.

Rapid mixing of the alum with a jar test apparatus did not significantly affect the turbidity removal achieved. The cationic polymer, CatFloc T, did not reduce the low turbidity of the raw water.