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Report No. DAAK02-67-C-0398-I

ENGINEERING DESIGN STUDY FOR THE DEVELOPMENT OF

A SELF-CONTAINED, AIR-TRANSPORTABLE

WASTEWATER TREATMENT PROTOTYPE (U)

(Interim Technical Report)

AUTHORED BY: Anthony Geinopolos
Richard E. Wullschleger
Donald G. Mason

February 1968

PREPARED FOR:

THE U. S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT

CENTER, FORT BELVOIR, VIRGINIA

Contract No. DAAK02-67-C-0398
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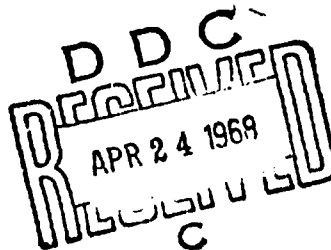
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MILWAUKEE, WISCONSIN

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SUMMARY

This report documents the Engineering Design Study phase of an overall effort to develop and test a prototype wastewater treatment system for renovating a combined advanced military base wastewater consisting of kitchen, laundry, and shower wastewaters for reuse purposes other than drinking and food preparation. The objective of this phase with respect to the overall effort was to develop a number of integrated wastewater treatment systems which may be used to treat satisfactorily the combined raw wastewater.

The work performed during this phase consisted of a literature survey, a laboratory investigation, and an engineering design evaluation. The literature survey was conducted to evaluate existing individual wastewater treatment processes which may be applicable in rendering the combined wastewater in question amenable to the required treatment. The laboratory investigation was performed on a synthetic wastewater to determine process applicability and to demonstrate the feasibility of the most promising treatment systems uncovered in the literature survey. The engineering design evaluation was carried out to design and evaluate a number of prototype integrated wastewater treatment systems using the pertinent information obtained from the laboratory investigation.

The literature search indicated that the most applicable wastewater purification methods for treatment of the combined wastewater were chemical treatment, adsorption, and chemical oxidation. The results of the laboratory investigation showed that a combination of chemical treatment and adsorption was necessary for satisfactory purification of the wastewater. Ferric sulfate, lime (CaO), and activated carbon (either powdered or granular) were the combination of chemicals and adsorbent giving the best results. It was found that the process elements associated with an integrated wastewater treatment system should include raw wastewater equalization, purification, filtration polishing, disinfection, and sludge treatment. Basic design information was obtained in the laboratory investigation for the design of the equipment components of an integrated wastewater treatment system.

Seven integrated wastewater treatment systems were designed and proposed for consideration in the selection of a prototype treatment system to be used in treating the wastewater. The proposed systems consisted of three batch treatment systems and four continuous flow treatment systems. The proposed systems were evaluated using the following evaluation parameters: total package weight, cubage (in transport and in operation), logistical support requirements, operational skills required, maintenance requirements, complexity of component assembly, power requirement, availability of fabrication materials, water recovery capability, odor control provisions, and cost per unit volume product water produced. Evaluation of the proposed treatment systems favored the selection of a batch treatment system for treating the wastewater.

FOREWORD

The work documented in this report was authorized by the U.S. Army Mobility Equipment Research and Development Center of Fort Belvoir, Virginia, as specified in the body of Contract No. DAAK02-67-C-0398 and its Attachments, "A" through "E". This is an Interim Technical Report, Type II, and represents the Engineering Design Study Phase of the project. The conclusions drawn were done so from the data obtained from two sources: (1) a comprehensive literature search of presently known waste and water treatment processes, and (2) detailed laboratory and bench scale tests conducted on those process elements which appeared to have applicability to the fulfillment of this contract. The recommendations made are subject to the approval of a Review Board whose function it will be to choose which system is to be employed in the design and fabrication of the prototype unit.

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1.0 INTRODUCTION

The objective of Contract No. DAAK02-67-C-0398 is to effect the design, fabrication, and testing of a self-contained air-transportable prototype wastewater treatment unit. This unit must be field-erectable and capable of treating 7500 gallons per day of combined wastewater in such a manner as to produce a potable effluent for reuse in activities other than drinking or food preparation. The source of the wastewater to be treated is a combined flow from kitchen, laundry, and shower facilities.

The first phase of the work scope on this contract was an engineering design study which was conducted in three steps: 1) a comprehensive literature search; 2) a compilation and laboratory testing of possible integrated process systems to treat the wastewater; and, 3) engineering evaluations for each of the integrated systems which appeared to be applicable to the problem. This Interim Technical Report is a documentation of the work done to complete this phase of the contractual agreement, and covers the period from 8 May 1967 to 4 October 1967.

2.0 THE LITERATURE SEARCH

2.1 Preliminary Remarks

At the outset, it was determined that an integrated treatment process for renovating the combined wastewater could best be arrived at by individually evaluating the various elements of wastewater treatment. Consequently, the search of published literature for information on pertinent process applications was directed to the following areas:

- A. Accumulation and blending of wastewater
- B. Purification
- C. Polishing the effluent
- D. Disinfecting the effluent
- E. Treatment of sludge for disposal
- F. Process control and effluent monitoring

The documentation of the literature search portion of Phase I will follow the order outlined above.

2.2 Accumulation and Blending

The combined wastewater, having its sources in three distinct areas, exhibits two variables which are pertinent to its treatment. First, the composition with regard to types and amounts of impurities, and, second, the flow with regard to rate. Normal usage of the facilities providing the wastewater dictates that their contributions will differ in composition and vary widely in the volume produced at any given time.

To simplify the treatment of the combined results, provision for an accumulation and blending of the influents will be made. This not only will allow for an equalization of flow rates to subsequent treatment facilities, but will facilitate the settling of readily removable solids. Further, it will serve as an aid to standardizing the additions of chemicals, oxidizing agents, and disinfectants during the treatment process. Support for the benefits accrued from the blending and equalization of combined wastewater flows is found in the literature.^{(1) (2)}

2.3 Purification

The major constituents of the wastewater to be treated include organic matter, detergents, soaps, dirt, oil, grease, and Coliform organisms. Most of these constituents have to be removed from the raw wastewater in varying amounts in order to produce the required characteristics in the effluent. The impurities may be in the form of suspended, colloidal, or dissolved matter. The readily separable suspended matter may be removed using primary treatment methods such as plain flotation or sedimentation. Particulate matter that cannot be separated by primary treatment, such as finely divided solids, may be further removed by intermediate or chemical treatment. Finally, objectionable matter in colloidal or dissolved form may be treated using biological or chemical oxidizing agents. These basic processes were researched as follows:

2.3.1 Sedimentation and Dissolved-Air Flotation

Sedimentation and dissolved-air flotation are established processes for removing suspended matter from wastewaters.⁽³⁾ The mechanisms by which these processes remove suspended solids may be illustrated with the aid of Stoke's Law, shown in Figure 1.

When the value of (v) in Figure 1 is positive, the direction of particle separation is downward. Conversely, when the value (v) is negative, the direction of particle separation is upward. It may be observed from Figure 1 that the magnitude of the particle separation velocity (v) is a function of the square of the particle diameter (D) and a function to the first power of the difference between the density of the particle and that of the suspending medium $(\rho_s - \rho_l)$. Further, the rate of particle separation is inversely proportional to the viscosity of the suspending medium. In actual practice, however, essentially little control may be exercised over the viscosity of the suspending medium.

In general, the sedimentation process is effective in accomplishing solids-liquid separation by virtue of the fact that the density of the particles to be separated is greater than that of their suspending medium. In practical applications of Stoke's Law to sedimentation processes, the value of (v) is positive, and the direction of particle separation is downward.

$$v = \frac{gD^2(\rho_s - \rho_l)}{18\mu}$$

where:

v = terminal velocity of particle in feet per second (ft/sec)

g = gravity constant in feet per second squared (ft/sec²)

D = diameter of particle in feet

ρ_s = density of particle in pounds per cubic foot (lb/cu ft)

ρ_l = density of liquid in pounds per cubic foot (lb/cu ft)

μ = viscosity of liquid in pounds per foot per second (lb/ft/sec)

Figure 1 - Stoke's Law

On the other hand, solids-liquid separation may be effected by dissolved-air flotation, a process which attaches fine air bubbles (less than 100 microns) to the solids. This process effectively decreases the density of the air bubble-solid combination to a value less than that of the suspending medium. Thus, the value of (v) in Stoke's Law becomes negative, and the direction of particle separation is upward. In addition, the attachment of an air bubble to the particle effectively increases the difference in density between it and the suspending medium. The effect of this is that the absolute values of (D) and the dependent quantity $(\rho_s - \rho_l)$ are increased, thereby increasing the rate of solids separation.

In dissolved-air flotation, the separated solids form a floating layer which consists of a mixture of solids particles and air bubbles. The gravitational forces acting to compact the separated solids into a smaller volume are enhanced by the buoyant force exerted by the entrapped air bubbles.

These facts indicate that where a wastewater is amenable to treatment by either sedimentation or flotation, higher rates of solids separation and higher concentrations of solids may be obtained through dissolved-air flotation. This conclusion is substantiated by Kalinske.⁽⁵⁾ Its practical significance is that dissolved-air flotation permits the use of smaller basins, results in smaller volumes of sludge to be disposed of, and allows a higher percentage of water recovery than does the sedimentation process.

A comparison of the physical operations associated with the two processes (see Figure 2) shows that the sedimentation process is a less complex one than the flotation process, and that it contains a lesser number of operating components. However, the component assembly for a flotation unit is not technically complex. That it does not require highly skilled operators has been demonstrated by the success of unskilled personnel in operating numerous prototype installations in the field. It is felt that the advantages offered by the flotation process far outweigh the disadvantages of its additional mechanical components.

Chemical treatment, where necessary, may be used as an adjunct to both the sedimentation and dissolved-air flotation processes. Organic and/or inorganic chemicals may be used for such treatments. The process elements associated with chemical treatment are common to both types of treatment, and include

<u>Sedimentation</u>	<u>Dissolved-Air Flotation</u>
1. Solids-liquid separation by gravity	1. Flow pressurization
2. Separated solids removal	2. Air introduction
	3. Air solution
	4. Pressure reduction and bubble formation
	5. Bubble-solids attachment
	6. Solids-liquid separation
	7. Separated solids removal

Figure 2 - Process Elements for
Sedimentation and Dissolved-Air Flotation

chemical introduction, uniform dispersion, and flocculation.

Flocculation is a particle growth process, accomplished through a collision of particles induced by controlled gentle mixing. Referring again to Stoke's Law (Figure 1), it may be deduced that by increasing particle size (D), chemical treatment may be instrumental in accelerating the rate of solids separation. However, the advantages of flotation over sedimentation with regard to rates of solids separation still hold. The chemical requirements, as well as chemical costs, for the two processes are comparable.⁽⁵⁾

The types of dissolved-air flotation processes presently in use for waste treatment are described by Chase,⁽⁶⁾ and include the pressure and vacuum types. Pressure flotation involves the use of operating pressures greater than atmospheric, whereas vacuum flotation, as the name denotes, utilizes operating pressures less than atmospheric. Pressure type applications for waste treatment far outnumber those for vacuum flotation, primarily because of their inherent flexibility of operation. For example, they have the capability of operating under a wide range of pressures, while the vacuum type process is limited in practice by the amount of reduced pressure that can be effectively used.

Variations of the pressure flotation processes that may be used are described in the literature.⁽⁶⁾⁽⁷⁾ These variations include:

- A) Total pressurization, in which the entire volume of raw waste is pressurized.
- B) Split flow, in which only a portion of the raw waste is pressurized and subsequently blended with the remaining portion of raw waste.
- C) Effluent pressurization, in which a portion of the flotation basin effluent is pressurized and subsequently blended with the entire volume of incoming raw waste.

The total pressurization and effluent pressurization variations are most widely used in practice. Of these two, the effluent pressurization type has inherent advantages where the raw waste contains solids in flocculent form, either naturally or chemically formed.⁽⁶⁾ Effluent pressurization avoids the breakup of available floc, since the raw waste influent is not passed through the pressurization pump as is the case with total pressurization. It should also be noted that the equipment and

power costs are substantially lower for effluent pressurization, due to the fact that the volume of liquid to be circulated through the pumps is 25% - 50% less than that of the raw waste.

An economic evaluation of the sedimentation and flotation processes for wastewater treatment centers around a comparison of the two with respect to the capital expenditures and operating costs involved. For producing comparable volumes of recovered effluent, the first (capital) costs of flotation equipment appear to be appreciably less than those for sedimentation equipment. The reason for this lies in the substantially higher rates of solids separation obtained with the flotation process. For example, Kalinske indicates that overflow rates of three to six gallons per minute per square foot may be used with flotation as opposed to one-half to two gallons per minute per square foot with sedimentation.⁽⁵⁾

A comparison of the operating costs, however, indicates that those for flotation are substantially higher than those for sedimentation. One of the major items contributing to the greater operating cost of pressure flotation is the increased power requirement for pumping. Kalinske presents an example indicating that the daily power cost for pumping a one million gallon per day flow at an operating pressure of 25 psig with a unit power cost of \$.02 per KWH would be \$7.00, or an annual cost of \$2,500.00.⁽⁵⁾ The example cited, however, was for a total pressurization application. It should be appreciated that a similar application using effluent pressurization would effect a power cost savings of 25%-50%.

2.3.2 Froth Flotation

Froth flotation with respect to waste treatment is essentially the same process used by the mining and metallurgical industries for separating and concentrating metallic ores. The process is a selective one in which chemical conditioning agents are added to the ore slurry entering the flotation chamber. Air is dispersed into the contents of the chamber using high speed impellers. The chemical frothers or flotation agents facilitate the inclusion of the metallic concentrates with the froth that is formed, and the useless gangue settles to the bottom of the chamber. The ore-bearing froth is then skimmed off for further processing.

Full scale application of the froth flotation process to sewage and industrial waste treatment is essentially non-existent, as is indicated from the meagre amount of information obtained from the literature. However, Hansen describes experimental laboratory batch and continuous flow work in which the froth flotation process was applied to the treatment of sewage and industrial wastes.⁽⁹⁾ Various frothers were tried, and the most efficient was a heteropolar lauryl-amine hydrochloride type. The efficiency of the frothing agent was affected by pH, with the most effective range being from 6.0 to 8.0. It was observed that as the pH approached 9.0, the reagent's frothing and collecting properties decreased appreciably. The results of the studies conducted by Hansen showed that froth flotation removed in excess of 97% of the suspended solids, but essentially did not remove any of the dissolved solids. It should be noted here that the waste solids with which our project is concerned are primarily dissolved rather than suspended.

Chemical coagulants in conjunction with the frother did not improve clarification over the results obtained with the frothing agent alone. With regard to the cost of the equipment and operating costs, Eliassen, in his discussion of Hansen's work, indicated that the use of the frother agent would result in a treatment cost of \$250.00 to \$300.00 per million gallons of sewage treated.⁽⁹⁾ These costs, of course, reflect 1943 prices.

2.3.3 Foam Flotation or Foam Fractionation

Foam flotation or foam fractionation may be best suited for the removal of foam-forming soluble organics such as surfactants. Eldib distinguishes between foam fractionation (removal of foam-forming soluble organics) and froth flotation (selective removal of suspended solids using a frothing agent).⁽¹⁰⁾ Eldib, Gassett, and Jenkins have all shown from experiments that appreciable amounts of the surfactant ABS (alkyl benzene sulfonate) may be obtained using foam fractionation.⁽¹⁰⁾⁽¹¹⁾⁽¹⁷⁾ The tests by Eldib were performed on a secondary effluent, whereas those performed by Gassett were done with synthetic solutions composed of ABS and distilled water. ABS removals reported varied from 49.7% to 87.4%, with initial concentrations of ABS ranging from 9.7 mg/l to 200 mg/l. It should be noted that the tests reported were performed on solutions relatively free from suspended solids; the effect of suspended solids on ABS removal was not investigated.

Gassett investigated, in the laboratory, the effect of several operating variables on ABS removal. It was noted that the rate of ABS removal and the amount of foaming occurring increased along with increasing initial concentrations of ABS. However, it was observed that for the range of initial concentrations investigated (50 mg/l to 200 mg/l), a constant equilibrium of residual ABS content in the bulk solution (about 16 mg/l) was obtained.

The operating variables investigated by Gassett included air flow rate, time of aeration, pH, and temperature. It was found that, in general, ABS removal increased with increasing pH for the range investigated, which was 4.0 to 11.0. It also decreased markedly as the temperature increased from 25° C to 40° C. At a pH of 6.7, little change in ABS removal was observed in the range from 5° C to 25° C.⁽¹¹⁾

An extensive search of available literature did not reveal the presence of any full scale application of foam flotation to sewage and industrial waste treatment. However, the inherent characteristics of the waste to be treated in this project may indicate that there is feasibility to using foam flotation to remove the surfactants.

In this connection, however, it should be pointed out that the dishwasher detergent Cascade is a non-ionic detergent,⁽¹²⁾ and that the literature indicates that such non-ionic detergents, when used alone, are accompanied by low foam volumes.⁽¹³⁾ Other sources, however, show that when they are mixed with other materials, the non-ionic detergents may foam excessively.⁽¹⁶⁾⁽²⁵⁾ In this respect, foam flotation may have applicability for the removal of surfactants during the pretreatment of raw waste or polishing steps of the treatment process.

If foam flotation is to be considered for inclusion in the integrated process system for this project, then the following parameters will have to be evaluated by laboratory tests and bench scale studies:

- a) Foam stability
- b) Effect of suspended solids on process
- c) Air bubble size required
- d) Air induction rate required
- e) Duration of aeration
- f) Effect of pH

- g) Effect of temperature
- h) Treatment efficiency
 - 1) surfactant removals
 - 2) residual surfactant concentration

Foam flotation as a process consists simply of bubbling a gas through a liquid containing surface-active compounds. The process elements involved in this treatment include foam generation, foam collection, collapsing of the collected foam, and disposal of the collapsed foam by dewatering and incineration. Of major concern with respect to this project is the fact that while foam flotation is applicable only to the removal of surfactants, other established processes, such as chemical treatment and activated carbon treatment, are capable of removing not only surfactants, but other contaminants as well.

2.3.4 Chemical Treatment

Particulate matter that cannot be separated through primary treatment may be collected into aggregates of larger size by virtue of chemical treatment processes. The aggregates are then susceptible to conventional solids-liquid separation techniques. Chemical treatment is also widely used for the removal of colloidal matter and for precipitating some dissolved matter in the treatment of industrial wastes.

No attempt will be made here to enter into the complex and sophisticated theory of the colloidal sciences. The pertinent aspects of the theoretical considerations involved are explained in depth by Rand.⁽¹⁴⁾ Rand also reviews and discusses the objectives, basic principles, and applications of chemical treatment as applied to sewage and industrial wastes. In outline form, the process elements of chemical treatment generally include the following:

- a) Introduction of the chemicals
- b) Rapid mix and dispersion
 - 1) mechanical mixing equipment
 - 2) kinetic energy of the wastewater
- c) Flocculation

The choice of chemicals to be applied is affected by several factors, including the composition of the waste, the desired nature of the effluent, chemical costs, and chemical availability. In view of this, each waste treatment application should be

evaluated in terms of its individual characteristics and requisites. However, some generalizations can be made regarding the choice of chemical coagulants to be used in treating sewage and wastewater.

For example, the chemicals used in waste treatment are generally those capable of forming a coagulated floc. Polyelectrolytes and polymers are types of organic chemicals commonly used to this end. In some cases, polymers are so effective as to allow the elimination of mechanical flocculation. The inorganic chemicals used are usually the salts of polyvalent metals, such as salts of iron and aluminum.

Under some circumstances, coagulant aids may be used to enhance the action of the coagulant and to improve the overall treatment results. Coagulant aids produce little or no floc by themselves. Examples of such compounds are lime for pH adjustment, activated silica for floc strengthening, and clay for nuclei provision.

Another use of chemicals for purposes other than coagulation is the addition of those which will cause precipitates to form. The use of such precipitating agents is often the most efficient means of removing dissolved solids from the waste.

Dissolved detergents represent a major constituent (480 mg/l) of the waste to be treated under this contract. Detergents possess the property of effecting soil removal, and their presence in the wastewater emanating from the laundry and kitchen is expected. The literature search revealed several detailed discussions of the nature and behavior of detergents.(13)(15)(16)

Synthetic detergents contain from 20% to 40% organic surface active material, with the remainder consisting of builders, fillers, dyes and other essentially non-active elements. The major portion of these remaining constituents is made up of the builders, which represent from 30% to 50% of the total detergent content. Most detergent builders consist mainly of sodium tripolyphosphate and tetra-sodium pyrophosphate. Small amounts (0.5% to 3.0%) of sodium carboxymethyl cellulose may be added to improve the soil-suspending power of the detergent and to prevent the re-deposition of dirt.

The effects of detergents on chemical coagulation using inorganic coagulating agents are well documented in the literature.⁽¹⁵⁾⁽¹⁶⁾⁽¹⁸⁾⁽¹⁹⁾⁽²⁰⁾ It was indicated that the presence of detergents adversely interferes with coagulation. However, it was pointed out that the surface active elements in synthetic detergents was not the interfering substance. Rather, it was observed that the phosphate builders were the major cause of interference with the coagulation process using such inorganic coagulants as the salts of aluminum and iron. The dispersing and sequestering properties of the phosphates are felt to be responsible for the interference.

This difficulty may be overcome by increasing the coagulant dosage to the point where the phosphates are precipitated as insoluble salts of aluminum, iron, and calcium. Higher concentrations of phosphates require correspondingly higher concentrations of coagulants to effect their removal by precipitation. Another factor which appears to be of value in this respect is the pH of the solution. Phosphate interference was minimized when the pH was adjusted to values greater than 9.1 with iron sulfate as a coagulant,⁽¹⁶⁾ whereas phosphate removal on alum floc in tertiary treatment was found to be best at a pH range of from 7.1 to 7.7.⁽²¹⁾

The removal of the surfactant component of detergents using the common inorganic coagulants was found to be significant but not appreciable.⁽²²⁾ The removal of ABS using adsorbents such as activated carbon alone is very effective, and this will be discussed in greater detail in a subsequent portion of this report. For the present, it suffices to say that the use of a combination of activated carbon and the common inorganic coagulants removed substantially higher percentages of ABS than do the inorganic coagulants by themselves.⁽²²⁾ However, it was concluded that the inorganic coagulant floc caused carbon blinding, thereby necessitating the use of impractically greater amounts of activated carbon. It was felt that activated carbon treatment should be a separate and subsequent operation.

The detergents present in the wastewater to be treated under this contract may include both a cold-water laundry detergent (Surf), which is an anionic agent, and a non-ionic dishwashing detergent (Cascade). The anionic detergents ionize in aqueous solutions to give a negatively charged organic ion.⁽¹³⁾ It may be possible to remove the surfactant component of the anionic detergent through the addition of a cationic detergent. The

reaction between the anionic and cationic agents will result in the production of insoluble compounds that do not have detergent properties.⁽¹⁶⁾ This principle has been effectively employed to effect the removal of anionic detergents from laundry wastes.⁽²³⁾ It should be noted, however, that this reaction does not contribute to the removal of non-ionic detergents.

Specific chemical agents which may be used to remove non-ionic detergents are described in the literature.⁽²⁴⁾ It was indicated that silicotungstic or phosphomolybdic acid will precipitate the non-ionic detergent as an insoluble complex.

Another constituent in the wastewater for this project is soap, which would come primarily from the shower facilities. The literature indicates that chemical treatment is highly effective in the removal of soap.⁽²⁵⁾⁽²⁶⁾⁽²⁷⁾ The inorganic chemicals which may be used for removing soap include aluminum, iron, and calcium compounds, either separately or in combination.

The remaining undesirables in the wastewater, such as dirt, grease, and colloidal matter, may be removed through chemical treatment as well. The processes involved could include adsorption, absorption, or entrapment by chemical flocs.

Since it appeared that the waste to be treated under this contract resembles in many respects that obtained from commercial laundries, a survey of laundry wastes, both separate and in combination with domestic sewage, was conducted.⁽²²⁾⁽²³⁾⁽²⁵⁾⁽²⁶⁾⁽²⁷⁾⁽²⁸⁾⁽²⁹⁾

McCarthy reported on a study of laundry wastes conducted in 1942.⁽²⁸⁾ He found that coagulants such as alum and ferric salts used alone or in combination with sulfuric acid, gave good reductions of BOD, fats, and turbidity. Both alum and ferric sulfate gave good removals at a dosage of 390 mg/l and 544 mg/l respectively. The use of sulphuric acid to reduce pH greatly reduced the coagulant demand. The floc formed was settled for two hours, and the resulting sludge volumes ranged from 1.0% to 12.0% by volume of the original waste. Certain calcium and copper salts, along with magnesium sulfate and ferrous sulfate, were also tried as coagulants, but their results were not as encouraging as those for alum and ferric sulfate.

Flynn and Andres reported using flotation to remove the flocculated particles from a laundry waste.⁽²²⁾ The chemicals used were alum (400 mg/l), and sulphuric acid (200 mg/l), and

sodium carbonate (50 mg/l). They estimated the cost of chemicals to be \$0.35/1000 gallons of water treated. The buildup of dissolved solids during treatment was about 300 mg/l per cycle.

Wollner et al attempted to use soda ash and alum, but found that the dissolved solids buildup was prohibitively high.(23) Substitution of sodium hydroxide for the sodium carbonate (soda ash) reduced the dissolved solids buildup to only 50 mg/l per treatment cycle. The chemical dosage used by Wollner was 685 mg/l alum and 154 mg/l sodium hydroxide, and was added using pH controlled metering. The alum was added first, and then the sodium hydroxide to provide neutralization. Calculated chemical costs were \$0.25/1000 gallons of waste treated.

Eliason and Schulhoff found ferric chloride to be an effective coagulant for laundry waste.(27) Dosage of 500 mg/l of ferric chloride reduced the BOD by 83% and the resulting pH was 6.8. They also found that lime dosage as high as 1200 mg/l did not give satisfactory results. The authors used vacuum flotation to separate the chemical flocs from the liquid. Sedimentation was not used because it was observed that chemical treatment caused a partial flotation of the solids.

This same difficulty with clarification by sedimentation following chemical treatment was also experienced by Rudolfs.(29) The partial flotation of solids following chemical coagulation was attributed to and is associated with the presence of a relatively high concentration of carbonates or bicarbonates in the waste. Under these conditions, a sufficient decrease in pH due to chemical treatment causes an evolution of carbon dioxide gas in the flocculated waste. The gas then acts as a flotation agent, attaching itself in bubble form to the suspended floc particles.

Gehm also reported that lime alone, even in dosages as high as 1600 mg/l, did little in the way of clarification. He found, however, that the addition of 100 mg/l of magnesium sulfate along with 1000 mg/l of lime produced complete clarification accompanied by 90% BOD removal. The sludge produced was easily compacted and not difficult to handle. Gehm also reports that small percentages of spent zeolite regenerating solution were found to be effective in removing BOD when used in conjunction with small dosages of lime.(30) A number of other investigators have used common inorganic chemicals and obtained results similar to those discussed above.(31)(32)(33)

Information on the use of organic polymers for treating laundry wastes was meagre. However, O'Dom reported a new polyelectrolyte (B-227⁴) produced by Reichold Chemicals Inc. which may prove to be effective in removing LAS and ABS from laundry wastes.(34)

Rudolfs and Ingols found that the addition of ground garbage solids to sewage caused no problems with the coagulation and flocculation of the waste. As might be expected, they found that a larger chemical dosage was required when these additional solids were present. Based on their work, it appears that ground food wastes may be removed by means of chemical coagulation, along with the soaps and detergents.

2.3.5 Biological Oxidation

In addition to the waste constituents discussed in the preceding section, the influent will also contain biodegradable organic material which contributes to the BOD and COD strength of the waste. The specified parameters for the renovated effluent indicate the need for removal of substantial amounts of these biodegradable constituents from the combined wastewater.

Biological treatment methods are available which may be used to treat wastes containing such biodegradable elements. The most common of these are oxidation processes utilizing either trickling filters (fixed bed) or activated sludge (fluid bed). Most of the constituents in the waste to be treated under this contract may be amenable to treatment by biological oxidation. For example, the proteinaceous matter and the soluble fraction of garbage solids derived from the kitchen waste may be degraded by activated sludge.(35) The anionic surfactant (Surf) and the non-ionic detergent (Cascade) are also biodegradable.(12) The rapid adsorption of soaps by activated sludge has also been demonstrated,(36) and the metabolic uptake of phosphorus is described by Levin and Shapiro.(37)

Considering again the similarity between portions of our project waste and commercial laundry waste, the literature was searched with regard to the treatment of laundry wastes by biological oxidation.(29)(30)(38)(39) It was found that laundry wastes are definitely amenable to this type of treatment. For example, oxidation by activated sludge is effective, although longer periods of aeration are required for laundry wastes than for domestic sewage. Also it was found that laundry wastes may be purified by either conventional or high rate trickling filters. Field

tests on domestic sewages containing biodegradable LAS showed that the removal of LAS was proportional to the contact time experienced in the aeration tank.

Both the activated sludge and trickling filter processes may or may not require preliminary treatment, depending upon the characteristics of the raw waste to be treated. However, both processes do require the use of final clarifiers following biological oxidation. The resultant waste sludges will also have to receive further treatment.

One factor which may preclude the use of biological oxidation in this project is the relatively long time required to start up and "build" the sludge solids or biological slimes necessary for the purification of the waste. For example, Laboon reports that it took three weeks during cold weather and one week during warm weather to develop a satisfactory activated sludge.⁽⁴⁰⁾ Bolenius states that over one month was required to build a good sludge concentration.⁽⁴¹⁾ Still more discouraging was the report that a trickling filter installation handling sewage and laundry wastewater for a military camp required about three months to reach full efficiency.⁽⁴²⁾

2.3.6 Chemical Oxidation of Organic Wastes

The technical feasibility of chemically oxidizing the organic compounds in any given waste can be determined by the COD test.⁽⁴³⁾ That chemical oxidation is an effective process for this purpose is well established, and discussions of the chemical oxidants which have a potential for use in water and waste treatment for the removal of organics are well documented in the literature.⁽⁴⁴⁾⁽⁴⁵⁾⁽⁴⁶⁾⁽⁴⁷⁾⁽⁴⁸⁾⁽⁴⁹⁾⁽⁵⁰⁾⁽⁵¹⁾⁽⁵²⁾⁽⁵³⁾

The advantages of chemical oxidation include the effective destruction of biological organisms and the removal of organic contaminants without the production of residual waste concentrates. Some of the technical difficulties connected with the successful treatment of wastes by chemical oxidation include measurement of the relatively dilute concentrations of organic materials present, the unknown composition of a wide range of possible organic compounds present, and the continually changing concentrations and compositions present in a combined wastewater flow such as the one with which this project is concerned.

These difficulties necessitate the use of gross parameters in evaluating the effectiveness of a given chemical oxidant. Such parameters would include knowing the chemical oxygen demand of the waste (COD), the concentration of the oxidizing properties in the chemical, and the total organic carbon present in the waste. Having this information, the oxidation efficiency of a given chemical may be determined by the equation shown in Figure 3.

Taking into consideration the possible variations in the composition of the combined wastewater flow, and looking to the desired characteristics of the treated effluent, an "ideal" chemical oxidant would have to satisfy the following requirements:

- a) It should not produce any secondary pollutants which create a new problem of removal.
- b) It must be non-specific in its oxidation attack on organic materials.
- c) It should not appreciably contribute to the inorganic salt load in the wastewater.
- d) Its required contact and retention time should not be excessive; preferably less than three hours.
- e) It should be relatively easy to handle and dispense.
- f) It should effectively oxidize the organic materials at the prevailing pH of the wastewater.

The type of treatment used to oxidize the organic impurities is another limiting aspect in the choice of oxidants. That is, the process systems as such are limited with regard to the oxidants that can be employed, depending upon which system is chosen. From the literature search it was found that six types of systems offer various degrees of potential for the treatment of organic impurities in wastewater. These systems will be discussed in the following order:

- a) Oxidation by oxidants containing active oxygen
- b) Accelerated molecular oxygen oxidation
- c) Catalytic oxidation of adsorbed organics
- d) Oxidation by chlorine and its derivatives
- e) Oxidation by oxy-acids and their salts
- f) Electrochemical oxidation

It should be noted, with regard to limiting parameters previously mentioned, that systems a), b), and c), above do not produce

$$\text{Oxidation Efficiency} = \frac{\Delta\text{COD}}{\text{Available Oxidation Equivalents}} \times 100$$

where:

ΔCOD = change in COD brought about by the oxidation process (in milligrams of O_2 per liter)

and:

Available Oxidation Equivalents = amount of chemical oxidation equivalents available from the oxidant used (in milligrams of O_2 per liter)

Figure 3 - Equation for Determining
Oxidation Efficiency

secondary pollutants nor do they necessarily increase the inorganic salt load in the treated effluent.

2.3.6.1 Oxidation by Oxidants Containing Active Oxygen

2.3.6.1.1 Air as an Oxidant

The chemical oxidation of organic matter using air (atmospheric oxygen) as the oxidant has been applied in the treatment of sewage plant sludges.⁽⁴⁸⁾ The process involved is called the Zimmerman process, and is a wet oxidation process which may be used to degrade organic matter at elevated temperatures and elevated pressures (500° F to 600° F and 1000 psig to 2000 psig). Generally, the wet air oxidation process in sewage and industrial waste treatment has been applied to waste streams containing relatively high concentrations of solids and organic matter having a high fuel value. For example, the application discussed by Hurwitz and Dundas dealt with a waste sludge having a total solids content of about 5.0%, a COD of about 63,000 mg/l, and a heat value of about 7,000 BTU/lb. The effluent from treatment was high in BOD (5,000 mg/l) and COD (10,000 mg/l), obviously requiring further biological treatment prior to discharge.⁽⁴⁸⁾

For dilute aqueous wastes, this process does not appear to have application potential, since the fuel value of such streams are low.⁽⁴⁹⁾ The waste to be treated under this contract falls into this category, having a total solids content of about 0.1% and a COD of about 400 mg/l.

2.3.6.1.2 Ozone as an Oxidant

The use of ozone as an oxidant for water and waste treatment is described in the literature.⁽⁴⁴⁾⁽⁴⁵⁾⁽⁴⁶⁾⁽⁴⁷⁾ The oxidation mechanism of ozone is not thoroughly understood. It is theorized that the O₃ itself may be the oxidizing agent, or that its decomposition in water provides free OH radicals. As a compound, ozone is extremely corrosive and is toxic in strong concentrations in the air. A safe upper limit of ozone concentration has been set at 0.2 milligrams per cubic meter of air.

Ozone, at treatment temperatures normally used, quickly reverts to oxygen; however, its oxidation time is rapid, accomplishing in minutes what it would require hours for chlorine to do. Ozone contact times of five to ten minutes are

indicated. O'Donovan reports that the oxidation efficiency of ozone in the oxidation treatment process is 85% to 90%.⁽⁴⁵⁾

The major constituents in the waste to be treated under this contract are synthetic detergents. Work done to determine the effect of ozone on ABS surfactant removal has shown that ozone is effective in degrading this surface active element of detergents.⁽⁴⁶⁾⁽⁴⁷⁾

The production of ozone requires the use of cold, clean, and dry air or oxygen. The manufacturing process involves the application of high frequencies (500 cps to 1000 cps) and high voltages (4,000 volts to 30,000 volts). Based on present commercial (Welsbach) ozone production costs, the expense of supplying 200 milligrams of available oxygen per liter is estimated at between \$.25 and \$.30 per 1000 gallons of treated wastewater in a ten million gallons per day facility. It should be noted that the COD strength of the waste for this project is approximately 400 milligrams per liter.

2.3.6.1.3 Hydrogen Peroxide as an Oxidant

Considerable work has been done regarding the application of hydrogen peroxide (H_2O_2) as an oxidizing agent in the treatment of waste and water containing organic impurities.⁽⁴⁴⁾⁽⁵⁰⁾⁽⁵⁴⁾

In aqueous media, hydrogen peroxide decomposes to form the $\cdot OH$ radical. This radical is one of the strongest oxidants known in aqueous systems. However, hydrogen peroxide does not, when used alone, oxidize organic materials within a practical reaction time. The system requires a multivalent iron salt as a catalyst, and a specific pH range of 3.0 to 4.0 must be maintained to produce the $\cdot OH$ oxidant efficiently. Ferrous ions react rapidly with H_2O_2 to produce the required $\cdot OH$ radical, while a somewhat slower production (two to three hours) is afforded by adding ferric salts to hydrogen peroxide at a temperature of 65° C.

This method of oxidizing organic wastes has been experimentally evaluated. Davidson found that phenols could be chemically oxidized (90% complete) to carbon dioxide and water in ten minutes.⁽⁵⁰⁾ Eisenhower demonstrated that in dilute aqueous solutions of phenol, the reaction efficiency was considerably increased in the presence of air-available oxygen.⁽⁵⁴⁾

Eisenhauer also found that the reaction between a hydrogen peroxide-ferrous salt combination and ABS was rapid and 80% to 90% of the ABS was destroyed in the first ten minutes. Further ABS removals were obtained at slower reaction rates, with a 99% ABS removal effected after fifteen to twenty hours. The optimum reaction pH level was found to be from 3.0 to 3.5. The optimum concentrations of the reactants were six moles of ferrous salt per mole of ABS, and nine moles of H_2O_2 per mole of ABS. Multiple incremental additions of the Fenton's reagent decreased the reaction time required.

Applying this information to a treatment of laundry wastes containing ABS, Eisenhauer obtained ABS reductions in excess of 90%, both with the raw waste and with effluent from a pre-treatment process in which the detergent builders were precipitated. For a laundry waste containing 50 to 80 parts per million ABS, it was found that chemical costs ranged from \$.45 to \$.70 per 1,000 gallons for the raw waste treatment and \$.15 to \$.25 per 1,000 gallons for the effluent pretreated with ferric sulfate. This includes the cost of ferrous sulfate, ferric sulfate, sulfuric acid, and hydrogen peroxide.⁽⁵⁴⁾

The cost associated with peroxide oxidation of municipal secondary effluents has been estimated at \$1.20 to \$1.50 per 1000 gallons when the peroxide supplies an equivalent of 100 milligrams per liter of available oxygen.⁽⁴⁴⁾

2.3.6.2 Accelerated Molecular Oxygen Oxidation

This process, commonly called autoxidation, involves a free-radical-chain oxidation reaction in which molecular oxygen acts as the chief oxidant. In the presence of excess oxygen, the general autoxidation mechanism includes the use of hydroxyl radicals that initiate the reaction between the O_2 and the organic compounds.

The autoxidation process was studied on secondary treatment plant effluents at nominal concentrations and at relatively large concentrations. A hydrogen peroxide-iron salt system was used to supply the hydroxyl radical initiator ($\cdot OH$). On the basis of the exploratory tests performed, ⁽⁴⁴⁾ the autoxidation rates achieved were not adequate to qualify H_2O_2 -initiated autoxidation as an economically feasible contender for the removal of organic pollutants from wastewaters. This does not rule out the possibility of using autoxidation as a process, however, and if a

suitable initiator and accelerating catalyst are discovered, the cost of supplying available oxygen could be quite low. For example, the cost of liquid oxygen at 100 milligrams of O_2 per liter is estimated at less than \$0.01 per 1000 gallons of treated effluent for plants of ten million gallons per day capacity.

2.3.6.3 Catalytic Oxidation of Adsorbed Organics

Although oxidation of the refractory organics in wastewaters by molecular oxygen is thermodynamically possible, the reaction rates are usually too slow to be of practical value. Reaction rates can, however, be accelerated in the presence of catalysts such as palladium or nickel which reduce the activation energies required. Moreover, oxidation rates may be improved by concentrating the organics on the surface of solid adsorbents. Solid adsorbents impregnated with suitable catalysts may therefore be used to take advantage of both these phenomena.⁽⁴⁴⁾

Because of the many problems arising from the complexity and variety of wastewater systems, and due to the difficulties associated with the use of catalysts, the achievement of a completely continuous adsorption-oxidation process does not appear probable. In view, however, of the extensive studies underway on activated carbon adsorption and the comparatively low cost of molecular oxygen, a feasibility evaluation will be made of this potential technique.⁽⁴⁴⁾

2.3.6.4 Oxidation by Chlorine and Its Derivatives

Chlorine or its derivatives are added to most municipal water supplies in the United States to kill micro-organisms. This process functions most probably by virtue of an oxidation attack by Cl_2 or $HOCl$ on the living organic structure. Important chlorine derivatives often employed to this end are the chloramines ($NHCl_2$ and NH_2Cl) and chlorine dioxide (ClO_2). Chlorine and its derivatives are less powerful oxidants than the active-oxygen compounds.

Although chlorine and its derivatives do oxidize many of the organic chemicals contained in municipal wastewaters, they do not usually convert them to the readily acceptable forms of carbon dioxide and water. Instead, the reaction of chlorine with organics may produce molecules having considerable taste

and odor, and complex compounds which serve as secondary pollutants may also be formed. The addition of stoichiometric amounts of chlorine will not effect oxidation of the refractory organics, and a large chlorine residual may be left. Since oxidation by chlorine is far less effective than by active-oxygen elements, and since the unknown by-products of chlorine oxidation may be toxic, chlorine and its derivatives are not considered to be good prospects for wastewater organics removal.⁽⁴⁴⁾

2.3.6.5 Oxidation by the Oxy-Acids

The oxy-acid oxidants are usually added to aqueous systems as the salt of the oxy-acid. Important oxy-acid salts with oxidation potentials include potassium permanganate (KMnO_4) and sodium or potassium ferrate (NaFeO_4). The oxidation potentials of the oxy-acids are strongly dependent upon the acidity of the aqueous system, with the potential increasing as the acidity increases. Thus, the oxy-acids have relatively low oxidation potentials at the neutral or alkaline pH ranges (7.0 to 9.0) usually occurring in municipal waste effluents. A further disadvantage is that the oxy-acid salts increase the inorganic salt load in the aqueous system.⁽⁴⁴⁾

Despite these limiting factors with regard to waste treatment, potassium permanganate is used as an oxidant in the treatment of municipal water supplies to improve the color, taste, and odor properties and to remove dissolved ferrous salts, manganese salts, and hydrogen sulfide. In neutral or alkaline systems, the oxidation product (MnO_2) acts as a coagulant, and may be removed by settling or filtration.

Based on preliminary evaluations, however, the potential for using KMnO_4 as an oxidant in our project is not particularly promising. References in the literature report only limited oxidation of organics with KMnO_4 , and a residual permanganate persists in the water for more than twenty-four hours.⁽⁵⁵⁾ Since this residual permanganate must be removed before the water can be reused, its removal by the application of reducing agents only serves to increase the inorganic salt load in the system.

Although ferrate salts such as potassium ferrate (K_2FeO_4) are not commercially produced, their high oxidation potentials and the coagulating properties of their oxidation

products, a highly insoluble ferric hydroxide, make the ferrates a potentially attractive group of oxidants for treating wastewaters.

Exploratory laboratory tests using K_2FeO_4 to treat filtered municipal secondary effluents in dosages supplying approximately 100 milligrams per liter of available oxygen showed the combination of ferrate oxidation and coagulation to be nearly as effective as the previously discussed H_2O_2 - iron salt system for removing organic materials from wastewaters.⁽⁴⁴⁾ Maximum organic removal as measured by the COD test was approximately 70% over a five minute reactive time at a pH of 2.2. Oxidation accounted for approximately 40% of the removal, with the remainder being effected through coagulation and filtration.

The comparatively high cost of the oxy-acid salts is a major factor limiting their application in advanced waste treatment processes. In carload lots, the cost of $KMnO_4$ sufficient to supply 100 milligrams of available oxygen per liter is estimated at \$.74 per 1000 gallons of effluent treated. Although specific cost data are not available for the ferrate salts, order of magnitude estimates based on the cost of required raw materials for their production place the cost between \$.59 and \$1.15 per 1000 gallons of effluent treated. Owing to this unfavorable economic outlook, the oxy-acids should be, at present, essentially eliminated from consideration as oxidants for large-scale applications in the treatment of municipal wastes.⁽⁴⁴⁾

2.3.6.6 Electrochemical Oxidation

Any material that increases the electrical conductivity of an aqueous solution may enter into a chemical reaction at the surface of electrodes placed in the solution. These chemical reactions are known as oxidation-reduction reactions, and their study is called electrochemistry. Interest in electrochemistry as a possible technique for purifying municipal wastewaters is based on the fact that many organic chemicals take part in such electrode reactions, often resulting in the complete degradation of complex organic molecules to carbon dioxide, water, and other oxides. The complete electrolytic oxidation of benzene and phenolic compounds has been reported in the literature.⁽⁴⁴⁾ Phenol disulfonic acid has been electrolytically degraded to carbon dioxide, water, and sulfuric acid. The similarity between phenol disulfonic acid and ABS lends encouragement to the

possibility that ABS could similarly be decomposed or oxidized.

The proposal to treat municipal wastewater by electrochemistry is not new. This process was used in full-scale sewage treatment plants many years ago, with the earliest patent being issued in 1889. Around 1911, at least one plant was operating at Crossness, a suburb of London, while similar plants in the United States were located at Santa Monica, California; Oklahoma City, Oklahoma; and Elmhurst, New York. At the Elmhurst plant, wastewater was dosed with lime before entering the electrochemical cells, and the resulting product water was described as being "...clear, odorless, and nonputrescent." All these early plants had been abandoned by 1930, however, on the basis that electrolysis accomplished no more than the lime pretreatment by itself. The literature does not offer any data to support this claim. A more justified reason for closing these plants might have been the excess operating costs, since electrolysis doubled the cost of treatment by conventional methods employed at that time.

More recently, work has been done in Europe on the electrolysis of municipal wastewater mixed with seawater. In this approach, the precipitation of magnesium salts present in the seawater aids in sludge flocculation. In addition, hypochlorite generated from the chloride ion oxidizes organics in the wastewater and serves to sterilize the effluent. Two European plants now electrolyze wastes mixed with seawater, and one plant claims satisfactory separation of solids at a power cost of \$.06 per 1000 gallons by using power with a unit cost of \$.01 per kilowatt-hour.

Feasibility research on the electrochemical oxidation of municipal wastewaters was undertaken in May of 1962 through a contract with the Pennsalt Chemicals Corporation.⁽⁴⁴⁾ This study was of a tertiary treatment process rather than of a process intended to replace existing primary or secondary processes. The principal results of the investigation conducted were summarized as follows:

- 1) Electrochemical oxidation of filtered municipal secondary effluent reduced COD by as much as 80%, ABS by 90%, and chloride content by 90% when lead dioxide anodes with platinum coated titanium cathodes were used. All systems studied had little effect on total dissolved solids.

- 2) The cost of treating secondary effluents by the electrolytic method in a ten million gallons per day plant will vary between \$.90 and \$2.40 per 1000 gallons, depending on the completeness of treatment and the electrical conductivity of the wastewater. To achieve approximately 50% COD removal would cost about \$1.20 per 1000 gallons, while an 80% removal would cost about \$2.40 per 1000 gallons.
- 3) Lead dioxide was shown to be the most effective anode material for the reduction of ABS, COD, and chloride in wastewater. It did not, however, reduce the total dissolved solids content.
- 4) Iron, lead, magnesium, aluminum, graphite, and copper all erode when made anodic in secondary effluent.
- 5) Lead dioxide, platinum, and platinum plated titanium do not erode when made anodic in secondary effluent.
- 6) All electrode materials studied, except lead dioxide, worked satisfactorily as cathodes in secondary effluent; however, a platinum coated titanium cathode in combination with a lead dioxide anode was more effective in reducing COD than was an iron cathode with the lead dioxide anode.
- 7) Oxygen and chlorine were produced at the anode, and hydrogen at the cathode.
- 8) Plant erection costs based on the most optimistic assumptions will vary between \$9,000,000.00 and \$26,000,000.00 for a ten million gallon per day facility.

Drawing conclusions from this information, there appears to be little likelihood of making the electrochemical process an economically practical one. The major cost factors are anode replacement and electrical power, which amount to 62% and 30% respectively of the total cost. Inasmuch as the estimated lead dioxide anode life may be optimistic, the cost range of \$.90 to \$2.40 per 1000 gallons could be substantially higher if anode deterioration is more rapid than predicted. Even were this possibility not to occur, the cost of electrochemical oxidation appears to be prohibitively high when compared with other promising methods of advanced waste treatment.

2.3.7 Evaporation and Condensation as a Means of Purification

The evaporation and subsequent condensation of wastewater may produce a treated effluent having a high level of purity and a low content of total solids. The treatment principle involved is

a simple one in which the wastewater is heated to form steam, the steam is separated from the remaining liquid, and then condensed to form water again.

The treated water obtained from this process is generally free of suspended matter, both organic and inorganic dissolved matter, and micro-organisms, which are usually destroyed at the above boiling temperatures employed. However, volatile impurities in the feed, such as greases, oils, and other low order hydrocarbons, will pass over in the distillate. These volatile impurities will have to be removed, either by pretreatment or by polishing subsequent to condensation.

Methods of evaporation available include simple distillation, multiple-effect distillation, multiflash distillation, thermocompression distillation, and submerged combustion. The equipment used for multiple-effect and multiflash distillation, as the names imply, consist of multiple units. Therefore, it is appreciably bulkier and heavier than the equipment used for the other types of processes.

Treatment of wastes by evaporation produces an effluent which is of a higher quality than what is required for general purposes, and consequently it is considered to be an excessively expensive mode of treatment. Where other treatment methods are available and applicable, the distillation process is usually avoided on the basis of the costs involved.⁽⁴⁴⁾⁽⁵⁶⁾ Further contributing to the operating costs of distillation processes is the need to minimize the formation of scale on the heat transfer surfaces. In a continuous treatment operation, this would necessitate a pretreatment step to remove the foreign and dissolved matter in the waste.

Also, the production output of distillation equipment is limited in its effectiveness. An inquiry was directed to a well-known producer of commercial thermocompression equipment with regard to its application to wastewater treatment. Their reply indicated that to produce 600 gallons per hour of distilled water, 900 gallons per hour of feed water would be required. This represents a water recovery rate of about 67% as opposed to the 80% minimum requirement for this project. The total estimated operating cost for this type of equipment was \$1.88 per 1000 gallons distilled. The approximate dimensions of a 600 gallon per hour unit are 9'6" long, 7'0" wide, and 9'5" high, with an estimated installed cost of \$39,500.00. This would include the following components: evaporator, heat exchanger, vent

condenser, vapor compressor and motor, distillate pump and motor, instrumentation, and skid mounting.

Another inquiry was directed to a firm specializing in submerged combustion equipment for wastewater treatment. Their reply indicated that this type of equipment was not suitable for our purposes because of the difficulties involved in condensing the vapors. It was felt that the large quantity of inert matter in our wastewater flow would bind the condenser.

From the above considerations, it appears that evaporation and condensation is not a suitable process for the treatment of the waste described in our contractual parameters.

2.4 Polishing the Effluent

Following the purification process, the effluent must be further treated to reduce the COD and BOD contents to acceptable levels, and to effect the removal of colors and/or odors where they exist. The types of polishing processes that can be effectively employed to these ends include the following:

1. Adsorption
2. Filtration
3. Evaporation
4. Disinfection

It should be recognized that the principles and components of most of the processes listed here may in some instances be used, either separately or in combination, in the purification process. For example, the use of activated carbon as an adsorbent may be coupled with a purification of raw waste using inorganic coagulants such as ferric sulfate and lime. In other words, the polishing process is in many instances only a concentrated extension of one or more of the elements employed in the purification step.

2.4.1 Adsorption Processes for Polishing

Adsorption is a physical phenomenon depending largely upon the type and effectiveness of exposed surface area. It is a very effective method for removing organic matter, odors, and color from aqueous solutions.(13)(44)(57) Having these characteristics, adsorption would appear to be an excellent

candidate for polishing the treated effluent for this project. For this reason, the literature search was directed to a comprehensive investigation of the materials which appeared to have potential for use in an adsorption polishing process. The resultant discussions follow.

2.4.1.1 Activated Carbon as an Adsorbent

Activated carbon is an adsorbent which has been widely used in treating domestic waters for taste and odor removal. Inasmuch as the taste and odor imparted to water may be largely of organic origin, removal of organics by activated carbon is an effective remedy. The adsorptive capacity of activated carbon is relatively large, partially due to the large amount of surface area available on comparatively small amounts. It is estimated that five pounds of activated carbon has an available surface area of one square mile or more.⁽¹³⁾

Two forms of activated carbon are available for use in water and waste treatment, namely powdered and granular. Powdered carbon is generally added to the feed liquor, and is subsequently removed by sedimentation or filtration. Granular carbon is usually used in packed beds through which the liquid to be treated flows on a continuous basis.

The granular form has several advantages over the powdered form. These include the elimination of the continuous feeding and dusting problems associated with the powdered form, and the elimination of the solids separation process necessary to remove the powdered form from the effluent. In conjunction with the removal of the powdered form, there arises a problem of handling and disposing of the spent material which, for reasons that are to be explained below, does not occur with the granular form. These same reasons explain how the use of granular carbon decreases the consumption of the adsorbent, thereby reducing the material costs involved.

The granular form may be used more efficiently due to the fact that it can be completely exhausted before it must be discarded or regenerated. When powdered carbon is used, an equilibrium is soon reached between the amount of adsorbate held by the carbon and that contained in the surrounding medium. Thereafter, the powdered carbon will not adsorb any further impurities unless it is removed from the equilibrium solution, say, by filtration, and then recontacted with more of the original

solution. This not only means an incomplete adsorption in each "batch", but necessitates a cumbersome and expensive extra step in the polishing process.

The granular form, in addition to not presenting this problem, can also be more easily regenerated when it does become exhausted. It is indicated that the cost of granular carbon regeneration ranges from \$.003 to \$.04 per pound. However, where relatively small effluent flows are involved, such as those indicated for this project, carbon regeneration may be impractical from the standpoint of capital expenditures and logistical support required.

Laboratory procedures for evaluating and selecting particular granular carbons for a given application, as well as procedures for scaling up the laboratory results, are presented in the literature.⁽⁵⁸⁾⁽⁵⁹⁾ There are many different types of granular activated carbons on the commercial market, and a screening of all of them is not feasible for this project. A screening of those carbons used in wastewater renovation applications was carried out in a recent study, and the results of this study may be used as a basis for our selection.⁽⁶²⁾ Working from this basis, further evaluations may be accomplished by running batch tests and comparing the adsorption efficiencies of the carbons tested in terms of the Freundlich adsorption isotherms obtained for each.

The carbon or carbons selected may then be subjected to small scale continuous flow tests to obtain the following information:

- 1) The residence or contact time necessary to obtain the required results.
- 2) The volume of liquid treated per pound of carbon before the concentration of retained contaminants in the effluent flow exceed the allowable limit.
- 3) The pressure drop (head loss) at the test flow rate through the carbon bed.
- 4) The shape of the carbon exhaustion curve.

This information will not only allow a final and most accurate choice of the carbon to be used, but will provide considerable data pertinent to the design of full-scale equipment for the prototype model.

The actual application of powdered carbon to the treatment of laundry wastes has been evaluated as the result of several

experimental studies conducted.(22)(60)(61) Flynn describes the use of a combination of alum and powdered activated carbon in the treatment of laundry wastewaters. It was noted that ABS removals were not satisfactory, and this failure was attributed to the blinding of the carbon adsorbent by the alum floc. For improved performance it was recommended (but not substantiated by tests) that activated carbon treatment either precede or follow the alum coagulation step.(22)

Eckenfelder also used alum and activated carbon powder, but it was observed that very little ABS was removed using alum alone, and that only 15% ABS removal was effected using activated carbon alone. In order to remove substantially all of the anionic detergent in the laundry waste tested, it was necessary to first add Al^{+++} ions, causing a salting out process to prepare the molecule for adsorption. The syndets can then be adsorbed on activated carbon, following which the colloids and dispersed carbon may be ccagulated with alum.(60)

Eckenfelder observed further that previously formed sludge still had some detergent removal capacity -- that a 60% to 70% removal of detergent could be effected from pre-formed sludge without the addition of chemicals. However, it was indicated that sludge could not be used more than twice in this manner.

In a test reported in an editorial item of the April 1962 issue of Water Works, it was found that laundry wastes could be treated by adsorption on powdered activated carbon followed by filtration using a diatomite filter. No indication was given of the pretreatment steps used prior to the adsorption step. In any event, this treatment technique reduced the ABS content from about 40 milligrams per liter to less than one milligram per liter. The amount of carbon required was 5.5 pounds per 1000 gallons, with a total chemical cost of approximately \$1.41 per 1000 gallons.(61)

The renovation of wastewaters using granular carbon is also described in the literature.(62)(63)(64)(65) Two factors affecting the design of carbon adsorption beds, in this case a vertical column, are the size of the carbon granules and the contact time of the liquid. These factors are interrelated, since the finer the particles are, the less contact time is necessary. There is, of course, a practical limit as to how fine a carbon particle size may be used, for excessive headlosses across the column during continuous flow are undesirable.

Carbon columns operating on filtered secondary effluent resulted in the reduction of COD from a level of from 40 to 100 milligrams per liter down to a range of from 12 to 20 milligrams per liter.(62)(63) These reductions were obtained at a fifteen minute detention time based on carbon bed volume. During the use of the carbon column, it was found that as the effective capacity of the carbon is utilized, an adsorbed organic front moves toward the discharge end of the column. This front may be detected easily when it reaches the end of the column by noting the increase in unadsorbed matter in the effluent.(58)(59)(62)(63) Such an increase can be taken as an indicator that the carbon in the column is exhausted and that it requires replacement.

Factors affecting the performance efficiency of activated carbon include the pH of the waste solution, the carbon dosage used, the contact time, the particle size of the carbon, the concentration and nature of the organic contaminant to be removed, and the temperature of the flooded carbon bed. The effects of carbon dosage, contact time, and particle size have been mentioned above, and their importance is fairly obvious.

It is indicated in the literature that pH may have an effect on carbon adsorption efficiency.(57) Another source shows that a reduced ABS uptake may occur in the higher pH ranges.(44) Generally, rates of carbon adsorption increase with a corresponding increase in the concentration of solute; however, carbon adsorption of ABS appears to become relatively more rapid as the concentration is lowered.(44) The effect of temperature, as it affects the viscosity of the liquid, is to increase the rate of carbon adsorption as it increases.(58)(59)

It is noted that when both activated carbon and chlorination are involved in treating a waste, it is better to apply the carbon treatment prior to chlorination.(57)(66) The reason for this is that carbon is an excellent dechlorination agent, apparently converting free available chlorine to the chloride ion.(57) It has been reported that activated carbon can adsorb 10% of its weight of chlorine and still remain effective for adsorbing tastes and odors.(57)

The use of activated carbon as a filter medium and adsorbent appears to be feasible.(64)(67) The carbon used in this capacity should be hard and resistant to abrasion so that backwashing will not cause it to break up and lose its fines. An

activated carbon produced from coal appears to have these and other properties which would allow it to serve the dual purpose role of filter-adsorber. Such a carbon is commercially produced by the Pittsburgh Activated Carbon Company. Their "SGL" carbon (8 x 30 mesh) showed a headloss of two inches of water per foot of bed at a flow of four gallons per minute per square foot, and an expansion during backwash of about 25% at a rate of 15 gallons per minute per square foot.⁽⁶⁴⁾ The recommended contact time is 15 to 37 minutes based on carbon bed volume, with a carbon volume of from two to five cubic feet per gallon per minute.

2.4.1.2 Coal and its Related Products as Adsorbents

An investigation was conducted by the Pittsburgh Coal Research Center of the Bureau of Mines to determine the effectiveness of coal and coal related products as adsorbents for organic contaminants in wastewaters.⁽⁴⁴⁾ The effectiveness of these products was rated by a comparison with the established effectiveness of an activated carbon produced by the Pittsburgh Chemical Company. Using this activated carbon, under conditions comparable to those under which the coal products were tested, COD removals of from 74% to 94% and ABS removals of from 92% to 97% were effected.

The major conclusion of this investigation indicated that although several coals showed a fairly good adsorption capacity, none was comparable to activated carbon. The data obtained demonstrated that the categorical rank of a coal is not necessarily related to its ability to adsorb refractory wastewater contaminants. One coal of a given rank may be a comparatively effective adsorbent, while another coal of the same rank may be completely ineffective. Details of the investigation are described below.

The complete list of materials studied included six anthracite coals, twelve low-volatile bituminous coals, fourteen medium and high-volatile bituminous coals, five sub-bituminous coals, and one lignite. Flyash from seventeen pulverized coal-burning power plants was also tested, as were twenty coals pretreated by oxidation and volatilization and one lignite char. Additional materials studied were two samples of coke and single samples each of Mont char, Disco, coal ash, steel mill slag, Michigan peat, and bituminous tar.

The initial step in the testing was a screening study to ascertain which materials had sufficient adsorptive capacity to warrant further investigation. This step resulted in a reduction from 84 to 15 in the number of materials which appeared to have promising adsorptive properties. The remaining 15 materials were then subjected to intensive evaluation. Included in this phase of the study were one anthracite coal, four bituminous coals, three sub-bituminous coals, one lignite, four flyashes, and one pretreated coal. The results are summarized below.

- 1) Anthracite coals are generally poor adsorbents.
- 2) Organic removal was relatively poor for low and medium-volatile bituminous coal.
- 3) Although most of the high-volatile bituminous coals showed comparatively poor adsorption characteristics, a few produced COD removals better than 30%. One sample of promising high-volatile C bituminous coal was subjected to ten repeated contacts with fresh effluent to determine how rapidly it lost its effectiveness as an adsorbent. This procedure demonstrated that this particular coal was capable of adsorbing 4.0% of its weight in organics (as measured by COD), and 0.4% of its weight in ABS.
- 4) Sub-bituminous coals were generally poor adsorbents, and showed wide variations in adsorption capacity during the limited number of tests conducted.
- 5) Tests with lignite produced either very small COD reductions or an undesirable addition of organics to the treated effluent.
- 6) In general, flyashes were fairly good adsorbents. COD reductions varying from 48% to 66% and ABS reductions ranging from 49% to 87% were obtained from those flyashes tested extensively. The relative effectiveness of flyash is dependent upon the amount of carbon it contains, with higher carbon content samples showing higher adsorption capacities.
- 7) Most pretreated coals were slightly better adsorbents than the same coals in an untreated state, but the slight advantage gained was not sufficient to warrant detailed investigations.
- 8) It was found that such miscellaneous materials as commercial chars and coke, coal ashes, mill slag, and Michigan peat were not efficient adsorbents for organic wastes.

Generalizing from these results, the study indicated that one high-volatile C bituminous coal and several relatively high carbon content flyashes might serve as good adsorbents for organic matter. However, none of these items compare favorably with activated carbon in this respect, and it is felt that their use could be best justified in the form of a primary filter-adsorber preceding a carbon column. Comparing coal with flyash, it is felt that coal has the advantage, since it can serve the secondary purpose of a fuel medium for the incineration of adsorbed matter. Disposal of the spent flyash if it were to be used, could pose an additional problem.

2.4.1.3 Clays and Earths as Adsorbents

Tests have been conducted in which the adsorptive effectiveness of clays and earths were studied.⁽⁴⁴⁾ Batch tests with municipal secondary effluent were made, and the results were rated against the efficiency of activated carbon under the same circumstances. None of the clays and earths studied proved to be as effective as the activated carbon, nor were they as effective as the best coal adsorbents or more promising flyashes.

2.4.1.4 Silicas as Adsorbents

Nine silicas, including diatomaceous earth, dicalite, celite, and florisil, were tested and found to be poor adsorbents. The largest COD reduction obtained was 10%.⁽⁴⁴⁾

2.4.1.5 Silicates as Adsorbents

The twenty silicates tested included materials such as Attacote, Attaclay, Attasorb, greensand, vermiculite, bentonite, and yellow gel. Only two of these showed substantial COD reductions, these being a 35% reduction with one sample of Attacote and a 26% reduction with one sample of Edgar ASP 101. With few exceptions, the other compounds either effected an insignificant removal or produced an increase in the COD measurement.⁽⁴⁴⁾

2.4.1.6 Ion Exchange Resins as Adsorbents

The removal of ABS using anion exchange resins was reported by Abrams and Lewson.⁽⁶⁸⁾ Of the several resins investigated, the strong basic resin Duolite A-102D was calculated to have an ABS capacity of 350 grams per liter, based on one equivalent per liter or 22 kilograins per cubic foot. Resin capacities were unaffected by the mineral content of the solution treated, but

decreases significantly with increases in the flow rate. Elution of the resin was accomplished using a combination of a mineral acid and a polar solvent.

Studies conducted with the ion exchange resins Ionac A-540 (Cl⁻ form) and Ionac A-300 (SO₄⁻ form) produced COD reductions of 94% and 34% respectively.⁽⁴⁴⁾ Eisenhauer, in comparing the operating costs of various laundry waste treatment methods, has indicated that the ion exchange resin cost for ABS ranges from \$1.25 to \$1.50 per 1000 gallons.⁽⁵⁴⁾

It appears that selective anion exchange resins may be applicable to the treatment of the combined wastewaters for this project. However, the ion exchange resins may be detrimentally more sensitive to increasing flow rate, turbidity, and suspended matter than activated carbon, and may be more costly to use.

2.4.1.7 Miscellaneous Materials as Adsorbents

Protein matter is said to be particularly effective in the adsorption of anionic detergents.⁽⁶⁹⁾ At the usual washing concentration, wool will remove 75% of the alkyl-aryl-sulfonate type of detergent (Surf) from twenty times its weight of neutral solution, and 97% of the same detergent from five times its weight of solution. The amount of adsorption is greatly increased by lowering the pH of the solution. The effect, if any, of protein matter on the removal of non-ionic detergents and phosphates was not reported. Inasmuch as the combined wastewater for this project may contain incidental amounts of protein matter from the kitchen waste source, some anionic detergent removal by adsorption may be expected to occur as an unregulated phenomenon.

Other miscellaneous materials have been tested to determine their effectiveness in removing organics by adsorption. Those reported in the literature included five metal oxides, calcium aluminate, limestone, monazite, "rare earth sodium sulfate", and cement stack dust.⁽⁴⁴⁾ None of these compounds was found to be an efficient adsorbent of organic matter.

2.4.2 Filtration Processes for Polishing

Filtration, as used in this discussion, refers to the process of separating solids from liquids, a step in waste and water treatment which generally follows the coagulation-

precipitation process. In the application of filtration as a means for polishing the waste to be treated under this contract, the liquid portion passing through the filter medium will be made available for reuse for purposes other than drinking or food preparation unless sample analysis indicates that further treatment is needed. If further treatment is required, it would most probably come in the form of adsorption on activated carbon, as discussed in the preceding section.

The filtration processes which have been investigated in the literature search are gravity filtration and pressure filtration. Gravity filtration, as the name denotes, operates by utilizing gravity to force the filter influent through the filtering medium. Pressure filtration employs mechanically supplied pressure, either positive or negative (vacuum), to aid in forcing the influent through the filter medium. Commonly used media for filtration processes are sand, coal, and activated carbon. The diatomite filter is a special type of pressure filter employing a processed diatomaceous earth, and its application will be discussed later, in detail. All of these media may be used either alone or in combination with each other.

The solids retained on the filter media are generally removed by backwashing. Minimum allowable amounts of filtrate are used for backwash purposes, and, therefore, the backwash water contains appreciably higher concentrations of solids than the liquid being filtered. This backwash water will have to be disposed of, and is not available for reuse. The loss of this water results in a decrease in the water-recovery percentage of wastewater renovation systems.

The alternative to backwashing is to remove and dispose of the filter medium itself. Generally speaking, the major portion of entrapped solids are accumulated in the surface layers of the filter bed. This means that in many instances only those layers will have to be removed on a regular basis. However, there is some penetration and accumulation of solids within the bed itself, and eventually the entire bed will have to be replaced due to the progressive accumulation of the solids.

The floc (solids) penetration into the bed appears to be a function of the "filterability index" as defined by Hudson.⁽⁷⁰⁾ This measurement of the performance characteristic of filter beds may be expressed in the form of the equation shown in Figure 4.

$$K = \frac{Vd^3h}{L}$$

where:

K = filterability index

V = filtration rate in gallons per
square foot per minute (gpm/ft²)

h = headloss at terminal breakthrough
in feet

L = bed thickness in feet

d = effective bed particle size in
millimeters

Figure 4 - Equation for
Filterability Index

The filterability index for polishing a given treated waste may be obtained by testing for the values in this equation, with the resulting data being used for design and application purposes.

Assuming that any removed filter medium will have to be disposed of, incineration would appear to be the most efficient means for getting rid of both the spent medium and the entrapped solids if the filter medium is coal or activated carbon.

The operation of conventional gravity or pressure type filters is accompanied by an increasing loss of head pressure through the filter medium. This, in turn, may bring about a declining flow rate through the filter. Such a declining flow rate may not be serious when filtration polishing follows batch waste treatment, but it can be a problem when the treatment system operates on a continuous basis. If the system is continuous, steps may have to be taken to either assure a uniform flow rate through the filter, or to control the flow of waste coming to the treatment facilities so that it matches the declining rate of flow through the filter. Of these, the latter solution appears to be more difficult and complex.

A uniform rate of flow through the filter bed may be obtained by designing the filtration system in such a manner that the limiting resistance to flow is located in the filter effluent line. This limiting resistance should be adjustable and proportional to the head pressure available for producing flow through it. Automatic regulators, such as rate-of-flow controllers, are available for this purpose.(71)

2.4.2.1 The Application of Filtration Polishing to Water Purification

The major application of gravity and pressure filtration systems is in the purification of municipal and industrial waters. Large installations for this type of water treatment are usually of the gravity type, and sand is the most commonly used filter medium with both types. Sand filters are categorized by the speed at which they function, and are usually designated as being either "slow" or "rapid".

In the slow sand filtration of water, the water rates usually applied to the filter vary from 0.032 to 0.160 gallons per minute per square foot. In general, an effective sand size

of about 0.35 millimeters with a uniformity coefficient of approximately 1.75 will give satisfactory service. The sand bed depth may be as shallow as twelve to eighteen inches of graded sand supported by twelve inches of graded gravel. The removal of solid matter from the wastewater is effected by straining the liquid through the pores of the sand layer. When the surface sand layers become clogged with accumulated solids, the sand and solids mixture is removed. This generally requires the removal of about one inch of material from the surface of the bed, and this depth is, of course, replaced with fresh sand.

In "free-surface" rapid sand filtration, the water application rates usually vary from two to three gallons per minute per square foot. The effective sand size used in such systems varies from 0.35 to 0.80 millimeters, and a uniformity coefficient of not more than 1.70 is optimum. A sand bed depth of from twenty-four to thirty inches on about eighteen inches of graded gravel is employed. The relatively high water application rates require that the water to be filtered be pretreated to remove much of the suspended matter from it. This is usually done through chemical coagulation and sedimentation.

Free-surface rapid sand filtration beds are cleaned by backwashing with a current of water induced from the bottom of the bed. This expands and scours the sand, carrying away the accumulated solids to waste.

Operating difficulties include the possible failure of the mechanical equipment and controls installed to regulate the flow of feed water, or a functional failure of the bed itself. For example, air binding is a problem which occurs in the filter bed because of negative heads which may develop during operation. Negative heads occur when the headloss developed in the sand bed exceeds the depth of water available for maintaining the flow. Under these conditions, dissolved gases are released from the water being filtered, thereby binding or "clogging" the filter medium. The design engineer may avoid such difficulties by making the filter box deep enough to maintain the required depth of pressure-producing surface water.(71)

In mechanically induced pressure filtration systems, water application rates vary from two to four gallons per minute per

square foot. Pretreatment for the removal of suspended matter is as important for pressure filters as it is for free-surface type systems. Cleaning of the filter bed is by backwashing, and the operating difficulties are similar to those experienced in rapid sand filters, with the exception that air binding rarely occurs.

Although, as has been mentioned, sand has been the most commonly used filter medium, it is reported that the use of anthracite coal in this capacity is steadily increasing. In 1956 it was being used in municipal water treatment plants in 23 states, with successful applications in Washington, D. C.; Wheeling, West Virginia; Rock Island, Illinois; and other places.⁽⁷¹⁾

Anthracite coal has an average specific gravity of 1.5, as compared to 2.65 for silica sand and crushed quartz. With weights per cubic foot of 94 pounds for coal and 200 pounds for sand, a ton of anthracite coal will fill almost twice as much filter volume as a ton of sand. This tends to compensate for its considerably greater cost. Other advantages claimed for anthracite coal are the fact that due to its lower specific gravity, it requires only about half the backwashing velocity needed to expand sand beds, and that anthracite material of comparable effective particle size has greater porosity than sand.

The use of multi-bed filtration to improve the polishing process in water treatment has come into use relatively recently. At present, combinations of anthracite coal and sand are being used in several locations.⁽⁷²⁾⁽⁷³⁾⁽⁷⁴⁾ Also under investigation are manufactured materials for use in combined filter bed applications.⁽⁷⁵⁾

Conley and Pitman concluded from a filter evaluation program that the performance of filters containing the proper sizes and depths of anthracite coal and sand together were superior to the performance of filters made out of either material alone.⁽⁷⁶⁾⁽⁷⁷⁾ This conclusion has been borne out by other investigators. Shull, for example, successfully used a multi-bed filter consisting of a twenty inch layer of anthracite coal with an effective size of about 0.90 millimeters placed over a six inch layer of sand having an effective size of 0.44 millimeters.⁽⁷²⁾

On the other hand, Hazelswart obtained improved performance over sand alone by using a filter bed composed of two inches of anthracite coal with a 0.90 millimeter effective size on top of a twenty-four inch layer of sand having an effective size of from 0.50 to 0.55 millimeters.(73) The improved performance with this type of combined filter may be explained by the fact that the upper layer (coal) retains the larger floc particles, thus allowing the sand layer to more effectively be sized for the retention of small solids. As a result, the bed is utilized to a greater depth than usually occurs with single element filters, where only the top two to four inches play an active part in the function of the unit.

The diatomite filter is a special type of pressure filter employing a processed diatomaceous earth as the effective medium. The filter is enclosed in a pressure tank along with accommodations for providing influent, wash water, and effluent drain connections. The structural support for the filter medium is either a fine metal screen, a synthetic fabric, or a porous ceramic material. The filter is prepared for operation by precoating, a process in which diatomaceous earth carried in suspension in water is built up on the filter base to a depth of about one-eighth inch. Filtration rates range from one to five gallons per minute per square foot or more, depending on the character of the influent and the desired characteristics of the effluent. When the concentration of retained solids begins to alter the nature of the effluent, the filter is backwashed and flushed. After precoating, it is again returned to service.

The diatomite filter was developed primarily for military use during World War II. It is standard military equipment, and portable filters of various capacities are readily available. It appears that the diatomite filter may be applicable to the filtration polishing of the waste to be treated in this project.

2.4.2.2 The Application of Filtration Polishing to Waste Treatment

The use of filtration polishing in waste treatment systems is not nearly as widespread as it is in water treatment systems. The reason for this is that while filtration polishing is an essential part of water treatment, waste treatment effluents have not, to date, required polishing to upgrade them prior to discharge into receiving watercourses. However, modern anti-pollution legislation and an increasing need for the reuse of

treated wastes indicate that polishing procedures with waste treatment will become more prevalent.

Because of the limited extent to which they are used in waste treatment, information regarding filtration polishing methods was scant in published form. Nowhere, for example, was there any report found of multi-bed filters being used for waste treatment applications.

Although no full scale applications were reported, the Journal of the Water Pollution Control Federation, Volume 33 (1961) contains a general description of the use of sand filters for treating and polishing domestic wastes.⁽⁷⁸⁾ This description parallels that of slow sand filters used in water treatment, but indicates that sand filters may be employed for either treating primary effluents or for polishing secondary effluents.

When sand filters are used for treating primary effluents, it is claimed that they effect removal of as much as 95% of the BOD and suspended solids. Such filters are intermittently dosed, and depend upon biological activity to remove a large portion of the organics in the sewage, converting the unconsumed portion to a more or less stable condition. Unlike the trickling filter, the intermittent sand filter strains out and retains on or near its surface most of the suspended matter carried over from the previous treatment process. Removal of the surface layers along with the entrapped solids is accomplished by scalping with a rake, fork, or shovel. The sand lost in this operation is subsequently replaced.

The application of a rapid sand filter to the treatment of primary effluent was reported in 1936.⁽⁷⁹⁾ Various sand sizes and filtration rates were employed, with sand of from 1.0 to 2.0 millimeters in diameter producing a 35% reduction in oxygen consumed value at a filtration rate of 0.74 gallons per minute per square foot. With sand of this relatively large particle size, the sewage particles were not retained exclusively in the surface layers, but were equally distributed throughout the filter bed. Backwashing was accomplished by means of air and raw feed, resulting in 200 milliliters per liter of settleable solids at the beginning of the wash cycle and 10 milliliters per liter of settleable solids at the end of the wash cycle. How the backwash water was subsequently treated and disposed of was not reported.

Reports on the use of coal and other carbon-related products as filter media for waste treatment polishing is also largely lacking in the literature. From what information is available, it appears that coal and carbon-related materials have two advantages over sand: 1) the fact that they have significant to appreciable adsorptive properties which may be utilized for removing soluble organic contaminants, and 2) that when they are exhausted, they may serve as fuel in the disposal of the adsorbed and filtered wastes by incineration. They are, in effect, self-destructing.

The use of activated carbon for the filtration polishing of wastes appears to be feasible to our application. The detailed discussion of activated carbon which appears in Section C.1.a of this report considers all those aspects of the material which make it an attractive possibility to play the dual role of a filter-adsorbent.

The operating difficulties involved in using coke as filter medium are described by Rudolfs. Coke was found to be a poor adsorber, was non-uniform in size, floated readily in the filter, and had poor resistance to abrasion, making it necessary to replace a comparatively large percentage when reused.⁽⁸⁰⁾

The use of coal as a filter medium in the treatment of sewage and wastewaters has not been widespread in the past. However, the results of an intensive investigation of the use of coal in this respect has been published recently.⁽⁸¹⁾ The study reported in this document covered the period from November 1963 to October 1965.

In summary, it was found that coal may be used as a combination filter medium and adsorbent to remove appreciable amounts of BOD, COD, suspended solids, and phosphates from sewage.⁽⁸¹⁾ Furthermore, it was reported that the filtered solids may be removed continuously during operation, and that the coal retains its value as a fuel even when exhausted as an adsorbent. It can therefore be economically disposed of without the need for backwashing.

During this investigation, tests were performed using raw sewage, primary effluent, and secondary effluent. A detailed summary of the results and conclusions obtained follows.

- 1) All American coals above the rank of lignite are suitable for use as a filter medium to remove suspended solid matter from sewage, and all coals, regardless of rank, were found to be able to adsorb dissolved organic matter from water solution to various degrees.
- 2) It was demonstrated that any coal (except lignite) can be employed to remove 50% or more of BOD or COD, more than 90% of suspended solids, and phosphates to a degree exceeding conventional methods.
- 3) High-volatile-C coal has shown the ability to remove 80% or more of BOD and COD, the same degree of removal claimed to be accomplished in a well operated conventional secondary treatment plant.
- 4) A semi-continuous process was developed whereby both the filtration and adsorption processes were combined into a one-step treatment process. This method was demonstrated with high-volatile-C coal on the municipal sewages of Cleveland, Ohio and Washington, D. C., and achieved the following average reductions in contaminant levels:

(a) Suspended solids	95% to 100%
(b) BOD	75% to 85%
(c) COD	75% to 85%
(d) ABS	75% to 85%
(e) Phosphate	35% to 85%
- 5) Coal was found to effectively adsorb, in varying degrees, a number of different types of matter from solution, including color, odor, dyes, acetic acid, and cyanides. Notable removals of coliform bacteria were also measured, the results varying with the length of exposure.
- 6) Coal was not found to be effective in removing such soluble ionic inorganic substances as chlorides, sulfates, or mineral acids. However, some materials of this type, notably phosphates and possibly sulfides, were removed to a high degree.
- 7) While all coals, with the possible exception of lignite, were suitable as filter media, their abilities to adsorb dissolved matter was found to vary considerably with their categorical ranks. In the case of purely organic materials, namely those contributing to oxygen demand, the coals appeared to fall into two categories.

Those ranking high-volatile-A and above were generally inferior adsorbents, being approximately 5.0% to 15.0% as effective as activated carbon. Coals ranking below high-volatile-B inclusive were, as a whole, notably superior in their adsorptive ability. In laboratory batch-type tests, these latter coals ranged from 15.0% to 40.0% in effectiveness when compared to activated carbon. In column tests where exposure times were optimum, one sample of high-volatile-C bituminous coal adsorbed fully 70.0% as much oxygen demand from municipal sewage as did activated carbon.

- 8) Solid coal was found to exert a substantial oxygen demand when included in otherwise pure water. Therefore, the removal of all coal particles was concluded to be a necessary aspect of both laboratory tests and any treatment process based on them. However, no coal was found to contribute soluble oxygen demand to water.
- 9) The coal filter-adsorption bed was found to be effective in the treatment of either raw or settled sewage, and could, therefore, merit consideration as either a separate process or an adjunct to a variety of existing sewage treatment methods. Average filtration rates in the unit tested, operating with raw sewage, ranged from 0.5 to 1.2 gallons per minute per square foot. Coal consumption was on the order of five tons per million gallons. The coal size range employed was + 20 mesh to - 250 mesh, with the bulk (75% by weight) falling in the range between (- 20 to + 42) and (- 60 to + 100) mesh.

From this discussion it would appear that coal and activated carbon may be usefully applied for filtration polishing of the wastewater to be treated under this contract, either as a separate filtration process or in conjunction with an adsorption process.

2.4.3 Evaporation Processes for Polishing

Evaporative processes as a means for total treatment of wastes and wastewater have been evaluated in Section B.7. of this literature survey. The general objections raised during this discussion to the use of evaporative methods such as vapor compression and flash distillation for treating raw waste may also

be used to rule out the use of evaporation and condensation for polishing a treated waste. It is recognized that pretreatment methods may remove the volatile components contained in the raw waste, elements whose possible presence was the basis for one of the objections raised to evaporative methods. However, the effects of pretreatment prior to polishing by evaporation may present additional problems, such as increasing the scaling potential due to the addition of chemicals during the pretreatment process. Such conditions might include variations of total alkalinity and undesirable concentrations of calcium and sulfates.(82)

It is indicated by one branch of the military service, the U.S. Army, that since the output of distillation equipment is limited and the process is expensive, its use must be restricted to situations in which no other process is adequate.⁽⁵⁶⁾ From the discussions to this point, it is obvious that other processes are both available and adequate to perform the polishing operation required for this project. The adsorption and filtration processes, for example, are felt to be more advantageous than the evaporative process from the standpoint of weight and cubage of required equipment, the operational skills required, equipment maintenance, power requirements, water recovery capability, and cost.

2.5 Disinfecting the Effluent

With the prime purpose of this project being the renovation of wastewater for reuse, it is reasonable to assume that military personnel will be in intimate personal contact with the renovated water. Because of this, it will be necessary to disinfect the treated effluent prior to its release for reuse. Disinfection, as opposed to sterilization, is the process by which vegetative forms of potentially harmful bacteria are destroyed. It does not destroy bacterial spores, as does sterilization, but complete destruction of all micro-organisms is not necessary when the renovated water is to be used for purposes other than drinking or food preparation.

About 1880, investigations demonstrated that certain bacteria, now designated as pathogenic bacteria, are the cause of certain diseases. Subsequent studies revealed that small concentrations of chemicals and chemical compounds, as well as the application of specific processes, are capable of destroying such pathogenic bacteria. Such chemicals include the halogens,

potassium permanganate, silver, and ozone. Processes which effect the same results include the application of heat (boiling) or light (irradiation through the use of ultra-violet rays).

Of the specific chemicals and compounds investigated, chlorine and its compounds proved to be so effective and economical that they are now the most commonly used agents in the disinfection of treated waste effluents. By controlling its concentration in the effluent, chlorine can be used to effect varying degrees of bactericidal action. For example, it can be used as a bacteriostatic agent when applied in small concentrations -- that is, it prevents an increase in the bacterial population. It becomes a disinfecting agent when applied in larger amounts, destroying those bacteria that cause infection or disease. In large dosages, chlorine can become a sterilizing agent, although it is rarely used in this capacity.⁽⁸³⁾

In addition to its disinfective ability for destroying harmful bacteria, chlorine has been used in waste treatment practice to effect such results as putrefaction and odor control, BOD reduction, corrosion control, grease removal, sludge bulking control, digester foaming control, trickling filter ponding control, and general treatment of industrial wastes.⁽⁸³⁾

Forms of chlorine which may be used for disinfection and other purposes include gaseous or liquid chlorine, chlorinated lime, calcium hypochlorite, sodium hypochlorite, chlorinated copperas, and chloramines. The standard form employed by the military branches is calcium hypochlorite, which is very active chemically, and dissolves readily in water.⁽⁵⁶⁾

When it is dissolved in water, calcium hypochlorite degrades into free available chlorine and a calcium carbonate sludge which settles out. The chlorine is present in the solution as hypochlorous acid or hypochlorite ion, both of which are powerful oxidizing substances. The relative amounts of these agents present is a function of the pH of the solution, with hypochlorous acid predominating in the range from 3.0 to 6.0, and the hypochlorite ion being in the majority at pH levels about 7.5. At pH 9.5 or greater, the hypochlorite ion constitutes 100% of the chlorine residual.⁽⁸³⁾

The efficiency of disinfection using common additive agents is dependent upon several factors in addition to the type and

concentration of the agent itself. These include (a) the contact time, (b) the type and concentration of micro-organisms, (c) the pH and temperature of the effluent, (d) the presence of interfering substances, and, (e) the degree of protection afforded to the micro-organisms by materials in which they may be imbedded. These factors must, of course, be taken into consideration in the design of the system and in the application of the disinfecting agent. For example, an application of chlorine following preliminary treatment of the waste will reduce the volume of solid matter in which organisms may be imbedded, thereby offering a possible reduction in the volume of chlorine and length of contact time required during the disinfecting process.

The pH and temperature of the flow to be disinfected are important because the quantity of free available chlorine required increases with increasing pH and decreasing temperatures.⁽⁸³⁾ This same source indicates that chlorine dosage and contact time may be related, with the contact time varying inversely to the dosage. It should also be noted that in addition to the chlorine exhaustion effected by organic matter, iron and manganese also consume chlorine. This information should be kept in mind in selecting the material used in transporting and storing the disinfected water. Further, where activated carbon is used in the treatment process and where a chlorine residual in the treated water is required, it is recommended that chlorine be applied after the activated carbon treatment because of the prodigious chlorine adsorbing capacity of activated carbon.⁽⁵⁷⁾

2.6 Treatment of Sludge for Disposal

Sludge treatment prior to its disposal consists primarily of dewatering it, thereby reducing its volume and weight. If the method of disposal happens to be incineration, dewatering also enhances the ease with which the sludge can be burned.

The purification of water for reuse by employing common inorganic coagulants such as the salts of aluminum and iron results in waste sludges containing the hydroxides of these metals. The technical feasibility of treating the hydroxide sludge with sulfuric acid to recover and eventually reuse the coagulant has been demonstrated for such sludges from water purification systems.⁽⁸⁴⁾ However, the waste sludges obtained from the treatment of combined wastewaters like those with which we are concerned differ in composition from plain water

purification sludges.

Whereas the water purification sludges contain essentially hydroxide precipitates, the sludges obtained from the combined wastewater in our project will contain, in addition to the hydroxides, phosphate precipitates of iron, calcium, or aluminum. The source of the phosphates is the detergent builders from the kitchen and laundry facilities. Subsequent treating of such combined wastes with sulfuric acid may result in a solution mixture of recovered coagulant and phosphoric acids which may be difficult to separate. In addition, because of the relatively large amounts of calcium ion required in treating the waste, treatment with sulfuric acid may result in significant amounts of calcium sulfate precipitate which would have to be separated prior to disposal. Due to these difficulties and the hazardous nature of sulfuric acid, treatment of the sludges from the combined wastewater treatment may be precluded. It should be noted here that the recovery requirements of this contract possibly can be met without the inclusion of a dewatering process per se. That is, the sludges may be amenable to incineration along with normal refuse without being treated specifically for the purpose of reducing their water content.

If, however, it becomes evident that a dewatering process is necessary, there are three methods available to accomplish this end. They include thickening, vacuum filtration, and gravity filtration. As an adjunct to these methods, a conditioning of the solids prior to dewatering may be accomplished, if necessary, by chemical additions or freeze conditioning.

2.6.1 Dewatering by Thickening

Volumes of waste sludges, in many cases, may be appreciably reduced by a thickening process prior to disposal. Either gravity (settling and compaction) or flotation thickening may be used for this purpose. The literature makes little reference to thickening of water treatment sludges although one source indicated that concentrations of 0.2% could be thickened to about 1.0% by gravity compaction.⁽⁸⁴⁾ Commercially produced flotation thickening units are available also.

If the waste sludge proves to be amenable to dewatering by thickening, both of these methods will be considered. For example, it would not pose too great a problem to design the solids-liquid

separation basin with adequate storage capacity to effect sludge compaction.

2.6.2 Dewatering by Vacuum Filtration

In a survey conducted to determine the manner in which water purification plants disposed of their waste sludges, it was determined that about 96% of the 1,530 plants reporting discharged their wastes directly into streams or lakes without treatment.⁽⁸⁹⁾ Of the remaining 4.0%, none were using vacuum filtration as a means for dewatering their waste sludges. None of the respondents were aware of any experimental work being conducted in water purification plants using vacuum filtration. A further search of the literature did not reveal any applications of vacuum filtration for sludge dewatering in water purification plants.

As far as waste treatment plants are concerned, only one application of vacuum filtration to the dewatering of chemically treated sludges was uncovered.⁽⁹⁰⁾ A portion of the difficulties involved in the vacuum filtration of chemically treated sludges for the refinery application cited was indicated by the fact that they found it necessary to blend other refinery sludges with the chemically treated ones in order to improve the dewatering characteristics. A precoat of the filter was used to facilitate the process, and the filter cake obtained was disposed of by incineration.

It appears that the application of vacuum filtration to the dewatering of the sludges expected in this project, if it were technically feasible, may prove prohibitively complex. Such a process could well involve considerable additional equipment and procedures. For example, chemicals and/or filter precoating may be necessary, along with the appurtenant equipment required for preparing and dispensing these substances. Changing compaction characteristics in the sludge would present an additional problem, and the filtrate from the filter could possibly require further treatment if it were to be blended with the renovated effluent.

All things considered, vacuum filtration does not appear to be an attractive or practical method of dewatering for our purposes.

2.6.3 Dewatering by Gravity Filtration

Gravity filtration equipment and its operation are significantly less complex than that for vacuum filtration. However, the amount of dewatering effected and the filtration rates are correspondingly less than those obtained with vacuum filtration. The two methods have similar problems where chemically conditioned sludges are concerned, but the gravity process has other and more serious problems in additional areas. For example, separating the filter cake from the filter medium and renewing the filter medium for repeated use with a continuous rotary-drum type vacuum filter is relatively simple. On the other hand, separating the filter cake from a gravity medium such as sand is a difficult and wasteful process.

In most gravity filter applications, a significant amount of the medium must be removed with the filter cake, necessitating the replacement of the removed medium as well as complicating the eventual disposal of the filtered solids if the medium is sand.

If one were forced to choose a gravity filtration medium which could most easily be applied to dewatering the sludges expected in this project, the optimum material would be one which could ultimately be disposed of along with the filter cake. This would eliminate the need for separating the cake from the medium, and simplify the development of a system in which solids removal and filter medium renewal could be accomplished on a continuous basis. This precludes the use of sand, and tends to lend favor to materials such as coal and activated carbon which can be easily incinerated.

Assuming for a moment that gravity filtration is feasible as a method, batch-type filtration, such as the sludge drying bed technique, may be considered. However, the use of such techniques would require appreciably more space than a continuous process, and could well present odor control problems. In addition, batch-type filtration would require more time and attention for the removal of dried sludge and the preparation of the drying bed for applications of fresh sludge.

In view of these objections, it appears that gravity filtration should be avoided where effective and less complex alternative processes are available. Since vacuum filtration is also a basically objectionable process for our purposes, dewatering by thickening emerges as the most likely candidate. Since

incineration facilities are an integral part of military installations, there will be convenient means available for disposing of the dewatered sludges obtained from the thickening process.

2.7 Process Control and Effluent Monitoring

As was discussed in the section of this literature search devoted to the accumulation and blending of the combined wastewater, the composition and volume of the wastes coming to the treatment facilities will vary widely during normal operation. As a partial solution to the obvious problem of coping with these variances, it was proposed to provide holding and mixing tanks in which the combined wastes could be accumulated and blended. This, however, is not a complete solution, nor can it be entirely solved by employing a treatment technique "broad" enough in its scope to encompass the range of variants. In fact, the delineated parameters for the renovated effluent preclude the use of such "catch-all" methods.

It becomes apparent, then, that there is a need for process control measures to assure the production of a properly treated effluent. In addition, some means of monitoring the treated water will be necessary to assess the efficiency of the overall waste treatment operation.

A significant degree of process control may be effected by judicious selection of the general waste treatment method to be used. It should be noted that treatment of the waste described in this contract may be carried out either by batch or continuous-flow treatment methods. From the standpoint of process control, the batch treatment method has certain advantages over the continuous-flow treatment method. The process elements involved for the two methods in treating the waste include (a) waste accumulation and blending, (b) purification, (c) polishing, (d) disinfection, and, (e) sludge treatment and disposal. Obviously, the waste accumulation and blending step is the starting point for both treatment methods. Thereafter, however, the flexibility for process control between the two methods differs significantly. For example, in the continuous flow method, the above process steps are effected concurrently, and any necessary adjustment in the coagulation chemical dosage (where chemical treatment is used for purification) and/or chlorine dosage will have to be made during operation and within a short period of time, as any delay in doing so may affect the purification step

effluent, filter polishing operation, and treated water quality. Conversely, in the batch treatment method, the above process steps do not take place concurrently, but are performed separately and in sequence. A subsequent process step may not be initiated until the previous step has been performed to the operator's satisfaction. Consequently, using the batch mode of operation provides for greater flexibility and treatment reliability than the continuous flow method. For example, the operator has greater flexibility in varying the detention time of the chemical rapid mix, flocculation, sedimentation, and sludge compaction process steps using the batch method than he does using the continuous flow method.

Attachment "A", paragraph 1, of this contract shows that the combined wastewater is composed of kitchen, laundry, and shower water. Paragraph 3.1 of Attachment "A" shows the anticipated quantities of waste emanating from each source. Finally, Paragraph 4.2.1 shows the various constituents and their relative quantities which may be expected to be found in the "ideal" waste obtained from an accurate blend (as described in Paragraph 3.1) of flows from the three waste sources.

To consistently obtain, in practice, the "ideal" waste, as described above, would be fortuitous, indeed. It is felt that it may be impractical and unnecessary to coordinate the operations of the kitchen, laundry, and shower room in such a manner as to consistently obtain the "ideal" waste described above. It is further felt that, as a general rule, the analysis of a typical waste to be treated in practice will vary significantly from that shown in Attachment "A", Paragraph 4.2.1. In fact, it should be expected, generally, that the analysis will vary significantly from one batch of waste to another. As a result, process control procedures are indicated for use on an individual waste batch basis which will consistently lead to effective treatment of the waste batch in question. In this regard, relatively rapid and effective laboratory tests may be developed to determine chemical dosages, rapid mix time, flocculation time, sedimentation effectiveness, filtration polishing effectiveness, and chlorine demand.

Other process control measures for which provision should be made include sampling, blending tank water level, and measurement of flow rate and pH. Means for accomplishing this may be manual, semi-automatic, or automatic. For example, sampling of the various process streams may be accomplished manually in an

intermittent manner or continuously using a sampling pump. Flow rate may be measured manually (bucket and stop watch method) or continuously using various available flow meters, both with and without provision for recording. Again, pH may be obtained manually, by colorimetric or other means, or may be obtained automatically and continuously recorded by use of available sophisticated instruments.

Effluent monitoring procedures may also be manual, semi-automatic, or automatic. The required renovated water characteristics shown in Table I of Attachment "A" of this contract are the likely variables that would require monitoring and include pH, turbidity, COD, BOD, coliform count, detergent content, odor, color, and chlorine residual. Effluent monitoring may be used as a process control measure in that if the magnitude of any of the variables shown in Table I, Attachment "A" exceed the required maximum, it would be indicative of the need for required remedial action. It should be recognized that the BOD measurement is not an effective process control measure (five days are required to obtain it) and may be used as a measure of the effectiveness of overall treatment. All of the above effluent criteria may be measured manually by the accepted standard methods, given the required laboratory equipment and chemical reagents. Note that incubation equipment is required for BOD and coliform determinations and that the required conditions for measuring odor are rather exacting. Also, the equipment and procedures required for determining COD and detergent content are relatively complex in comparison to those which will be described subsequently. The above restrictions may preclude the field determination of BOD, COD, coliform count, detergent and odor unless simplified procedures, which are presently unavailable are developed. However, standard military kits are available for the manual, routine measurement of pH, turbidity, color, chlorine residual, soap hardness, alkalinity, chlorides, sulfates, and coagulation efficiency.(56)

Complex and sophisticated instrumentation is also available for the semi-automatic and automatic measurement and recording of such effluent characteristics as pH, COD, turbidity, color, dissolved solids, and chlorine residual. These means for measurement may not be acceptable as standard measuring methods but may be used for routine monitoring and control purposes. This instrumentation is commercially available, but most of it may be largely experimental in nature and all are in the \$1,000 to \$2,000 and greater cost range. It should be recognized that

use of automatic instrumental means for obtaining or accomplishing the process control and effluent monitoring tasks described above are more complex, less rugged, have greater maintenance requirements, require greater operational and maintenance skills, require greater power requirements and are more costly than the simple instruments requiring manual use.

2.8 Summary Remarks for Literature Search Section

The material contained in this section of the Interim Technical Report was compiled in an effort to uncover all the known process elements applicable to the treatment of wastes similar to those with which Contract No. DAAK02-67-C-0398 is concerned. As stated in the work plan for this project, the information gained from this literature search will be used as a guideline for laboratory and bench-scale tests to determine what combination(s) of the various process elements is (are) best suited to the design, fabrication, and operation of a prototype combined wastewater renovation unit.

Although a literature search is technically concerned only with the reporting of data found in published form, some of this data, for one reason or another, can be eliminated from further consideration without the benefit of laboratory testing. As a result, this report comprises a certain number of engineering judgments and/or evaluations. Such judgments, however, have been made only where the material available or the investigator's experience have justified making them. That data which appeared to have genuine value to the completion of the contractual agreement has been carried forward to the laboratory studies portion of the project.

3.0 THE LABORATORY STUDIES SECTION

3.1 Preliminary Remarks

The contract with which this project is concerned calls for the design and construction of a prototype air-transportable waste treatment unit to be used by the U. S. Air Force during construction of advanced air bases. This waste treatment unit will treat the wastewaters resulting from the kitchen, laundry and shower areas, with the renovated water being reused in the laundry and shower areas.

The first phase of this contract consists of a review of existing literature, laboratory studies of the potentially useful processes revealed by the literature review, and engineering evaluations of potentially amenable systems. The results of the laboratory studies are presented in this section of the report.

3.2 Investigation Parameters

The composition of the wastewater tested and the degree of treatment are specified by the contract. The contract specifies that the test water contain the following:

1. 3.7 lbs. canned dog food per 1000 gallons
2. 2.0 lbs. dishwasher detergent (non-foaming) per 1000 gallons
3. 2.0 lbs. cold water, biodegradable laundry detergent per 1000 gallons
4. 0.4 lbs. Fuller's earth or clay per 1000 gallons
5. 0.3 lbs. ground personal bar soap per 1000 gallons
6. 0.1 lbs. SAE-10 lubricating oil per 1000 gallons

In addition, a sufficient quantity of sewage must be added to provide a minimum coliform count of 10 per milliliter. Tap water is to be used in the preparation of the test liquid, and contaminants are to be blended so as to provide a homogeneous mixture.

The contract specifies that the treatment unit produce a renovated water having the following characteristics:

1. pH should be between 5.5 and 9.0
2. 50 mg/l maximum chemical oxygen demand (COD)
3. 10 mg/l maximum biochemical oxygen demand (BOD)

4. 5 units maximum turbidity
5. 5 mg/l maximum surfactant content (as LAS)
6. 3 OII maximum odor
7. 15 units maximum color
8. 1 per 100 ml maximum coliform count
9. 5 ppm free available chlorine

3.3 Experimental Procedures and Apparatus

3.3.1 Wastewater Preparation

To meet the specifications set forth in the contract, the test wastewater was prepared using the following ingredients:

1. Vet's Dog Food
2. Cascade (non-foaming dishwasher detergent) (non-ionic detergent)
3. Surf (Cold water, biodegradable laundry detergent) (anionic detergent)
4. Fuller's earth
5. Ivory soap (personal bar soap)
6. Mobil SAE 10 Oil
7. City of Milwaukee tap water

A stock solution of the oil, Fuller's earth, soap and detergents was prepared to facilitate the preparation of the individual batches of test wastewater. This stock solution contained:

1. 11.98 g/l Surf
2. 11.98 g/l Cascade
3. 1.794 g/l Ivory
4. 0.594 g/l Oil
5. 2.394 g/l Fuller's earth

The stock solution was refrigerated during storage. A typical ten liter batch of test water was prepared by adding 200 ml of warmed, well-mixed stock solution and 4.43 grams of dog food to 9.8 liters of tap water. This test water was mixed for several hours using a Model L Lightnin Mixer. After it was found that aging of the waste made chemical treatment more difficult, the waste was stored overnight at room temperature and mixed several additional hours before chemical treatment tests were performed.

3.3.2 Test Procedures and Equipment

The clarification test procedures used in these laboratory

studies are the standard laboratory test procedures used by Rex Chainbelt. They are described in Section A of the Appendix, Clarification Tests and Rate of Separation. A more detailed description of the flotation test procedure may be found in Section B of the Appendix, Demonstration Kit Procedure. The sedimentation test procedure was modified slightly in that the flotation test graduated cylinder was used. Effluent samples were obtained from the side-arm of the cylinder rather than by siphon. Nearly all the sedimentation tests were performed for a 30 minute laboratory detention period.

The foam fractionation tests were performed by placing 1000 ml of wastewater in a flotation test cylinder and adding air by means of a porous diffuser stone. Aeration was continued until no more foam escaped the cylinder. Samples were then taken for analysis.

The carbon isotherm test procedure is described in the Appendix, Section D. The carbon column bench scale test apparatus and procedure are described in the Appendix, Section E.

3.4 Analytical Procedures and Apparatus

The following analyses were performed according to Standard Methods for the Examination of Water and Wastewater, Twelfth Edition, 1965. The page numbers of the analytical procedures used and the modifications to the listed procedures are noted:

Total Solids - Method A, p. 423. The amount of sample used was determined by weight rather than by volume.

Approximately 20 grams of sample was used for total solids.

Suspended Solids - Method C, p. 424. Commercially prepared glass fiber mats were used in place of the mats prepared using an asbestos cream.

Chemical Oxygen Demand (COD) - p. 510. The standard procedure was used for the analysis of the raw waste and the effluent samples from the chemical treatment tests. The "alternate procedure for dilute samples" (p.513) was used to analyze the effluents from the carbon adsorption tests.

Biochemical Oxygen Demand (BOD) - p. 415. The BOD tests were performed as described. Fresh raw sewage from the Milwaukee Sewage Treatment Plant was allowed to settle one day at 20° C. The supernatant was used as seed; the volume of seed used in each 300 ml bottle was 3 ml. The results of the tests on which this volume and type of seed are

based are listed in the Appendix, Section F. The azide modification of the iodometric method (Method A, p. 406) was used for the analysis of the dissolved oxygen content. Surfactant Content - Method A, p. 296. This method measures surfactants containing ABS and LAS. Other surfactants, such as nonionic, are not measured. Odor, p. 499. Chlorine Demand, p. 112. Free available chlorine and total chlorine were measured with the Hellige Aquatester (see below). Total chlorine determinations were also done by titration according to Standard Methods.

The following analyses were performed using special instruments or apparatus. Procedures used in these analyses were procedures specified by the manufacturer of the equipment.

Conductivity - Measurements were made at 25° C using a conductivity meter and a conductivity cell with a 2 cm⁻¹ cell constant.

Turbidity - Hellige Turbidimeter.

Color - Hellige Aquatester using a 0 to 70 ppm color disc.

Chlorine - Hellige Aquatester using a 0 to 1 ppm chlorine disc. Samples were diluted for measurement using chlorine-demand free water.

pH - Beckman Model N and Beckman Model H-2 pH meters were both used.

Coliform - Millipore coliform test apparatus was used according to the manufacturers instructions.

A listing of the major pieces of equipment and instruments is included in the Appendix to this report, Section C.

3.5 Results and Discussion

3.5.1 Raw Waste Characteristics

The characteristics of the raw waste are summarized in Table A. Variations in the analysis of the raw waste were noted throughout the test work. Variation in suspended solids content and pH appeared to be associated with the age of the waste. Other variations, which did not appear to be correlated with the waste age, were apparently due to variations in the waste preparation. The values listed in Table A are the average values of the raw wastes tested. The complete raw waste analytical data is presented in the Appendix to this report, Section G.

3.5.2 Solids Content Comparison

A comparison of the amount of solids added in the preparation of the test water to the measured total solids values is made in Table B. With the exception of the dog food, the waste ingredients were assumed to be 100% solids. The dog food contained 14% solids. Milwaukee tap water contains 187 mg/l dissolved solids. The measured total solids were within 73 mg/l of the expected solids content. Some of this variation may be due to moisture in the waste contaminants.

An analysis of the Surf detergent showed that this product contained 14.8% LAS as measured by the methylene-blue test. Analysis of the Cascade detergent showed that it contained no measurable LAS. Based on these results, it was expected that the test water would contain about 35 mg/l LAS. The test water mixture analysis showed an average LAS content of 34 mg/l.

3.5.3 Effects of Aging on Test Water

A period of aging altered some of the characteristics of the test water. The fresh waste slowly formed a floc which settled leaving a clear supernatant. A short period of flocculation resulted in a rapidly settling floc. As the test water aged, however, the ease of developing a floc and the clarity of the flocculated supernatant decreased. The appearance of the aged wastewater also changed; the aged water was more turbid than the fresh water. The aging of the waste appeared to be a function of time and mixing. Waste "A", mixed for two hours after preparation, and allowed to stand overnight (16 hours), might have the appearance of a fresh waste, whereas waste "B", mixed for five or six hours after preparation, might begin to exhibit the aged waste characteristics. A waste mixed for one hour after preparation, allowed to stand overnight, and mixed an additional two hours, generally exhibited aged waste characteristics. A decrease in pH appeared to be the best analytical indicator of the waste age. The soluble solids content and soluble COD content of the wastewater was little changed by aging.

3.5.4 Analysis of Processes

The following processes were studied in the laboratory testing. In studying these processes, only those analyses which would give the most information regarding the value of these processes were performed. Full analyses were performed only on

those processes which were the most successful. Generally COD analyses were performed to indicate the amount of organics removed. The laboratory test results have been grouped according to the process being studied. The test data are listed in the tables at the end of this section. Test numbers have been used in the tables to facilitate reference to the data from the body of the report. Since one test may have been used to study more than one process, the results of this test may appear in more than one table under different test numbers.

3.5.4.1 Treatment Without The Use Of Chemicals:

Settling tests were performed on the test water to determine the extent of treatment that might be accomplished without the use of chemicals. These tests were performed with and without the use of flocculation. The results of these tests appear in Table C. Some solids, which appeared to be primarily dog food solids, settled rapidly and could be removed from both the fresh and aged wastes using laboratory detention times of less than five minutes. The volume of these settled solids was usually less than 2 gal/1000 gal.

Most of the suspended solids in the fresh waste settled readily after a short period of flocculation. Total solids and COD content of the supernatant approached the values measured in the soluble portion of the raw waste after a five minute flocculation period and a 30 minute settling period (Tests 3, 7, 11, 14). A small amount of flocculation was more effective than merely extending the detention time without flocculation (Tests 2 and 3). As the waste aged, however, flocculation became much less effective. The effect of age and mixing was tested in Tests 6, 7, 8 and 9. A batch of wastewater was mixed for one hour immediately after preparation. This waste was then allowed to stand overnight at room temperature. This waste was used in Tests 6 and 7 and was called the "fresh" waste. A portion of this waste was stored an additional five hours with occasional mixing and was used in Test 8. Another portion was mixed continuously for the additional five hours. Flocculation was noticeably poorer in Test 8 than in Test 7. The floc formed in Test 9 was very poor in quality; a settling rate could not be determined and the supernatant remained very turbid. It was evident from these tests that removal of the suspended solids was not reliable without chemical treatment.

Subsequent tests were performed using wastewater from which the heavier particles were removed by ten minutes of settling. The

supernatant after a ten minute settling period was fairly consistent in quality. Analyses of various samples of this supernatant are listed in Table D. Although the fresh water flocculated on standing, this flocculation did not occur within the first ten minutes; consequently the supernatants from the fresh water and the aged waste were similar after this period of time.

3.5.4.2 Treatment With Organic Polyelectrolytes:

Tests were performed (Table E) to determine the effectiveness of organic flocculant aids in the flocculation of the waste suspended solids. Early work using a wastewater containing Dreft (containing sulfonated fatty alcohols) instead of Surf indicated that a high clarity effluent could be obtained by treatment with 70 mg/l Purifloc C-31, a cationic polyelectrolyte. (It should be pointed out that Dreft is not a cold water detergent. When this was discovered, work with Dreft was terminated and Surf, a cold water detergent, was used.) The same dosage of Purifloc C-31 applied to the specified test water appeared to disperse the solids rather than flocculate them. Jar tests indicated, however, that a low dosage of Purifloc C-31 was helpful in forming a strong, rapidly settling floc in the fresh waste. The supernatant, however, was little different than that which might be expected from flocculation of the fresh waste without chemical treatment. Purifloc C-31 at a low dosage was ineffective in flocculating the solids in the aged waste.

The use of bentonite clay to act as a possible adsorbent and as nuclei for floc formation was also tested. In these tests, the clay was mixed with an aged wastewater for a period of time prior to treatment with the polyelectrolyte. Jar tests indicated that either Purifloc C-31 or Purifloc N-11 (a nonionic polyelectrolyte) would be effective in coagulating this waste mixture. In these tests, Purifloc C-31 was effective in reducing the COD below the soluble COD level, although the turbidity remained high. The fact that this reduction in COD was probably due to the reaction between the cationic polyelectrolyte and the anionic surfactant rather than by adsorption on the clay is indicated by the results of tests 4 and 5. In these latter tests, the waste COD was reduced only to the level of the soluble COD content of the wastewater in spite of the presence of the bentonite clay. Effluent clarity in

each of these tests was poor.

3.5.4.3 Foam Fractionation:

Two foam fractionation tests were performed to indicate the degree of treatment that might be accomplished with this technique. Air was added by means of a diffuser stone to 1000 ml of waste placed in a one liter graduated cylinder. The foam was allowed to overflow from the cylinder. Aeration was stopped when the foam stopped overflowing. A sample of the remaining liquid was then removed for analysis. The results of these analyses are listed in Table F. In each test performed on samples of fresh and aged waste, the COD content was reduced to less than the soluble COD content of the raw waste. Reduction of the COD content to the required 50 mg/l value, however, would require additional treatment.

3.5.4.4 Treatment with a Cationic Surfactant:

The use of a cationic surfactant as a means of treatment by reacting with the anionic surfactant in the waste was studied. Roccal, a commercial benzalkonium chloride, was used as the cationic surfactant. Although the addition of Roccal caused a precipitate to form in the waste, other chemicals were required to form a settleable floc. Jar tests indicated that a settleable floc could be formed by raising the pH of the treated waste to 9 with lime and adding calcium chloride. The results of settling tests using this method of treatment are listed in Table G. It is apparent from the results of Tests 1 through 5 that increasing dosages of Roccal had little effect on the total solids content and increased the COD content of the effluent. Apparently, the COD reduction obtained was due to the added calcium ion (Test 3). The addition of 75 mg/l activated carbon did not materially affect the effluent characteristics.

3.5.4.5 Oxidation with Fenton's Reagent:

Brief tests were performed to indicate the process problems involved in using hydrogen peroxide with ferrous sulfate catalyst to oxidize the organic matter in the test wastewater. The experiences of Eisenhauer in the treatment of laundry waste and of Busch in the oxidation of phenol were used as guidelines. (54) (49) Concentrations of reactants used were similar to those concentrations used by Eisenhauer and Busch in their work.

Reactions were conducted at room temperature for 15 minutes. The peroxide was added in increments; two thirds was added at the start of the reaction and the remainder 5 minutes later. At the end of the reaction period, the pH was raised to approximately 11 with lime. After pH adjustment, the precipitate formed and was allowed to settle. Large quantities of gas were produced during the reaction and after pH adjustment. These gas bubbles caused flotation of some of the solids during the settling period. This was particularly severe using Busch's procedure. Results of these tests are listed in Table H.

Further testing of this process was not done because of the apparent disadvantages of this method of oxidation relative to conventional methods of treatment: (1) the oxidation process works best at low pH requiring special materials of construction, (2) several process steps are required after oxidation (pH adjustment, clarification, neutralization), (3) the ferric floc is not amenable to clarification by settling, and (4) the increase in dissolved solids content exceeds the required level.

3.5.4.6 Treatment With Calcium Hypochlorite:

The use of calcium hypochlorite as a combined oxidizing and flocculating agent was investigated. Jar tests indicated that a settleable floc could not be obtained using calcium hypochlorite alone or in combination with Purifloc C-31. Combinations of calcium hypochlorite and ferric or alum salts produced a satisfactory floc. Results of settling tests using these chemicals are listed in Table I. The COD values reported in Table I may be low due to interference from the remaining chlorine. An attempt was made in Test 5 to eliminate free chlorine with sodium sulfite but the contact time was insufficient for complete chlorine destruction.

The dosage of ferric salts used in Tests 8 and 9 was such that the amount of ferric ion added was the same in each test. Based on the settled sludge volume and the effluent color and solids content, it appeared that ferric sulfate was more effective than ferric chloride. The use of alum as a flocculent (Test 4) resulted in high effluent soluble solids.

A number of tests were performed on 8 September 1967 using calcium hypochlorite and ferric sulfate. The results of these tests are shown in Table Y. Tests 1, 2, and 3 utilized 400 mg/l calcium hypochlorite and 200 mg/l ferric sulfate. In Test 1 the

hypochlorite was added along with the iron salt, flocculated and settled. In Test 2, the hypochlorite was added and mixed for 15 minutes prior to the addition of iron, flocculation and settling. In test 3, both the hypochlorite and iron were added and mixed 15 minutes prior to flocculation and settling. The effluents from settling in Tests 1, 2, and 3, were filtered through diatomaceous earth prior to analysis. As can be seen from the analysis (Table Y) the pH, color, and COD all meet the renovated water quality standards. The residual chlorine, however, is very high, (267 mg/l). The dosage of hypochlorite provides 280 mg/l chlorine, hence very little, if any, chemical oxidation is taking place. The tremendous quantity of chlorine remaining must be removed. This could be accomplished using activated carbon.

In Test number 4, the hypochlorite and iron were mixed for 15 minutes. Powdered activated carbon was then added and mixed for an additional 15 minutes. This mixture was then flocculated, settled, and filtered. The results of the analysis of the effluent from this test (Table Y) show pH, color and COD values which meet specifications, but a residual chlorine of 40 mg/l, which is still very high. To remove this chlorine requires either longer contact times or more carbon.

The results from the above tests indicate the use of calcium hypochlorite and ferric sulfate will produce a very clear effluent. Since very little oxidation of organic matter is occurring, the prime removal method is by chemical precipitation and flocculation. The large amounts of chlorine remaining in the effluent makes this method of treatment undesirable, since activated carbon or some other method will be required to remove this large excess of chlorine. It has also been shown elsewhere in this report that effective chemical precipitation and coagulation can be obtained using chemicals other than calcium hypochlorite. It can therefore be concluded that the use of calcium hypochlorite as an oxidant and flocculant should not be considered in the treatment of this waste.

3.5.4.7 Treatment With Ferric Chloride:

The high effluent clarity achieved by treatment with calcium hypochlorite and ferric salts led to tests to determine whether some other forms of calcium ion might work as well with ferric chloride. Lime, calcium chloride and calcium hypochlorite were

studied. The results of these tests appear in Table J. The amount of calcium ion added in Tests 3, 5, 6, 7, and 8, was about the same. At this equivalent calcium ion dosage and a ferric chloride dosage of 200 mg/l, calcium hypochlorite was the most effective of the calcium salts. Calcium chloride was the least effective. The effectiveness of lime was increased by increasing the ferric chloride dosage from 200 to 300 mg/l at a calcium hypochlorite dosage of 200 mg/l.

In comparing the effectiveness of the use of lime or calcium hypochlorite with ferric chloride, it should be noted that at least one treatment step must follow either treatment process. Additional organic solids and turbidity must be removed from the lime-treated effluent. LAS and excess chlorine must be removed from the calcium hypochlorite-treated effluent. Presumably, an activated carbon column could be used for each effluent. Since both effluents require further treatment, the lower chemical cost and lower total chemical weight used makes the use of lime somewhat more attractive than the use of calcium hypochlorite.

3.5.4.8 Treatment With Ferric Sulfate:

Tests were also conducted to determine the relative effectiveness of various calcium salts with ferric sulfate (Table K). Again, calcium hypochlorite, lime and calcium chloride were tested. These tests showed that lime was a better source of calcium ion than calcium chloride. A series of tests were performed using various combinations of lime and calcium chloride at a constant total calcium ion concentration (Tests 9, 10, 11, 12). Best effluent results were attained using 350 to 400 mg/l ferric sulfate and 150 to 175 mg/l lime. This may be due to the higher pH resulting from the use of lime. This resulted in effluents having pH values of 9 to 10.7. Since the final effluent pH must be no higher than 9.0, it is desirable to use dosages requiring the least amount of acid for neutralization. The use of 400 mg/l ferric sulfate and 175 mg/l lime has resulted in effluent pH values of 9.0 to 9.5. Approximately 35 mg/l sulfuric acid is required to reduce the treated effluent pH from 9.5 to 9. Addition of the sulfuric acid did not produce a precipitate.

Treatment with ferric sulfate and lime worked equally well on both fresh and old wastes. Best results were most consistently achieved using 400 mg/l ferric sulfate and 175 mg/l lime. For this reason, this method of chemical treatment was used to prepare

the waste for the carbon treatment and filtration tests which followed.

3.5.4.9 Treatment With Aluminum Salts:

Tests were performed on the effectiveness of alum [$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$] and sodium aluminate (Na AlO_2) in chemical treatment. A commercial brand of sodium aluminate, Nalco 2, was used.

Treatment with alum at pH values of 6.6 to 7.4 was shown by jar tests to be poor. Lime dosages of 50 to 100 mg/l were used to control pH. The use of 200 mg/l bentonite clay and 200 mg/l alum appeared to be better, but not as effective as a combination of bentonite and Purifloc N-11. (The results of tests in which the latter combination of chemicals were used appear elsewhere in this report). Treatment with alum at higher pH values was better. The results of one test performed at a pH value of 10.3 is listed in Table L. The effluent color, turbidity, suspended solids and pH were higher than desired. COD values were slightly higher than that attained using ferric sulfate and lime.

The results of a series of tests performed using sodium aluminate are also presented in Table L. Best results were obtained in Tests 6, 7, 8, and 9. The soluble solids content of these effluents, however, were very high. These high soluble solids values were generally observed in other tests when calcium chloride was used. The use of lime as a source of calcium would not be practical since the effluent pH would be increased further.

All the effluent samples from treatment with the aluminum salts formed a precipitate when neutralized with sulfuric acid. A precipitate was also formed when the effluent samples were refrigerated.

3.5.4.10 Treatment With Ferric Chloride and Limestone:

Samples of ferric chloride and limestone presently used by the military in their water treatment units were tested as substitutes for ferric sulfate and lime in the treatment of the test waste. The dosage of ferric chloride used in these tests resulted in a ferric ion concentration equivalent to that obtained using 400 mg/l ferric sulfate. Limestone dosages used varied from 300 mg/l to 1500 mg/l. The pH of the treated waste was between 6 and 6.5. Floc formation was poor and effluent clarity was very poor. Quantitative tests were not performed

because of the poor results observed in the jar tests.

3.5.4.11 Combined Chemical Treatment and Carbon Adsorption:

Adsorption with powdered activated carbon before and during the chemical treatment step was studied. The results of these tests appear in Table M. In Tests 2 and 4, 75 mg/l carbon was added to the waste before chemical treatment. The waste was gently mixed during the carbon contact period. Tests 1 and 3 were run concurrently to indicate the effect of carbon treatment. The chemical treatment procedure used in Tests 1 and 2 was found to be a poor method. Although the COD of the Test 4 effluent was less than that of the Test 3 effluent, the BOD and color values were similar. The carbon dosage and contact time were probably insufficient.

Subsequent carbon adsorption tests were performed during chemical treatment. In Test 5 through 14, 100 mg/l of the ferric sulfate (alum in Test 8) were added to the waste prior to the addition of the carbon. Higher carbon dosages and longer contact periods were used in these tests. The pH of the waste during the carbon contact period was about 7.4. After the carbon contact period, the remainder of the ferric sulfate and the lime were added, the waste flocculated and settled. Three types of activated carbon were tested: Mallinckrodt, Aqua Nuchar A, and powdered Filtrasorb 300. The Mallinckrodt carbon was added as a water suspension; the others were added to the waste in a dry state. Use of the carbon slurry resulted in the fastest settling rates and lowest final sludge volumes. The dry carbon settling rates and final sludge volumes were near the values observed when treatment was performed without the use of carbon. The use of carbon decreases the COD, color and LAS content values to well below the required value. The pH may require adjustment with acid to keep the pH below 9.0. BOD values are at or near the acceptable level.

Tests were performed to determine the effect of reusing treated water in the preparation of the test waste water. Treatment of each test wastewater consisted of:

1. ten minutes settling to remove heavy solids,
2. addition of 100 mg/l ferric sulfate while mixing,
3. addition of 400 mg/l dry Aqua Nuchar A,
4. mixing for 30 minutes,

5. addition of 300 mg/l ferric sulfate while mixing,
6. addition of lime while mixing,
7. flocculating gently for ten minutes, and,
8. clarification by settling for 30 minutes.

The effluent was removed by siphon and a portion saved for analysis. The remaining effluent was used in the preparation of the next batch of test water. No make-up water was added to compensate for the volume lost due to removal of the settled sludge, so that high dissolved solids contents were reached more quickly. The clarified waste was not filtered prior to preparing the new sample.

The results of tests in which the renovated water was reused are listed in Table N. The clarified effluent from the first cycle was used without pH adjustment to prepare the waste for the second cycle. The amount of lime used in the second cycle was reduced to 150 mg/l to keep the effluent pH about 9.0. This effluent was more turbid than the previous effluent. The dosage of lime used in cycle 3 was 175 mg/l. The cycle 3 effluent clarity was similar to the cycle 1 effluent. The pH of the effluent was reduced to 9.0 using sulfuric acid.

The COD of the treated waste increased as the recycling continued. The waste color became gray due to an accumulation of fine powdered carbon. Various tests were performed on the recycled wastewater to determine a procedure for reducing the COD content (Table O). The treatment procedure used in Test 1 was the same procedure used in the previous cycles. Increasing the activated carbon dosage to 800 mg/l (Test 2) was very effective in reducing the effluent COD. In Test 3, the entire ferric sulfate dosage was added to the waste prior to the carbon adsorption. This resulted in a lower pH where carbon adsorption is more effective. Effluent COD was slightly lower than when adsorption was performed after only one-fourth of the ferric sulfate was added. Treatment with calcium hypochlorite and ferric sulfate resulted in an effluent with a low COD value.

Samples of cycle 3 effluent and cycle 4 effluent were also tested to determine a method for reducing the COD values. Additional treatment of cycle 3 effluent with 400 mg/l activated carbon for thirty minutes resulted in a COD reduction from 72 mg/l to 42 mg/l. The carbon was removed from the sample by filtration. The COD of cycle 3 effluent was unaffected by treatment with 100

mg/l calcium hypochlorite. The sample was dechlorinated by treatment with sodium sulfite; excess sulfite was removed by aeration. This result indicates that the low COD value obtained in Test 4 (Table O) was probably due to superior chemical treatment and/or the activated carbon treatment used for dechlorination rather than oxidation. Filtration of the cycle 4 effluent through diatomaceous earth (Hyflo Supercel) removed 36 mg/l COD, indicating that a substantial portion of the effluent COD was due to suspended matter.

The results of a series of tests performed on cycle 5 wastewater are presented in Table P. These tests were performed to compare the effect of additional carbon, treatment with calcium hypochlorite and filtration of the effluent through diatomaceous earth. In Tests 1 and 2, the carbon was added to the waste after the entire 400 mg/l ferric sulfate was added. The pH of the waste during carbon adsorption was 5.5. The effluent pH was 9.1 before adjustment. In Test 3, 400 mg/l activated carbon was mixed with the effluent from chemical treatment for 30 minutes to dechlorinate the sample. The carbon was removed from the effluent by filtration. Apparently, the amount of carbon used was insufficient for complete dechlorination since the dissolved oxygen content of the BOD bottles containing these samples were higher than the blanks. Unfortunately, the use of filtration and higher carbon dosages were not sufficient to reduce the BOD values to the 10 mg/l level.

Combined chemical and carbon treatment tests followed by filtration through diatomaceous earth were performed on samples of the specified test water. The results of these tests are listed in Table M (Tests 15, 16 and 17). Sewage was added to the raw waste used in Tests 16 and 17 to provide a coliform population. Two 100 ml portions of effluent (after filtration) contained no coliform. Samples of effluent subjected to chlorination likewise contained no coliform. The effluent samples from Tests 16 and 17 had high pH values. This high pH was probably due to the use of an improperly prepared lime solution. The lime dosage used in these tests was probably higher than the intended 175 mg/l.

3.5.4.12 Removal of Organics by Activated Carbon Column:

Carbon isotherm tests were performed using three commercially available carbons: Barneby-Cheny (8 x 12 mesh), Cliffs Dow

(10 x 30 mesh), and Calgon Filtrasorb 300 (8 x 30 mesh). The data from these isotherm tests are listed in Table Q. The results of the COD isotherm tests are plotted in Figure 5, and those for BOD isotherms in Figure 6.

The amount of COD adsorbed per weight of carbon at saturation was 60%, 28.5%, and 13.5% for Calgon, Cliffs Dow, and Barneby-Cheny, respectively. Hence, Calgon carbon has the greatest capacity for adsorbing COD from this particular waste.

Effluent samples from clarification tests performed on waste treated with ferric sulfate and lime were passed through an adsorption column filled with Barneby-Cheny activated carbon. The clarified waste was not filtered prior to passage through the carbon column. The results of these tests are listed in Table R. Insufficient ferric sulfate was used for chemically treating the waste used in Test 1. This resulted in a high effluent pH and color. Satisfactory COD, BOD, color and turbidity values were measured in the effluents from Tests 2, 3, and 4.

Two column runs were made reusing the renovated water. The waste was treated with ferric sulfate and lime. Filtrasorb 300 was used as the adsorbent. In run 1, the feed was not filtered before it was put through the column. Hence the column acted as a filter as well as an adsorber. In run 2, the feed was filtered through a 1/8 inch layer of diatomaceous earth supported on S&S 597 filter paper in a Büchner funnel prior to putting it through the column. The effluent from the column was reused to make raw waste and simulated the effect of recycling the renovated water. Recovery rates were held constant at 85% and 90% in runs 1 and 2, respectively, by adding the necessary amount of tap water.

The results of Run No. 1 using the unfiltered feed are shown in Table S. It can be observed from this table that the quality of the effluent deteriorated with each cycle. The main cause of this deterioration was probably due to penetration of floc particles into and through the carbon bed as measured by increasing turbidity. Since the floc particles were white and contrasted very well on the black carbon, floc particles could be seen 8 inches below the bed surface after eight hours of running. This blinding of the bed due to floc accumulation is also shown by a constantly increasing headloss through the bed at constant flow.

FIGURE 5
COD Isotherms

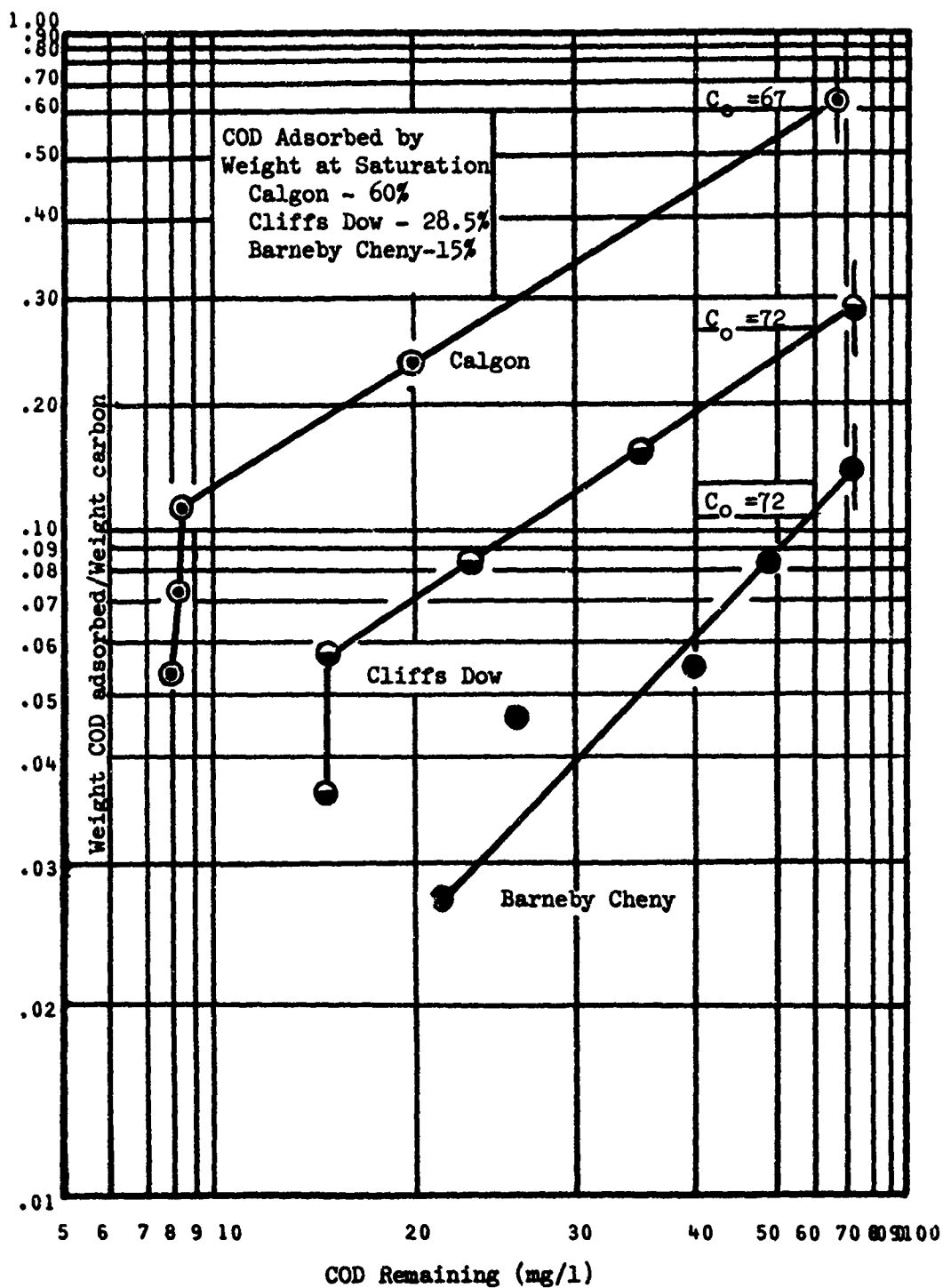
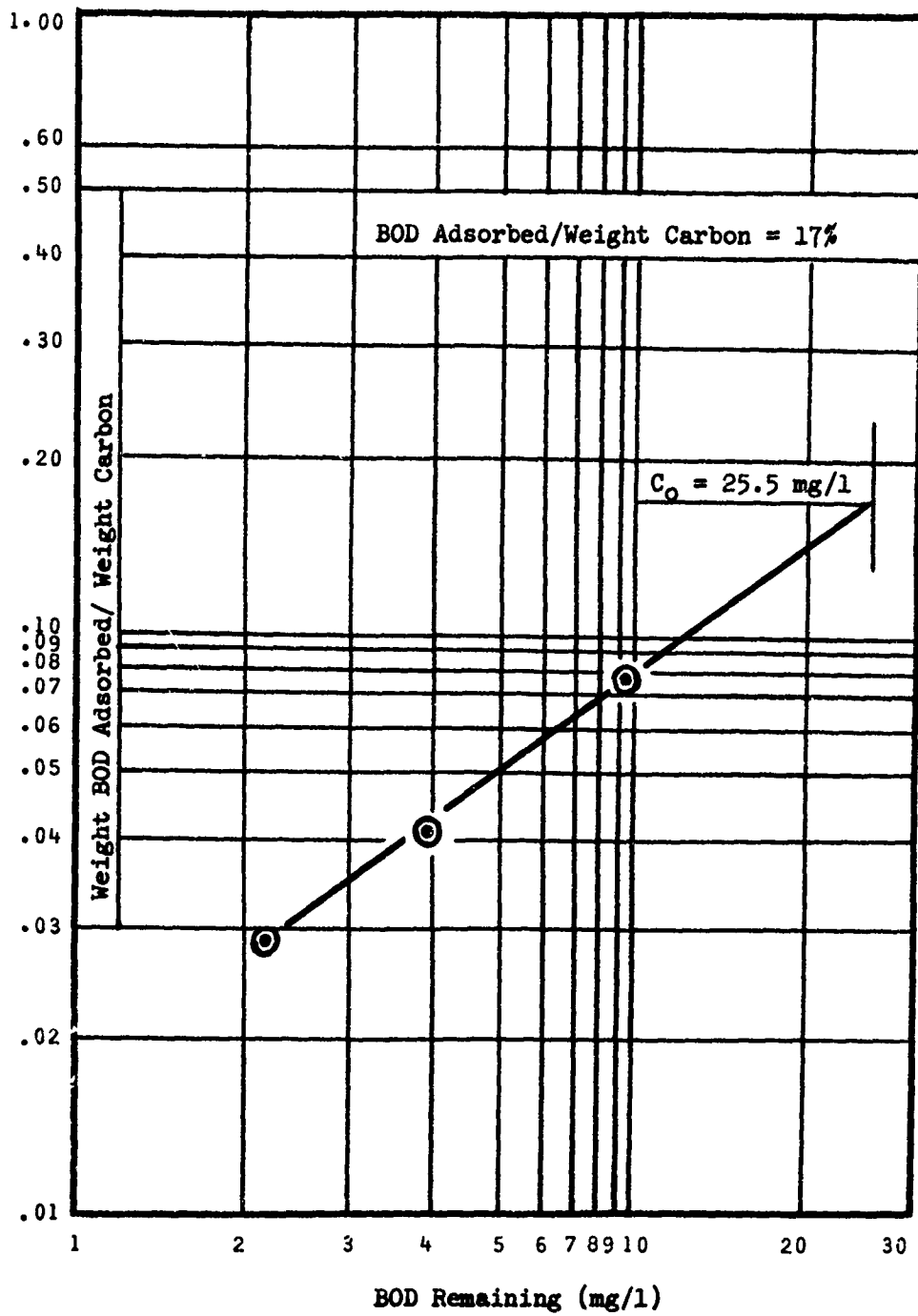


FIGURE 6
BOD Isotherm - Carbon Column



This relationship is shown in Figure 7.

The second run through the carbon column (using fresh carbon) was made using chemically treated-settled waste which was filtered through diatomaceous earth. The data from the second run are also shown in Table S. As can be seen from this data, a much more consistent quality of effluent was obtained during this run. The headloss in the column also remained constant (3-1/4 inch H₂O) for the entire six cycles (12 hours running time), and no white floc particles could be seen on the carbon. The finished water quality was good except that the pH was higher than 9.0. If a pH of about 9.5 cannot be tolerated, a neutralization step will be necessary. Comparing runs 1 and 2, it can be seen that the pH criteria was met in run 1 while in run 2, pH was consistently higher. This high pH may have been caused by use of a lime stock solution which was improperly prepared. To completely exhaust the laboratory column would have taken an extended period of time and was not considered feasible. The shape of the break-through curve and the usable life of the column will have to be determined from prototype data.

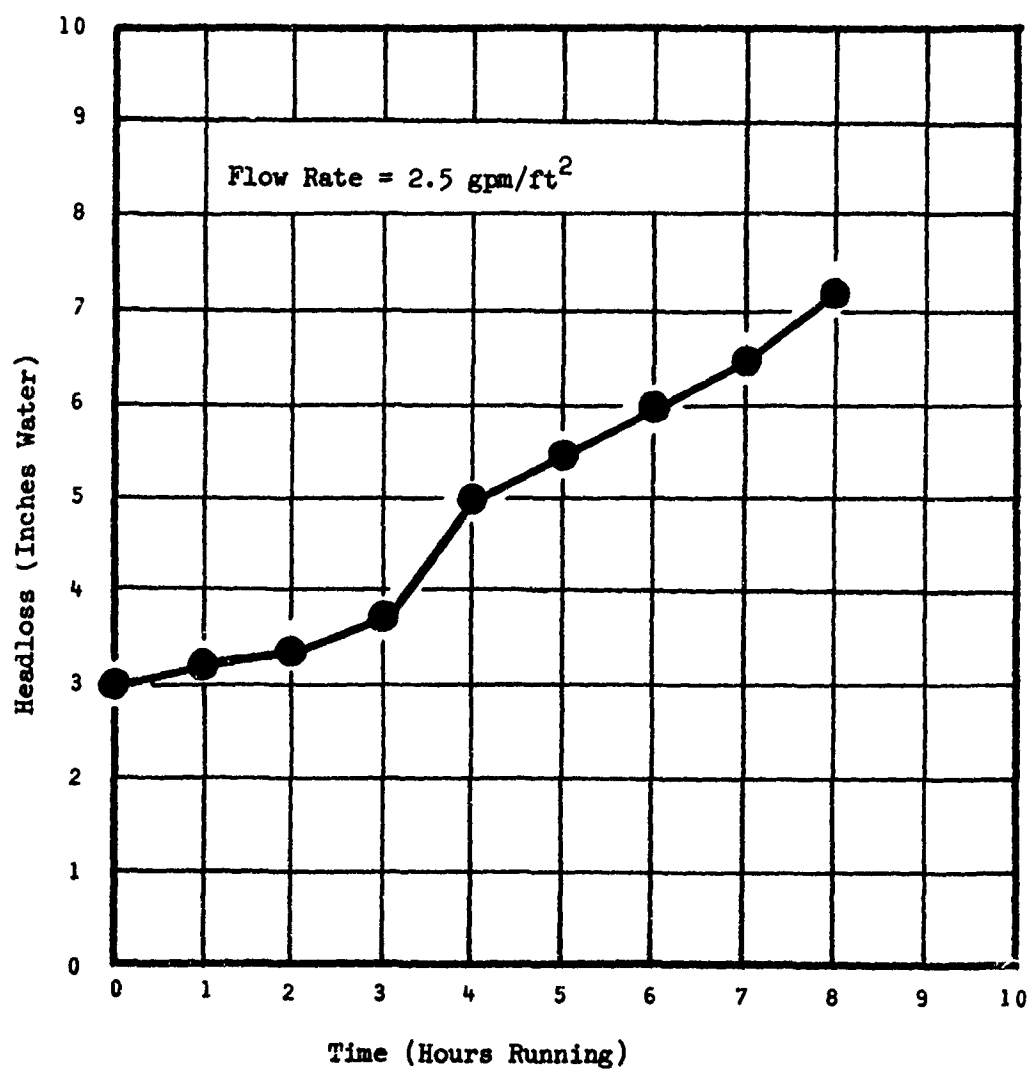
The contact time during the column runs was approximately six minutes. Short experiments performed by varying the contact time showed little difference between six minutes and 15 minutes contact time. It appears from the two runs that a six minute contact time is adequate, but the effect of contact time when the bed is partially exhausted will have to be determined along with breakthrough curves on the prototype columns.

3.5.4.13 Clarification of Treated Waste:

Clarification of the treated waste by dissolved-air flotation was investigated. The results of two flotation tests and a settling test performed on the same waste sample are listed in Table T. These clarification tests were performed on the waste after treatment with ferric sulfate and lime. Effluent from settling tests was used as the source of recycle water. The amount of recycle used in Test 2 was insufficient; much of the floating solids remained suspended in the supernatant. Since these solids were near the scum layer, they were not included in the effluent sample. In both flotation tests, the detention time was extended from the usual 5 or 8 minutes to 12 minutes to allow the slowly floating solids to rise. The floating scum was unstable, resulting in a resuspension of particles into the effluent.

FIGURE 7

Headloss During Carbon Column Run
(Unfiltered Feed)



Test No. 3 was repeated using 4 mg/l Purifloc N-11 as a flocculent aid. This was ineffective in strengthening the floc; some of the floating solids started to settle before all the solids had floated.

The settling characteristics of the waste after various types of chemical treatment are listed in the tables describing the chemical treatment. A thirty minute detention period was used throughout these tests to facilitate the comparison of various treatment processes. This detention time is apparently satisfactory for clarification. Lower sludge volumes may be obtained, however, by increasing the sludge detention time. The effect of longer detention times on sludge volume is shown in Table U.

3.5.5 Effect of Waste Source on Chemical Treatment:

Two tests were performed to determine the effect of changes in the waste composition on chemical treatment with ferric sulfate and lime. Two waste samples were prepared: one lacking the detergent and water that might result from the laundry operations and the other lacking the detergent and water from the kitchen activity. The results of these tests are listed in Table V. Absence of either the Surf or the Cascade did not adversely affect the chemical treatment.

3.5.6 Conductivity Measurements:

Conductivity measurements were performed on the effluents from the various treatment processes investigated in order to determine if a usable relationship existed between conductivity and effluent total solids (effluent suspended solids were considered negligible). Any usable relationship obtained would, of course, be employed as a control measure in a full-scale treatment operation. It may be seen by inspection and examination of Tables G, I, J, K, L, and M, that the data comparing conductivity and total solids are erratic, and a usable pattern or trend relating the two variables was not observed.

3.5.7 Chlorine Demand Tests:

Free available chlorine and total residual chlorine were measured using the Hellige Aquatester and the 0 to 1.0 ppm chlorine color disc (the highest range disc available). Since

the free available chlorine concentration desired in the renovated water is 5 mg/l, the effluent chlorine concentration desired in the renovated water is 5 mg/l. The effluent chlorine concentrations tested ranged from 5 to 20 mg/l. This required that the effluent samples be diluted at least ten-fold (with chlorine demand-free water) prior to analysis. Since the increment between color discs is 0.1 mg/l (below 0.6 mg/l) and 0.2 mg/l (above 0.6 mg/l); the values obtained using the Hellige Aquatester may be in error by 1 or 2 mg/l. In addition, the total chlorine measured by the Hellige Aquatester was approximately one-half the total chlorine concentration as measured by titration with standard sodium thiosulfate. Since the orthotolidine test indicated that free chlorine accounted for almost all of the total chlorine in the range tested, it was felt that use of the titration procedure for measurement of residual chlorine was more accurate than the use of the Hellige Aquatester.

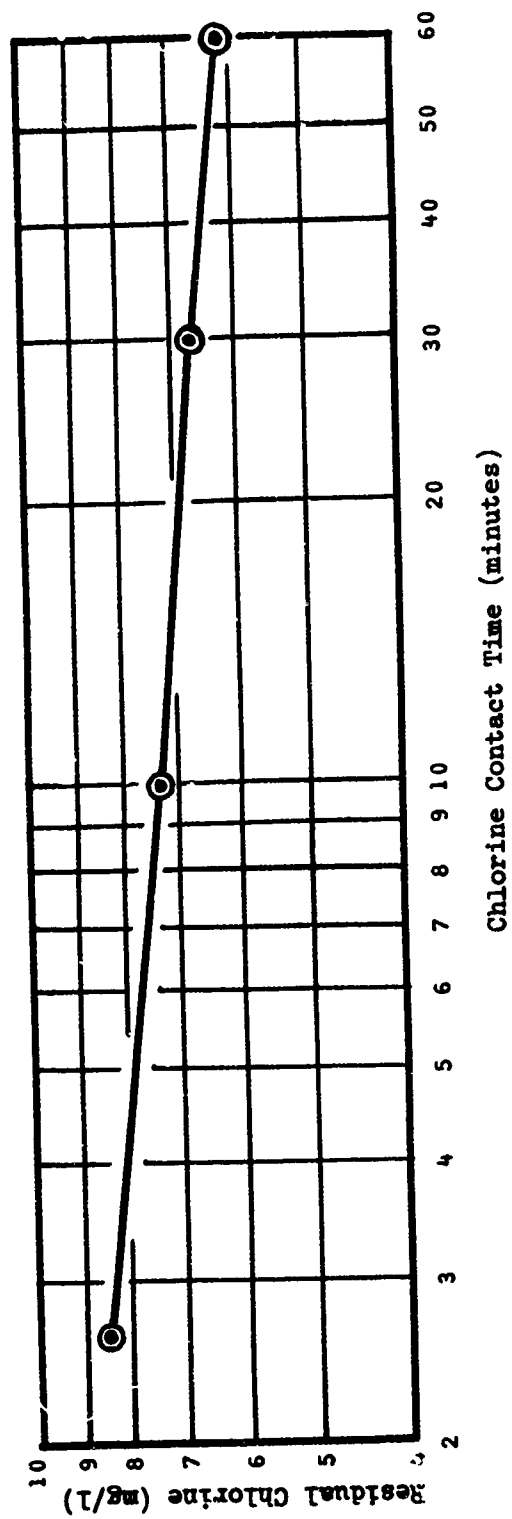
Chlorine in the form of calcium hypochlorite was added to several portions of wastewater that had been chemically treated with 400 mg/l ferric sulfate, 800 mg/l activated carbon (Aqua Nuchar A), and 175 mg/l lime. The waste was mixed with the carbon for a 30 minute contact period prior to the lime addition. The treated waste was flocculated for 10 minutes, settled for 30 minutes, and the effluent filtered through diatomaceous earth. The wastewater treated with chlorine had a COD of 18 mg/l and a BOD of 9 mg/l. After a 15 minute chlorine contact period at room temperature, the waste treated with 10 mg/l chlorine had a residual total chlorine content of 8.5 mg/l. At a dosage of 15 mg/l the residual chlorine content was 13 mg/l. A residual chlorine content of 17 mg/l was titrated after dosage with 20 mg/l.

The chlorine residual of another sample treated with 10 mg/l chlorine was also measured after various periods of contact time. The total residual chlorine was measured by titration. The calcium hypochlorite solution was contacted with the waste effluent in the dark at room temperature. The measured amount of chlorine after various contact times is shown in Figure 8.

3.5.8 Treatment of the Settled Sludge Resulting From Chemical Treatment

The volume of sludge resulting from the two methods of treatment discussed above will vary with settling time. When

FIGURE 8
Effect of Time on Residual Chlorine Content



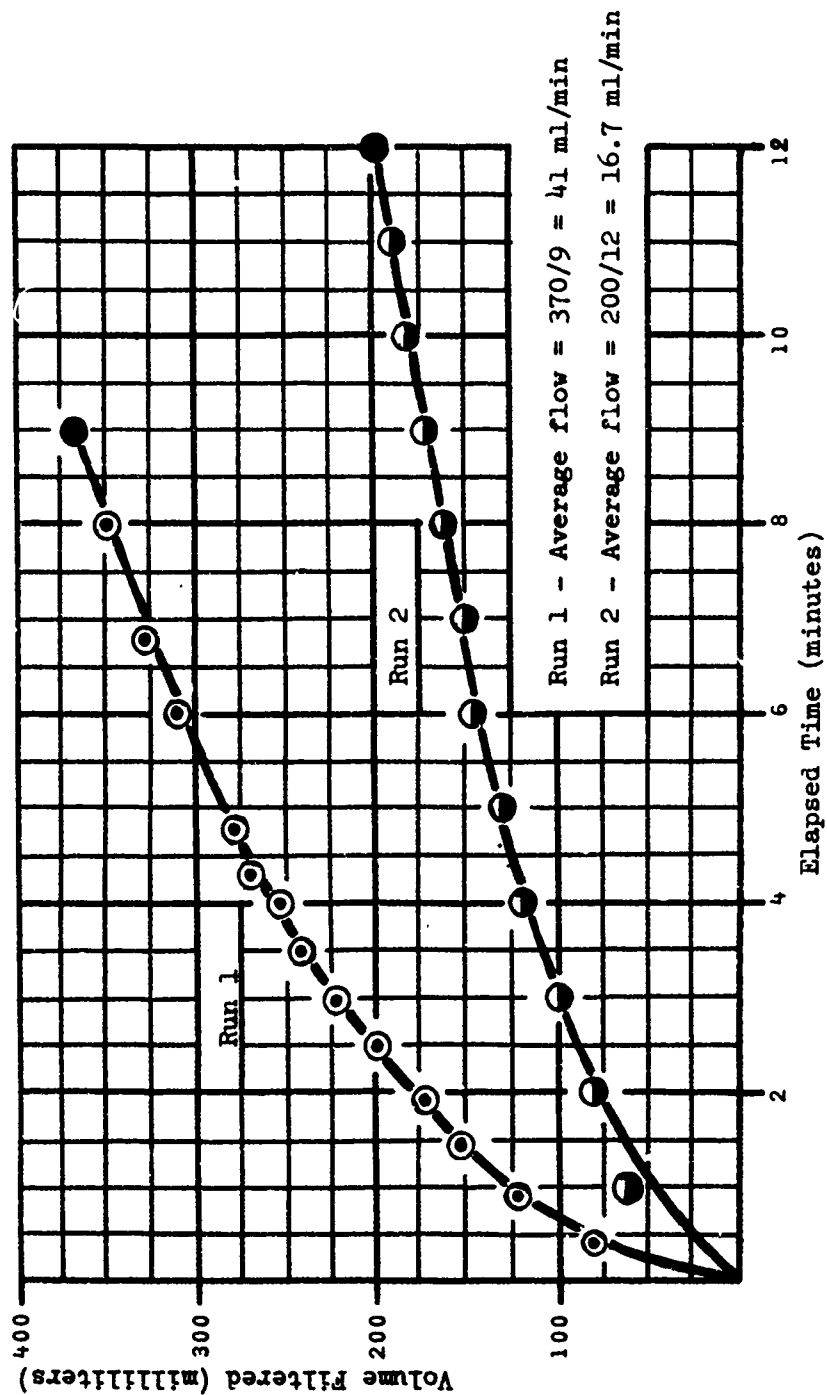
Method B (Table X), using powdered carbon, is utilized, the settled sludge volumes will range from 5 to 6% of the raw waste volume after two hours of settling. After 24 hours, this volume is reduced to about 3%. When Method A (Table X) is used, the settled sludge volume produced after two hours is about 7% and after 24 hours is about 5% of the raw waste volume. From this data it may be seen the maximum sludge volume anticipated using a nominal two hours detention time will be 500 - 700 gallons per day in a prototype unit (based on a daily raw waste volume of 10,000 gal). The solids concentration of this sludge ranges between 3500 to 8800 mg/l depending upon the treatment method used. Hence about 21 lbs. per day dry solids are produced from the chemical treatment process using Method A. Method B will result in an increase in dry solids produced per day to about 54 pounds per day due to the use of 400 mg/l powdered carbon. In addition to these solids, about 20 pounds per day of diatomaceous earth would be used. Hence the total pounds of dry solids produced per day using Method A and Method B is 41 and 74 respectively.

Disposing of this sludge in wet form without further dewatering would require approximately 83 fifty-pound plastic bags per day. Further dewatering may be desirable to reduce the volume of material to be handled.

The sludge could possibly be dewatered in a number of ways. Probably the most convenient and simplest way would be filtration using diatomaceous earth filters, since these are standard military components and will probably be used to filter the water from the purification step. Laboratory bench scale tests using vacuum filtration with a 1/8" pre-coat of diatomaceous earth filtered at an average rate of 0.1 to 0.15 gpm/ft² of filter surface. The results of the filtration tests are shown in Figure 9. Use of body feed or addition of polyelectrolytes (Purifloc N-11 or Reten A-1) to the raw sludge did little to improve the filtration rate. Another possible filtration method using a multi-media bed may prove more effective, since more area for floc storage would be available. This type of filter, however, would complicate the multi-media logistics problem, require manual removal of spent media, and may present an odor control problem.

Centrifuging the sludge in a lab centrifuge at 900 G's for two minutes reduced the sludge volume six-fold or from 500 gallons to 84 gallons. A commercially available centrifuge may be

FIGURE 9
Filtration of Sludge Through Diatomaceous Earth
(9.0 cm Buchner Funnel with 1/8" pre-coat)



available to handle this type of waste. This type of equipment, however, may complicate the operating procedure, in that the centrate may contain a significant amount of solids requiring further treatment. Considering all factors, it may be best to waste the 500 gallons per day directly to the incinerator instead of developing a more complicated sludge treatment process.

3.5.9 Odor Analysis

Odor analysis tests were run on a portion of waste treated by the following method:

1. Coagulation and flocculation with ferric sulfate and lime
2. 30 minute settling
3. filtration through diatomaceous earth (vacuum)
4. carbon column adsorption

Dilutions of 25:200, 50:200, and undiluted renovated waste water were used which represented OII values of 3, 2, 1, and 0, respectively. Six testers were used for analysis. Four of the six testers found no odor in any of the samples (0 OII). Two of the testers found odor at the 50:200 dilution which is an OII of 2. It should be noted that these same two testers reported odor in one of the blank samples which contained no renovated water. Hence, it can be inferred from the above data that the OII value for the renovated waste water will be less than 3. The data taken during the odor analysis can be found in Table W.

3.5.10 Coliform Removal

The removal of coliform organisms during two different methods of treatment were determined (the results are shown in Table X). Treatment Method A consisted of chemical treatment and filtration followed by carbon column adsorption. Treatment Method B consisted of combined chemical and powdered carbon treatment followed by filtration. Chlorination was not used during this series of tests. Therefore, the removal of coliforms was not due to chlorine. Sewage was added as the source of coliform organisms. Using Method A, the coliform count on the raw waste was 1620 per ml and after treatment was zero. Using Method B, the coliform count in the raw waste was 500,000 per ml and the effluent was zero. The data clearly shows that the removal of coliforms will be no problem with either treatment method even without chlorination.

TABLE A

SUMMARY OF WASTE CHARACTERISTICS

Mixed Raw Waste (After Mixing in Waring Blender)

pH	8.8 to 8.9 fresh
	7.8 to 8.8 aged
Total Solids	750 mg/l
Suspended Solids	190 mg/l
COD	371 mg/l
BOD	120 mg/l
LAS	34 mg/l

Soluble Portion of Waste (After Filtering Through S & S 597 Filter Paper):

Total Solids	534 mg/l
COD	142 mg/l
BOD	37 mg/l
Color	15 to 20 units
LAS	22 mg/l

TABLE B

COMPARISON OF EXPECTED AND MEASURED SOLIDS CONTENT
OF SPECIFIED WASTEWATER

SPECIFIED WASTE:

240 mg/l Cascade @ 100% solids =	240 mg/l
240 mg/l Surf @ 100% solids =	240 mg/l
48 mg/l Fullers earth @ 100% solids =	48 mg/l
36 mg/l Ivory @ 100% solids =	36 mg/l
10 mg/l oil =	10 mg/l
443 mg/l Vets dog food @ 14% solids =	62 mg/l
	636 mg/l
Tap water contains 187 mg/l dissolved solids	<u>187 mg/l</u>
Expected total solids content =	823 mg/l
Measured total solids content =	750 mg/l

TABLE C
TREATMENT WITHOUT THE USE OF CHEMICALS

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Test Date	6/15	6/15	6/15	6/15	6/19	6/19	6/20 ¹	6/20 ¹	6/20 ¹	6/24	6/24	6/24	6/26	6/26	6/29
Age	Fresh	Fresh	Fresh	Fresh	Old	Fresh	Fresh	Old	Older	Fresh	Fresh	Old	Fresh	Fresh	Fresh
Flocculation Time, min.	0	0	5	0	0	0	5	5	5	0	5	0	0	5	0
Settling Rate, fpm	--	--	0.16	--	--	--	0.20	0.12	--	--	--	--	--	0.13	--
Detention Time, min.	10	60	40	10	10	10	30	30	30	10	30	10	10	30	10
Sludge Vol., gal/1000 gal	<5	40	45	--	--	--	65	80	45	--	--	--	--	70	--
Scum Vol., gal/1000 gal	0	0	0	--	--	--	0	0	0	--	--	--	--	0	--
Effluent:															
Sus. Solids, mg/l	164	63	15	162	274	0	0	--	--	--	--	--	168	5	183
Total Solids, mg/l	650	560	520	636	924	389	240	--	--	654	487	641	701	540	722
COD, mg/l	288	187	148	289	285	177	138	--	--	280	168	287	210	116	322
BOD, mg/l	--	--	--	--	--	--	--	--	--	86	46	108	--	--	112
Color, units	--	--	--	--	--	--	--	--	--	--	--	--	--	30	--
Turbidity, units	--	--	--	--	--	--	22	--	--	--	--	--	88	11	--
Cond., umhos/cm	--	--	--	--	--	--	--	--	--	--	--	--	560	--	505
pH	8.5	8.5	8.5	8.75	8.1	8.9	8.9	8.65	8.50	--	--	--	8.8	8.8	8.7
Raw Waste:															
Soluble COD, mg/l	--	148	--	152	--	138	--	134	153	157	--	--	99	--	121
Soluble Solids, mg/l	--	523	--	438	--	295	--	--	--	507	--	--	567	--	549
Raw Color, units	--	--	--	--	--	15	--	--	15	--	--	--	10	--	--
BOD, mg/l	--	--	--	--	--	--	--	--	--	50	--	--	--	--	42

1. The measured solids content of the raw waste used in these tests was very low. The raw waste may have been improperly prepared.

TABLE D

WASTE COMPOSITION AFTER 10 MIN. SETTLING PERIOD

Test Date	6/19	6/24	6/26	6/29	8/2	8/15	<u>AVERAGE</u>
Total Solids, mg/l	636	647	701	722	---	---	676
Suspended Solids, mg/l	162	---	168	183	194	173	176
COD, mg/l	289	284	210	322	---	---	276
BOD, mg/l	---	97	---	112	---	---	105
LAS, mg/l	---	---	---	33	---	31	32
pH	8.75	---	8.8	8.7	8.4	---	---

TABLE E

TREATMENT WITH ORGANIC POLYMERS

Test No.	1	2	3	4	5
Test Date	6/19	6/19	6/19	6/19	6/19
Waste Age	Fresh	Old	Old	Old	Old
Bentonite Dosage, mg/l	None	None	400	200	400
Bentonite-waste Contact Time,min.	--	--	45	30	30
Purifloc Type	C-31	C-31	C-31	N-11	N-11
Purifloc Dosage, mg/l	4	4	35	7.5	12.5
Flocculation Time, min	5	5	3	3	3
Settling Rate, fpm	--	--	0.25	0.5	0.7
Detention Time, min	30	30	30	30	30
Sludge Volume, gal/1000 gal	--	--	105	30	40

Effluent:

pH	--	8.1	8.1	8.1	8.1
Total Solids, mg/l	489	849	551	538	678
Sus. Solids, mg/l	28	250	118	84	165
COD, mg/l	168	214	100	146	157
BOD, mg/l	--	--	--	--	--
Color, units	--	--	20	15	30
Turbidity, units	--	--	34	32	62

Purifloc C-31 - a cationic polyelectrolyte (Dow Chemical Company)

Purifloc N-11 - a nonionic polyelectrolyte (Dow Chemical Company)

TABLE F

FOAM FRACTIONATION

Test Date	6/26	8/15
Age	Fresh	Old
Collapsed Foam Volume, ml	18	--
Effluent:		
Sus. Solids, mg/l	114 (54 removed)	--
Total Solids, mg/l	650 (51 removed)	--
COD, mg/l	102 (108 removed)	92
LAS, mg/l	12	3.5
pH	8.7	

TABLE G
TREATMENT WITH A CATIONIC SURFACTANT (ROCCAL)

Test	6	7	1	2	3	4	5
Roccal Dosage, mg/l	200	200	0	25	50	100	150
CaO Dosage, mg/l	15	15	12	20	20	20	20
CaCl ₂ Dosage, mg/l	400	400	400	400	400	400	400
Act. Carbon Added, mg/l	0	75	0	0	0	0	0
Test Date (1967)	6/29	6/29	7/5	7/5	7/5	7/5	7/5
Floc Time, min	6	6	6	6	6	6	6
Settling Rate, fpm	0.10	0.11	--	--	--	--	--
Detention Time, min	30	30	30	30	30	30	30
Sludge Vol, gal/1000 gal	130	100	90	90	90	90	90
Scum Vol, gal/1000 gal	0	0	0	0	0	0	0
Effluent:							
Sus. Sol., mg/l	---	---	---	---	---	---	---
Tot. Sol., mg/l	862	832	809	808	809	811	836
COD, mg/l	260	260	97	105	116	141	207
BOD, mg/l	790	790	---	---	---	---	---
Cond., umhos/cm	1020	876	---	---	---	---	---
pH	8.9	8.8	---	---	---	---	---

CaO added to get pH 9.0
initial pH = 8.3

TABLE H

OXIDATION WITH FENTONS REAGENT

FeSO ₄ Dosage	318 mg/l	136 mg/l
First H ₂ O ₂ Dosage	63 mg/l	450 mg/l
Elapsed Time at 2nd H ₂ O ₂ Addition	5 min.	5 min.
Second H ₂ O ₂ Dosage	30 mg/l	240 mg/l
Total Reaction Time	15 min.	15 min.
Initial pH	9.5	9.4
Final pH	3.2	6.15
Initial Total Solids	531 mg/l	531 mg/l
Final Total Solids	993 mg/l	900 mg/l
CaO Added	376 mg/l	500 mg/l
Flocculation Time	6 min.	6 min.
Effluent pH	10.9	10.6

TABLE I

TREATMENT WITH CALCIUM HYPOCHLORITE

Test No.	1	2	3	4	5	6	7	8	9
Test Date	6/21	6/21	6/21	6/21	6/29	6/26	6/26	6/26	6/26
Ca(OCl) ₂ , mg/l	500	400	200	500	400	200	300	400	400
FeCl ₃ ·6H ₂ O, mg/l	--	200	300	--	200	200	200	200	--
Fe ₂ (SO ₄) ₃ ·6H ₂ O, mg/l	--	--	--	--	--	--	--	--	185
Al ₂ (SO ₄) ₃ ·18H ₂ O, mg/l	--	--	--	300	--	--	--	--	--
Floc. Time, min.	5	6	6	5	6	6	6	6	6
Settling Rate, fpm	0.07	0.12	0.10	0.07	0.10	0.12	0.11	0.10	0.10
Detention Time, min.	30	30	30	30	30	30	30	30	30
Sludge Vol, gal/1000 gal	132	140	130	155	140	115	125	145	115
Scum Volume, gal/1000 gal	--	--	--	--	--	Trace	Trace	Trace	Trace

Effluent:

Sus. Sol., mg/l	--	--	--	--	--	--	--	--	--
Total Sol, mg/l	748	632	570	822	748	594	637	755	573
COD, mg/l (a)	--	50	--	--	44	89	78	22	72
BOD, mg/l	--	--	--	--	--	--	--	--	--
Color, units	--	5	--	--	--	20	20	15	10
Turb., units	--	3	--	--	--	10	5	3	11
Cond., μmhos/cm	--	--	--	--	--	12	10	--	--
LAS, mg/l	8.6	7.6	--	7.5	7.6	7.4	7.6	7.6	--
pH	--	--	--	--	--	--	--	--	7.6

(1) Probability of chlorine interference in COD test. Results are probably low.

TABLE J

TREATMENT WITH FERRIC CHLORIDE

Test No.	1	2	3	4	5	6	7	8
Test Date	6/26	6/26	6/26	6/21	6/21	6/21	6/26	6/26
FeCl ₃ ·6H ₂ O, mg/l	200	200	200	300	200	300	200	200
CaO, mg/l	--	--	--	--	--	125	125	--
CaCl ₂ ·2H ₂ O, mg/l	--	--	--	--	--	--	--	333
Ca(OCl) ₂ , mg/l	200	300	400	200	400	--	--	--
Ca ⁺⁺ conc., mg/l	46	68.5	92	46	92	89	89	90
Floc. Time, min.	6	6	6	6	6	6	6	6
Settling Rate, fpm	0.12	0.11	0.10	0.10	0.12	0.12	0.15	0.10
Detention Time, min.	30	30	30	30	30	30	30	30
Sludge Vol., gal/1000 gal	115	125	145	130	140	145	130	100
Scum Vol., gal/1000 gal	Tr.	Tr.	Tr.	--	--	--	--	--
Effluent:								
Sus. Sol., mg/l	10	0	0	--	--	--	14	29
Total Sol., mg/l	592	637	755	570	632	493	826	923
COD, mg/l	89 ¹	78 ¹	22 ¹	--	50 ¹	72	100	89
BOD, mg/l	--	--	--	--	--	--	--	--
Color, units	20	20	15	--	5	15	30	>70
Turbidity, units	10	5	3	--	3	8	13	48
Cond., μ mhos/cm	720	900	1040	--	--	--	680	1080
LAS, mg/l	12	10	--	--	--	--	--	--
pH	7.4	7.6	7.6	--	7.6	8.7	9.6	6.8

(1) COD values of effluent samples from treatment with Ca(OCl)₂ are possibly low due to interference from free chlorine.

TABLE K

TREATMENT WITH FERRIC SULFATE

Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Test Date	6/26	6/29	7/11	7/11	7/11	7/14	7/18	7/12	7/12	7/12	7/12	7/12	7/12	7/12	7/12	7/12	8/2	8/2	8/22	7/25	7/19
Fe ₂ (SO ₄) ₃ ·6H ₂ O, mg/l	188	350	350	350	350	400	400	300	300	300	300	300	350	400	400	400	400	400	400	400	400
CaO, mg/l	--	175	125	150	200	175	175	100	175	125	75	0	175	125	175	125	175	150	175	175	175
CaCl ₂ ·2H ₂ O, mg/l	--	--	--	--	--	--	--	195	0	130	260	460	0	0	--	130	--	--	--	--	--
Ca(OCl) ₂ , mg/l	400	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Ca ⁺⁺ , mg/l	--	125	89	107	143	125	125	106	125	125	125	125	125	89	125	125	125	107	125	125	125
Floc Time, min	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Settling Rate, fpm	0.10	0.17	--	--	--	--	0.14	--	--	--	--	--	--	--	--	--	0.10	0.07	0.14	--	--
Detention Time, min	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Sludge Vol., gal/1000 gal	115	100	95	110	125	--	100	100	138	120	120	65	135	110	120	130	125	100	--	--	--
Effluent:																					
Sus. Sol., mg/l	0	--	--	--	--	--	10	--	--	--	--	--	--	--	--	--	--	8	--	4	--
Total Sol., mg/l	573	681	656	693	784	825	702	--	--	745	790	1121	758	703	752	871	746	654	--	660	640
COD, mg/l	72	62	96	90	76	67	--	62	56	--	62	78	59	62	59	59	67	71	--	76	71
BOD, mg/l	--	28	--	--	--	18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Color, units	10	20	--	--	--	30	20-30	10	--	--	--	--	5	30	15	10	10	40	5	30	--
Turbidity, units	11	--	--	--	--	--	11	--	Turbid	Turbid	--	--	--	--	--	--	--	--	--	--	--
Cond., umhos/cm	1090	470	820	840	1060	764	--	1060	960	920	1080	1270	900	850	870	1020	13.5	56	6	11.5	--
LAS, mg/l	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	840	820	--	--	--
pH	7.6	9.5	9.4	9.4	10.7	10.75	9.1	9.25	10.7	9.9	8.7	6.3	10.6	9.3	10.3	9.1	8.8	8.3	9.4	9.35	--

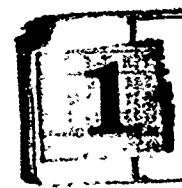
TABLE I

TREATMENT WITH ALUMINUM SALTS

Test No.	1	2	3	4	5	6	7	8	9
Date	8/2	8/2	7/11	7/11	7/11	7/11	7/11	7/11	7/11
Chemical Dosages									
CaCl ₂ ·2H ₂ O	--	--	200	200	400	600	600	700	600
Nalco 2	--	--	100	300	300	300	400	500	500
Al ₂ (SO ₄) ₃ ·18H ₂ O	300	300	--	--	--	--	--	--	--
CaO	200	--	--	--	--	--	--	--	--
Ca(ClO) ₂	--	500	--	--	--	--	--	--	--
Mix Time, min.	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
Floc. Time, min.	6	5	6	6	6	6	6	6	6
Settling Rate, fpm	0.08	0.07	--	--	--	--	--	--	--
Detention time, min	30	30	30	30	30	30	30	30	30
Sludge Volume, gal/1000 gal	155	155	52	55	110	110	125	150	158
Effluent:									
Total Solids, mg/l	618	822	655	798	785	996	950	1064	1023
Suspended Solids, mg/l	53	--	--	--	--	--	--	--	--
COD, mg/l	81	--	--	--	82	77	71	68	71
BOD, mg/l	--	--	--	--	--	--	--	--	--
LAS, mg/l	--	--	--	--	--	--	--	--	--
Color, units	30	--	--	--	--	20	15	10	10
Turbidity, units	50	--	--	--	--	--	--	--	--
Conductivity, μ mhos/cm	760	--	820	850	1080	1440	1340	1500	1410
pH	10.3	7.5	8.65	9.3	9.1	8.9	9.25	9.3	9.45

TABLE M - COMBINED CHEMICAL TREATMENT AND CARBON ADSORPTION

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Test Date	6/29	6/29	6/29	6/29	8/2	8/2	8/2	8/11	8/11	8/15	8/15	8/18	8/18
Treatment Code (see below)	None	Mall	None	Mall	None	Mall	None	Mall	Calgon	Mall	Calgon	Mall	Cal
Activated Carbon Used	0	75	0	75	0	400	0	400	400	400	400	400	400
Activated Carbon Dosage, mg/l	200	200	---	---	---	---	---	---	---	---	---	---	---
Roccal, mg/l	---	---	350	350	400	400	---	---	400	400	400	400	400
Fe ₂ (SO ₄) ₃ ·6H ₂ O, mg/l	---	---	---	---	---	---	300	300	---	---	---	---	---
Al ₂ (SO ₄) ₃ ·18H ₂ O, mg/l	15	15	175	175	175	175	200	200	175	175	175	175	175
CaO, mg/l	400	400	---	---	---	---	---	---	---	---	---	---	---
CaCl ₂ ·2H ₂ O, mg/l	15	15	15	15	30	30	30	30	30	30	30	30	30
Carbon Contact Time, min	6	6	6	6	6	6	6	6	6	6	6	6	6
Flocculation Time, min	0.10	0.11	0.17	0.15	0.10	0.13	0.08	0.10	0.09	0.19	0.13	0.18	0.1
Settling Rate, fpm	30	30	30	30	30	30	30	30	30	30	30	30	30
Detention Time, min	130	100	100	88	125	82	155	110	100	80	90	115	145
Sludge Volume, gal/1000 gal	862	832	681	658	746	627	618	617	---	---	---	742	778
Effluent:	---	---	---	---	---	---	53	---	---	---	---	---	---
Total Solids, mg/l	290	260	62	42	67	24	81	29	25	---	---	26	25
Sus. Solids, mg/l	>90	>90	28	28	---	---	---	---	12	---	---	12	11
COD, mg/l	---	---	20	20	10	10	30	30	---	---	---	---	---
BOD, mg/l	---	---	---	---	13	12	50	37	---	---	---	---	---
Color, units	---	---	---	---	---	0.4	---	---	---	---	---	0.4	0.8
Turbidity, units	1020	876	470	760	840	840	760	760	---	---	---	---	---
LAS, mg/l	8.9	8.8	9.5	9.5	8.8	9.0	10.3	10.3	---	---	---	---	---
Conductivity, umhos/cm	---	---	---	---	---	---	---	---	---	---	---	---	---
pH	---	---	---	---	---	---	---	---	---	---	---	---	---



MICAL TREATME NT AND CARBON ADSORPTION

11	10	11	12	13	14	15	16	17
8/15	8/15	8/15	8/18	8/18	8/22	8/24	9/2	9/2
3	3	3	3	3	3	4	4	4
Calgon	Calgon	Calgon	Calgon	Calgon	Nuchar	Mall	Nuchar	Nuchar
400	400	400	400	400	400	400	400	400
--	--	--	--	--	--	--	--	--
400	400	400	400	400	400	400	400	400
--	--	--	--	--	--	--	--	--
175	175	175	175	175	175	175	175	175
--	--	--	--	--	--	--	--	--
30	30	30	30	30	30	30	30	30
6	6	6	6	6	6	6	6	6
0.13	0.13	0.13	0.18	0.14	0.17	0.17	0.17	0.17
30	30	30	30	30	30	30	30	30
90	90	115	145	--	--	--	100	--
--	--	742	778	650	684	763	773	--
--	--	--	--	--	--	--	--	--
--	--	26	25	36	31	11	18	18
--	--	12	11	--	18	14	9	9
--	--	--	--	5	0	0	0 to 5	0 to 5
--	--	--	--	6	2	1.5	1.5	0.5
--	--	0.4	0.8	--	1.5	--	--	--
--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--
--	--	--	--	9.45	9.0	10.1	10.1	10.1

Treatment Code:

1. No carbon used.
2. Carbon added to raw waste prior to chemical treatment.
3. Carbon added to waste after addition of 100 mg/l ferric sulfate (alum in Test 8).
4. Carbon added to waste after addition of ALL the ferric sulfate.

NOTE: Carbon contact period listed immediately followed the carbon addition.

Carbons Used:

Mall: Mallinckrodt No. 4394 activated charcoal.
Calgon: Filtrasorb 300.
Nuchar: Aqua Nuchar A.

TABLE N

EFFLUENT RECYCLING TESTS

COMBINATION CHEMICAL TREATMENT AND ACTIVATED CARBON

Cycle No.	1	2	3	4	5
Date	8/22	8/22	8/23	8/23	8/24
Raw Waste Soluble Portion					
Total Solids, mg/l	525	994	1336	1721	2182
COD, mg/l	120	151	151	149	—
Color, units	10	20/30	20	20/30	—
Turbidity, units	2.5	22	11	25	—
pH	8.7	9.35	9.05	8.9	7.5
BOD, mg/l	—	—	—	—	60
Chemical Treatment Dosages					
Ferric Sulfate, mg/l	400	400	400	400	400
Activated Carbon, mg/l	400	400	400	400	400
Lime, mg/l	175	150	175	175	175
Carbon Contact Time, min.	30	30	30	30	30
Clarification					
Flocculation Time, min	6	6	6	6	6
Settling Rate, fpm	0.14	0.14	0.14	0.15	0.12
Detention Time, min	30	30	30	30	30
Sludge Volume, gal/1000 gal	—	70	80	85	70
Effluent Quality					
Soluble Solids, mg/l	650	1116	1508	2034	2390
COD, mg/l	36	67	72	93	—
Turbidity, units	6	18	11	8.5	15
pH	9.45	9.1	9.5	9.5	9.1
H ₂ SO ₄ needed to reduce pH to 9.0, mg/l	—	0	25	22	7
Filtered Effluent ¹ .					
COD, mg/l	33	51	67	80	49
Turbidity, units	1.5	2.0	2.8	2.5	1.5
Color, units	5	5/10	5/10	5/10	0
BOD, mg/l	—	—	—	—	33
LAS, mg/l	—	—	—	—	0.6

1. Filter paper used for cycles 1, 2, 3 and 4. Diatomaceous earth used for cycle 5.

TABLE O

COD REDUCTION IN EFFLUENT RECYCLING

TEST NO.

TREATMENT PROCEDURE

EFFLUENT COD

1	100 mg/l ferric sulfate	62 mg/l
	400 mg/l activated carbon	
	30 min. mixing	
	300 mg/l ferric sulfate	
	175 mg/l lime	
	6 min. flocculation; 30 min. settling	
2	100 mg/l ferric sulfate	38 mg/l
	800 mg/l activated carbon	
	30 min. mixing	
	300 mg/l ferric sulfate	
	175 mg/l lime	
	6 min. flocculation; 30 min. settling	
3	400 mg/l ferric sulfate	57 mg/l
	400 mg/l activated carbon	
	30 min. mixing	
	175 mg/l lime	
	6 min. flocculation; 30 min. settling	
4	400 mg/l calcium hypochlorite	31 mg/l
	200 mg/l ferric sulfate	
	6 min. flocculation; 30 min. settling	
	Effluent sample dechlorinated with	
	400 mg/l activated carbon. Carbon	
	removed by filtration.	

TABLE P
TREATMENT OF CYCLE 5 WASTEWATER
(COMBINED CHEMICAL AND CARBON TREATMENT)

Test No.	1	2	3
Test Date	8/23/67	8/23/67	8/23/67
Raw Waste:			
pH	7.5	7.5	7.5
Total Solids, mg/l	2182	2182	2182
COD, mg/l	--	--	--
BOD, mg/l	60	60	60
Treatment	400 mg/l ferric sulfate 400 mg/l act. carbon 175 mg/l lime	400 mg/l ferric sulfate 800 mg/l act. carbon 175 mg/l lime	400 mg/l $\text{Ca}(\text{OCl})_2$ 200 mg/l ferric sulfate (400 mg/l carbon added to effluent for dechlorination)
Carbon Contact Time, min.	30	30	30
Floc Time, min	6	6	6
Settling Rate, fpm	0.12	0.16	0.085
Detention Time, min	30	30	30
Sludge Volume, gal/1000 gal	70	65	110
Effluent:			
Total Solids, mg/l	2390	2350	2396
COD, mg/l	49	32	49
BOD, mg/l	33	22	--
Color, units	0	0	0 to 5
Turbidity, units	1.5	1.6	0
LAS, mg/l	0.6	0	0.6
pH	9.0	9.0	7.0
H_2SO_4 added for pH adjustment, mg/l	7.4	7.4	--

TABLE Q

CARBON ISOTHERM DATA

<u>Carbon Type</u>	<u>Shaking Time</u>	<u>Vol. Sample</u>	<u>Wt. of Sample</u>	<u>COD</u>	<u>BOD</u>
	min.	ml	mg	mg/l	mg/l
Calgon	90	400	0	67.4	25.5
Calgon	90	400	80	20.0	9.4
Calgon	90	400	200	8.3	3.9
Calgon	90	400	320	8.3	2.3
Calgon	90	400	440	8.0	4.0
Barneby	60	200	0	72	--
Barneby	60	200	63.8	46	--
Barneby	60	200	110.5	41	--
Barneby	60	200	202	26	--
Barneby	60	200	364	22	--
Cliffs	60	200	0	72	--
Cliffs	60	200	51.2	26	--
Cliffs	60	200	113.7	23	--
Cliffs	60	200	199.7	15	--
Cliffs	60	200	295.1	15	--

TABLE R

CARBON COLUMN TESTS - BARNEBY - CHENEY CARBON

Test No.	1	2				3	4
Date	7/12	7/18				7/18	7/19
Chemical Treatment:							
Fe ₂ (SO ₄) ₃ •6H ₂ O dosage, mg/l	350	400				400	400
CaO dosage, mg/l	175	175				175	175
Effluent:							
Total Solids, mg/l	758	702				702	--
Suspended Solids, mg/l	--	10				10	--
COD, mg/l	59	--				--	71
BOD, mg/l	--	--				--	--
Color, units	--	20 - 30				20 - 30	--
Turbidity, units	--	11				11	--
pH	10.6	9.1				9.1	--
Effluent from Carbon Column:							
Contact Time, min	30	2.5	5	10	15	20	2
Total Solids, mg/l	682	--	--	--	--	--	655
Sus. Solids, mg/l	--	--	--	--	--	--	--
COD, mg/l	5	34	21	11	13	26	32
BOD, mg/l	--	--	--	--	--	--	--
Color, units	20	--	--	--	--	5	- 10
Turbidity, units	--	--	--	--	--	2	--
pH	--	--	--	--	--	--	8.55

TABLE S
CARBON COLUMN TESTS - FILTRASORB 300

RECIRCULATED WATER

Run No.	1						2					
Cycle No.	1						2					
Raw Waste:	1						1					
Soluble Solids, mg/l	584						538					
Soluble COD, mg/l	156						124					
Carbon Column Influent:												
Total Solids, mg/l	1034						654					
COD, mg/l	68						67					
Carbon Column Effluent:												
Total Solids, mg/l	623						536					
COD, mg/l	3						4					
BOD, mg/l	--						--					
Color, units	0-5						0-5					
Turbidity, units	0						1					
pH	8.9						9.4					
Test Procedure	1.						1.					
	Treat with 400 mg/l						Treat with 400 mg/l $\text{Fe}_2(\text{SO}_4)_3$					
	$\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$ and						6H ₂ O and 175 mg/l CaO.					
	175 mg/l CaO.						2. Flocculate 10 minutes.					
	2. Flocculate 10 minutes.						3. 45 minutes settling period.					
	3. 60 minutes settling						4. Clarified effluent passed					
	period.						through diatomaceous earth filter.					
	4. Clarified effluent passed						5. Filtered waste passed through					
	through carbon column -						carbon column - 6 minute contact.					
	6 minute contact.											

TABLE T
CLARIFICATION BY FLOTATION

Test Date	7/18	7/18	7/18
Test No.	1	2	3
Type	Settling	Flotation	Flotation
Treatment:			
$\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$, mg/l	400	400	400
CaO, mg/l	175	175	175
Floc Time, min	6	6	6
Recycle Rate, %	--	33	50
Separation Rate, fpm	0.14	--	0.20
Detention Time, min	30	12	12
Scum Vol., gal/1000 gal	0	67	--
Sludge Vol., gal/1000 gal	100	0	0
Effluent:			
pH	9.1	9.1	9.1
Total Solids, mg/l	702	737	--
Susp. Solids, mg/l	10	6	2
COD, mg/l	--	79	66
Color, units	20 to 30	20	20
Turbidity, units	11	25	7

TABLE U

SLUDGE COMPACTION WITH TIME

Date	8/15	8/15	8/15	8/22
Treatment Dosages:				
Fe ₂ (SO ₄) ₃ ·6H ₂ O, mg/l	400	400	400	400
Activated Carbon, mg/l	400	400	None	400
CaO, mg/l	175	175	175	175
Carbon Type	Mallinckrodt Filtrasorb 300 -- Aqua Nuchar A			
Sludge Volume, gal/1000 gal				
30 minutes	80	90	110	85
60 minutes	60	70	85	--
90 minutes	55	65	75	--
2 hours	50	60	70	--
24 hours	--	--	--	34

TABLE V

EFFECT OF CHANGE IN WASTE COMPOSITION

Waste Source	Laundry and shower	Kitchen and shower
Waste Composition:		
Surf, mg/l	300	None
Cascade, mg/l	None	327
Dog Food, mg/l	78	78
Ivory, mg/l	45	49
Fullers earth, mg/l	60	66
Oil, mg/l	13	14
Raw Waste:		
pH	7.7	11.1
Total Solids, mg/l	566	--
Soluble Solids, mg/l	450	493
COD, mg/l	271	--
Soluble COD, mg/l	200	154
Conductivity, μ mhos/cm	496	--
LAS	--	0
Settling Data:		
$\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$, mg/l	400	400
CaO , mg/l	175	175
Floc Time, min	6	6
Settling Rate, fpm	0.10	0.19
Sludge Volume, gal/1000 gal	95	60
Effluent:		
pH	8.8	8.8
Total Solids, mg/l	605	642
COD, mg/l	67	69
Turbidity, units	7	-
Color, units	30	--
LAS, mg/l	7.2	0.0
Conductivity, μ mhos/cm	770	--

Run Number	Volume Waste	Volume Diluting Water	Equivalent OII	Testers					
				1	2	3	4	5	6
1	25 ml	175 ml	3	-	+	-	-	-	-
2	50 ml	150 ml	2	-	+	+	-	-	-
3	100 ml	100 ml	1	-	-	-	-	-	-
4	200 ml	- 0 -	- 0 -	+	+	+	-	-	-
(+) indicates odor was detected (-) indicates no odor was detected									

TABLE W
Data from Odor Analysis

Date Run	Treatment Method	MPN Coliforms/ml in raw waste	MPN Coliforms/100 ml in treated effluent (2)
9/1/67	B	500,000	- 0 -
9/13/67	A	1620	- 0 -
(1) Treatment method "A" uses $\text{Fe}_2(\text{SO}_4)_3$ and CaO. Processes include flocculation, sedimentation, diatomaceous earth filtration, and carbon column adsorption. Treatment method "B" uses $\text{Fe}_2(\text{SO}_4)_3$, CaO, and powdered activated carbon. Processes include flocculation, sedimentation, and diatomaceous earth filtration. (2) No chlorination used on these samples.			

TABLE X

Effect of Treatment on Coliform Removal

Effluent Quality					
Test Number	pH	Color	COD(1) (mg/l)	Residual Chlorine (mg/l)	Total Solids (mg/l)
1	7.8	0/5	56	267	740
2	7.8	5/10	56	267	744
3	7.8	5/10	47	267	768
4	7.1	5/10	40	40	848
(1) Samples dechlorinated with sodium sulfite and aerated prior to COD analysis.					

TABLE Y
Combined Chemical Treatment and Oxidation

4.0 ENGINEERING EVALUATION OF APPLICABLE INTEGRATED WASTE TREATMENT SYSTEMS

4.1 Preliminary Remarks

An analysis of the results obtained from the investigation conducted indicates that the waste described in this contract may be satisfactorily treated using any of the following methods:

- (1) Batch treatment
- (2) Continuous flow treatment
- (3) Combination of both batch and continuous flow treatment

In the discussion which follows, the integrated waste treatment systems described and proposed for consideration will fall into the above broad categories.

4.2 The Process Elements

Treatment of the waste, using any of the above treatment methods, will incorporate the following process elements, generally in the order listed.

- (1) Waste accumulation and blending
- (2) Purification
- (3) Sludge treatment
- (4) Neutralization, if necessary
- (5) Polishing
- (6) Disinfection

General considerations regarding each of the above process steps will be discussed below. The discussion will include evaluations of the major pieces of equipment required to accomplish the process step in question, as well as the pertinent auxiliary equipment and chemicals needed. In this regard, all electrically driven equipment discussed below should require electrical characteristics compatible with those furnished by the military.

4.2.1 Waste Accumulation and Blending Step

It may be apparent that this step is a necessary one and a common one for both batch and continuous flow treatment methods. An appropriate holding tank may be used to accomplish this process step. Provision for at least two holding tanks is proposed and recommended. A capacity for each holding tank of 10,000 gallons is initially proposed, and the basis for this is that the maximum daily waste flow anticipated is 10,000 gal/day. It is expected

that one day's waste flow will be accumulated in one of the holding tanks and subsequently treated, while one of the other holding tanks is accumulating another day's waste flow.

The basis for design, the configuration, and the overall dimensions of a proposed holding tank design is shown in Appendix H. The configuration of the holding tanks consist of a square section with a pyramidal-shaped hopper bottom. A 45° slope, as shown, was selected for the bottom hopper to facilitate accumulation and removal of settled sludge. The effective capacity of the holding tank shown is 10,000 gallons with provision for a freeboard of one foot. Note that the overall dimensions of the holding tank proper are 12 feet square by 14.5 feet overall height. It is recognized that if the holding tank is fabricated of steel or other rigid material, it will not be possible to load it, in one piece, into the Type C-130E Cargo Aircraft through the main loading door. The maximum dimensions of the main loading door of the Type C-130E Aircraft are 115 inches to 117.3 inches wide by 104.8 inches to 108 inches in height. The ramp incline angle and the fact that a 463L rail system (Attachment "A" of the contract) is to be used should also be taken into consideration. When a 463L handling system is used, the usable height is reduced by 1.5 inches. It appears feasible to hold a rigid-material-of-construction-type holding tank if the holding tank is fabricated in sections. Breaking down the holding tank into a series of flat plates will also minimize cubage in transport. However, difficulties in water-tight sealing may be encountered in the field during subsequent assembly, installation, and operation of the holding tank. This difficulty may be minimized by using a flexible rubber lining to be installed after assembly in the field.

It appears, however, that if the holding tank design shown in the Appendix, Section H is adopted, it would be preferable from a weight, cubage, and corrosion standpoint to fabricate the holding tank from a flexible material of construction, such as rubber, which will allow the holding tank to be shipped to and from the operation site in collapsed form. The cubage of the holding tank in collapsed form may be on the order of 15% of the cubage of the holding tank in operation. This may be an appreciable advantage of the flexible type of material of construction over the rigid type. A similar advantage of the flexible material over the rigid material is not expected from the standpoint of weight.

4.2.1.1 Continuous Flow Treatment

The function of the holding tank in the continuous flow treatment method is primarily to accumulate and blend the raw waste flow. It may also be possible in some instances to use the holding tank for the purpose of adding and mixing a chemical in the raw waste where a number of chemicals are required for the purification step. Another function of the holding tank will be to accumulate those solids in the raw waste which are readily settleable. The laboratory tests indicated that the quantity of readily settleable solids will be significant.

It may be apparent that the holding tank will require openings for inlet, overflow, sludge removal, sampling, and raw waste flow to the purification step. The inlet opening will connect to the source of raw waste. The overflow opening may connect either to another holding tank or to drain. The sludge and raw waste may have a common opening located at the apex of the bottom hopper, with appropriate valving to allow the sequential removal, first, of the accumulated settled sludge and, second, of the raw waste to the purification step.

In most instances, the holding tank should be provided with a variable speed mechanical mixing device to (1) blend the raw waste, (2) provide the dispersing means if a chemical is added, and (3) promote flocculation of the raw waste without chemicals. It may have been noted from the laboratory test results that significant flocculation took place with fresh raw waste.

4.2.1.2 Batch Treatment

In addition to performing the function of accumulating and blending the raw waste, the holding tank, in batch treatment, will also serve as a means in which the purification and sludge treatment steps may be accomplished.

The openings in the holding tank used in batch treatment will be identical to those described above for continuous flow treatment.

The purification step to be conducted in the holding tank will require the need for mixing and flocculation. Therefore, a variable speed mechanical mixing device to perform these functions will be required, having electrical characteristics compatible with that furnished by the military.

4.2.2 Purification Step

The laboratory studies demonstrated that chemical treatment may be employed to satisfactorily treat the waste described in this contract. Two methods using various combinations of chemicals were found most suitable in treating the waste. The two methods and the corresponding laboratory treatment procedures involved are briefly described below for subsequent reference.

4.2.2.1 Purification Method No. 1

This method involved the use of ferric sulfate as $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$ and lime as CaO . (It is intended that the purification step using this method be followed by neutralization, filtration polishing, carbon column adsorption, and disinfection, in that order.) The laboratory procedure and process steps developed in using this method for purification were as follows,

- (1) Addition of ferric sulfate, as $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$, at a concentration of 400 mg/l.
- (2) Quick mix, to disperse the chemical uniformly in the waste.
- (3) Addition of lime, as CaO , at a concentration of 175 mg/l.
- (4) Quick mix.
- (5) Flocculation. A period of relatively slow, gentle mixing for a laboratory period of six minutes.
- (6) Sedimentation. Solids-liquid separation under quiescent conditions for a laboratory period of thirty minutes.

In a full-scale treatment process, the effluent from Step 6, above, would be subsequently treated by filtration polishing followed by carbon column adsorption. The settled sludge from Step 6, above, would be subjected to sludge treatment, in a full-scale process, to further dewater the sludge.

In a full-scale process, the quick mix steps, Steps 2 and 4 above, should be accomplished, wherever possible and practicable, using the kinetic energy of the water. When this is not possible or practicable, then mechanical means will have to be used. On the other hand, flocculation will have to be accomplished using mechanical means for positive control of the flocculation step.

It may be evident that chemical stock tanks for preparation of chemical solutions or slurries as well as chemical feed equipment will be required, as appurtenant equipment, for the treatment process. In this connection, the chemical stock tanks may be designed using the following properties of the chemicals involved.

Ferric Sulfate

(Ferric sulfate may also be fed in dry form.) Ferric sulfate is very soluble in water (solutions on the order of 2 lb/gal may be prepared). Ferric sulfate solutions are corrosive, and therefore, stainless steel (316), rubber, lead, ceramic, polyethylene, or Duriron materials of construction will have to be used in fabricating stock tanks handling this solution.

Calcium Oxide (Quick Lime)

Calcium oxide reacts with water to form calcium hydroxide, having a solubility of 0.16 gm/100 ml of water at 20°C, and each pound of CaO will slake to form 1.16 to 1.32 pounds of Ca(OH)₂ and from 2 to 12% grit, depending on purity. In slaked form, iron or steel tanks may be used to prepare this chemical. The chemical feed equipment may be designed on the basis of the chemical requirements required for treatment and the strength of the respective chemical solutions prepared.

4.2.2.1.1 Batch Treatment

Batch treatment in treating the waste using the six steps outlined above for Method No. 1 may be carried out, sequentially, in the Waste Accumulation and Blending holding tank. Each step may be carried out for as long a time as is reasonably necessary, with due regard for the need for finished product water.

The settled sludge from batch sedimentation will be subjected to sludge treatment and the effluent will be subsequently neutralized, filter polished, passed through an activated carbon adsorption column, and disinfected.

4.2.2.1.2 Continuous Flow Treatment

Continuous flow treatment may also be used in treating the waste using the six steps outlined above for Method No. 1. The process steps of quick mix, flocculation, and sedimentation may each be carried out in individual, separate compartments or chambers or all three process steps may be carried out in an integral unit such as an upflow basin or a solids contact unit. An upflow basin, as defined for this discussion, is one which is identical to a solids-contact basin with the exception that provision is not made for recirculating solids to the mixing zone (solids contact) for the purpose of expediting chemical precipitation.

The design of the units to be used in the purification step by continuous flow treatment will be based upon the waste flow to be treated, the laboratory solids settling rates obtained, laboratory detention times, laboratory sludge volumes observed, etc., with due allowance made for such interfering factors as short-circuiting and turbulence associated with continuous flow equipment. In this regard, the use of standard military equipment will be investigated. In connection with the design flow rate to be used, a design flow rate of 20 gpm is selected. Based upon a daily waste flow of 10,000 gal/day, a design flow of 20 gpm will allow complete treatment of the waste in 8 to 10 hours, including preliminary treatment and preparation of the waste in the holding tank prior to continuous flow treatment.

Again, the effluent obtained from continuous treatment by Method No. 1 will be subsequently treated by neutralization, filter polishing, carbon column treatment, and disinfection and the settled sludge obtained will be further dewatered by thickening.

4.2.2.2 Purification Method No. 2

This method is also a chemical treatment method and involved the use of ferric sulfate as $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$, powdered activated carbon, and lime as CaO . (It is intended that this purification step be followed by neutralization, filtration polishing and disinfection in that order.) The laboratory procedure and process steps developed using this method for purification were as follows:

- (1) Addition of ferric sulfate as $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$ at a concentration of 400 mg/l.
- (2) Quick mix, to disperse the chemical uniformly in the raw waste.
- (3) Addition of powdered activated carbon at a concentration of 800 mg/l.
- (4) Quick mix.
- (5) Contact of the above chemicals with the waste for a laboratory detention time of thirty minutes. The type of mixing required here is of the flocculation type to minimize activated carbon break-up.
- (6) Addition of lime, as CaO , at a concentration of 175 mg/l.
- (7) Quick mix.
- (8) Flocculation. A period of slow, gentle mixing for a laboratory period of six minutes.
- (9) Sedimentation. Solids-liquid separation under quiescent conditions for a laboratory period of thirty minutes.

In a full-scale treatment process, the effluent from Step 9, above, would be subsequently treated by neutralization, filtration polishing followed by disinfection. The pH of the effluent after Step 9, above, is about 9.0. The settled sludge from Step 9, above, would be subjected to sludge treatment, in a full-scale process, to further dewater the sludge.

In a full-scale process, the quick mix steps, Steps 2, 4, and 7, should be accomplished wherever possible and practicable, using the kinetic energy of the water. When this is not possible or practicable, then mechanical means will have to be used. On the other hand, flocculation, Steps 5 and 8, will have to be accomplished using mechanical means for positive control of the flocculation step.

Chemical stock tanks for preparation of the chemical solutions or slurries as well as chemical feed equipment will be required, as appurtenant equipment, for the treatment process. The design of the appurtenant equipment may be based upon the properties of the chemicals involved. The appurtenant equipment required for handling ferric sulfate and CaO may be designed on the same basis as that set forth for Purification Method No. 1. The appurtenant equipment required for handling powdered activated carbon may be based upon the following properties of activated carbon. Powdered activated carbon is black in color, about 400 mesh in size, has a bulk density varying from 8 to 28 lb/cu ft, and is insoluble in water. The powdered activated carbon may be fed wet or dry. The best feeding form when continuously fed dry is as a powder, preferably with a bulk density of 12 lb/cu ft. The best feeding form when fed wet is in slurry form having a concentration of 1.0 lb/gal. The materials of construction recommended for handling powdered activated carbon in dry form are iron and steel, whereas those recommended for handling powdered activated carbon in wet form are stainless steel, rubber, duriron, or polyethylene.

4.2.2.2.1 Batch Treatment

Batch treatment in treating the waste using the nine steps outlined above for Method No. 2 may be carried out, sequentially, in the Waste Accumulation and Blending holding tank. Each step may be carried out for as long a time as is reasonably necessary, with due regard for the need for finished product water.

The settled sludge from batch sedimentation will be subjected to sludge treatment and ultimate disposal. The effluent from batch sedimentation will be subsequently neutralized, filter polished and disinfected.

4.2.2.2.2 Continuous Flow Treatment

Continuous flow treatment may also be employed in treating the waste using the nine steps outlined above for Method No. 2.

Steps 1 through 5 may be considered one phase of Purification Method No. 2. The purpose of this phase is to prepare the contaminants for adsorption and to carry out the adsorption itself by providing sufficient contact time between the powdered activated carbon and the contaminants. Note that there is not a solids-liquid separation step in this phase of purification. The introduction of the chemicals and the subsequent quick-mix steps, Steps 1 through 4, may be carried out in individual units or in the waste holding tank, or using the kinetic energy of the water in the pipeline leading to the contact chamber. The contact chamber, in which Step 5 is to be carried out, may be a conventional flocculation basin or the waste holding tank.

Steps 6 through 9 may be considered the second phase of Purification Method No. 2. The process elements of this phase may be carried out in individual compartmental units or in a single unit such as a solids-contact basin. A solids-contact unit is particularly attractive, from a process standpoint, in accomplishing this phase of purification in that additional carbon adsorption may be affected by solids recirculation, as was indicated in the literature (60).

The design of the units to be used in the purification step by continuous flow treatment will be based upon the waste flow to be treated, the laboratory solids settling rates obtained, laboratory detention times, laboratory sludge volumes observed, etc., with due allowance made for such interfering factors as short-circuiting and turbulence associated with continuous flow equipment. In this regard, the use of standard military equipment will be investigated. In connection with the design flow rate to be used, a design flow rate of 20 gpm is selected. Based upon a daily waste flow of 10,000 gal/day, a design flow of 20 gpm will allow complete treatment of the waste in 8 to 10 hours, including preliminary treatment and preparation of the waste in the holding tank prior to continuous flow treatment.

Again, the effluent obtained from continuous treatment by Method No. 2 will be subsequently treated by neutralization, filter polishing and disinfection and the settled sludge obtained will be further dewatered by thickening.

4.2.3 Sludge Treatment Step

The settled sludges arising from the purification step in the treatment of the raw waste will have to be prepared for ultimate disposal. Any mechanism or step which may be utilized to effectively minimize the volume of waste sludge to be disposed of will (1) increase product water recovery, (2) minimize waste sludge handling, and (3) minimize the burden or load on the ultimate sludge disposal facilities. The value of increasing product water recovery is important and readily apparent. The importance of minimizing sludge handling cannot be over-emphasized. For example, Attachment "A" of the contract stipulates that the waste sludges shall be collected in 50 lb plastic bags in preparation for incineration. If the minimum water recovery (80%) is effected, 2000 gal/day (based on a daily raw waste volume of 10,000 gallons) of the waste sludge will have to be handled. Collecting 2000 gal/day of waste sludge in 50 lb plastic bags will necessitate the handling of about 33¹/₄ plastic bags per day. The laboratory investigation conducted demonstrated that about 90% water recovery will be effected using 30 minute laboratory detention times. This would amount to 1000 gal/day waste sludge (10,000 gal/day raw waste basis) or 16²/₇ plastic bags per day. Compaction of the waste sludges obtained from the purification step to a volume of 5% of the total raw waste flow (95% water recovery) were indicated by the laboratory studies. This would result in handling 500 gal/day of waste sludge or about 8¹/₄ plastic per day.

The above discussion indicates that, for a full-scale treatment process, product water recovery may be maximized and waste sludge handling minimized by thickening the sludges accumulated from the purification step.

Thickening of the sludges accumulating from the purification step may be accomplished in separate chambers or compartments, or it may be accomplished in the same vessel in which the sedimentation-purification step is performed by providing sufficient additional volume in those vessels for sludge compaction and dewatering.

The general considerations described above for full-scale thickening are applicable to both batch and continuous flow treatment processes.

4.2.4 Neutralization Step

In Attachment "A" of the contract, it may be seen that the required pH range for the renovated water is 5.5 to 9.0. The results of the laboratory investigation indicated that a pH of the treated water less than 5.5 is not expected. However, it may be recalled from the laboratory study that the pH of the waste after treatment using Purification Methods No. 1 and 2 may be slightly greater than 9.0. This observation indicates that neutralization with acid may, at times, be necessary to bring the pH of the renovated water within the pH range specified. It was indicated from the laboratory investigation that about 35 mg/l sulfuric acid may be required for neutralization and the probable point of acid introduction is prior to filtration polishing.

The above considerations may be used in the design of prototype neutralization facilities for both batch and continuous flow waste treatment processes. The equipment required consists of a chemical stock tank and an acid chemical feeder.

4.2.5 Polishing Step

The results of the laboratory investigation indicated that a filtration polishing step was necessary and essential in the treatment of the raw waste in a closed system in order to insure consistent quality of the renovated water.

The laboratory work demonstrated that filtration using diatomaceous earth was applicable as a polishing means. In this regard, the military has available various standard size filtration equipment which may be utilized for full-scale application. The 25 gpm size military standard diatomite filter is recommended to maximize the length of filter runs and to minimize amount of sludge wasted by backwashing. If the amount of backwash water is minimal, it is intended to dispose of it with the thickened sludges from purification. If the amount of backwash water is significantly great, then it will be discharged back to one of the holding tanks for further recovery of the water associated with the solids.

The literature survey conducted indicated the feasibility and advantages of using coal as a filter medium for filtration polishing. The use of a coal filter for filtration polishing is hereby proposed for consideration in a full-scale treatment process. In contrast with the standard military diatomaceous earth filters, which are readily available and fully developed, it should be recognized that it would be necessary to develop the final design of a coal filter for this treatment application during the prototype

test period. The particle size of coal to be used, the filtration rate, hydraulic headloss, depth of floc penetration, filterability index, etc., information will have to be obtained for the design of an effective prototype coal filter.

The general considerations described above for full-scale use of diatomaceous earth or coal for filtration polishing are applicable to both batch and continuous flow treatment processes.

4.2.6 Disinfection

In Attachment "A", it is stipulated that disinfection of the renovated water shall be by chlorination to a level of at least 5 ppm free available chlorine through the use of calcium hypochlorite (70% available chlorine).

The results of the laboratory investigation indicated that an applied dosage of 14 mg/l calcium hypochlorite (70% available chlorine) will provide at least 5 ppm free available chlorine in the renovated water. A chlorine contact time of five minutes appeared to be sufficient.

The above considerations may be used in the design of prototype disinfection facilities for both batch and continuous flow waste treatment processes. The equipment required consists of a chemical stock tank, mixer and chemical feeder.

4.3 Conceptual Designs of Applicable Prototype Integrated Waste Treatment Systems

Using the principles involved in the individual process elements described above, as well as the pertinent information obtained from the literature survey and laboratory studies, it is now possible to design the necessary mechanical hardware associated with the integrated waste treatment systems to be proposed for consideration in treatment of the waste described in this contract.

Seven integrated waste treatment systems are proposed for consideration. Three of these systems employ the batch treatment method and the other four systems are of the continuous or semi-continuous flow treatment method. For identification purposes, the systems proposed will be classified under the purification method of treatment used, either Purification Method No. 1 or Purification Method No. 2. (These purification methods are described above.) In the design of each system, military standard components are

included were applicable. These military standard components include pumps, chemical feeders, diatomite filters, and solids-contact clarifiers. In addition, each system is evaluated from the standpoint of (1) weight of total package, (2) cubage, in transport and in operation (3) operating skill requirements, (4) maintenance requirements, (5) logistical support requirements, (6) complexity of component assembly, (7) power requirements, (8) availability of fabrication materials, (9) water recovery capability, (10) odor control provisions, and (11) cost per 1,000 gallons of water recovered. Based upon the above evaluation parameters, a recommendation will be made by the Contractor, for the Contracting Officer's consideration, as to the Contractor's preference for the integrated system to be adopted.

4.3.1 Integrated Treatment Systems Using Purification Method No. 1

4.3.1.1 Batch Treatment System

4.3.1.1.1 Batch System 1.1

This system is shown schematically in Figure 10. The components comprising this system and their functions are:

- (1) Holding tank for blending and purification
- (2) Neutralization facilities, if necessary
- (3) Diatomaceous earth filter for polishing
- (4) Activated carbon column for polishing
- (5) Disinfection facilities

The design of the various components involved in this system are detailed in Appendix H. It should be pointed out that a military standard component was selected for the diatomaceous earth filter used in polishing. A thirty-inch diameter nominal size steel pipe was selected for the carbon column. Evaluation of this system in terms of the evaluation parameters above is summarized in Table Z.

4.3.1.1.2 Batch System 1.2

This system is shown schematically in Figure 10 and the components comprising Batch System 1.2 are identical to those of Batch System 1.1, with the exception that a coal filter is used for polishing in Batch System 1.2 whereas a diatomaceous earth filter was proposed for polishing in Batch System 1.1.

The design of the various components involved in Batch System 1.2 are presented in Appendix I. Evaluation of this system in terms of the evaluation parameters listed above is summarized in Table Z.

4.3.1.2 Continuous Flow Treatment Systems

4.3.1.2.1 Continuous Flow System 1.3

This system is shown schematically in Figure 11. The components comprising this system and their functions are,

- (1) Holding tank for blending of raw waste.
- (2) Flocculator (conventional). Used in purification of the waste.
- (3) Clarifier-Thickener (conventional). Used in purification of the waste.
- (4) Neutralization facilities, if necessary.
- (5) Coal filter for polishing.
- (6) Activated carbon column for polishing.
- (7) Disinfection facilities.

Note the absence of a mixer in the holding tank for this system. The treatment chemicals are added and mixed in the line leading from the holding tank to the conventional flocculator.

The design of various components involved in this system are detailed in Appendix J. Evaluation of this system in terms of the evaluation parameters listed above is summarized in Table Z.

4.3.1.2.2 Continuous Flow System 1.4

This system is shown schematically in Figure 11. This system is functionally identical to Continuous Flow System 1.3. One of the differences between the two systems is indicated in Figure 11. Whereas in Continuous Flow System 1.3, the process elements of flocculation, and sedimentation thickening are carried out in individual units, in Continuous Flow System 1.4 these operations are combined in a package upflow clarifier unit (Erdlator, a military standard component). Another difference between Continuous Flow Systems 1.3 and 1.4 is that a diatomaceous earth filter is to be used for polishing in System 1.4 whereas a coal filter was proposed for System 1.3.

The design of the various components for System 1.4 are detailed in Appendix K. Evaluation of this system in terms of the evaluation parameters listed above is summarized in Table Z.

4.3.2 Integrated Treatment Systems Using Purification Method No. 2

4.3.2.1 Batch Treatment System 2.1

This system is shown schematically in Figure 12. The major components comprising this system and their functions are,

- (1) Holding tank for blending and purification.
- (2) Neutralization facilities, if necessary.
- (3) Diatomaceous earth filter for polishing.
- (4) Disinfection facilities.

The design of the various components involved in this system are detailed in Appendix L. Evaluation of the system in terms of the evaluation parameters listed above is summarized in Table Z.

4.3.2.2 Continuous Flow Treatment Systems

4.3.2.2.1 Continuous Flow System 2.2

This system is shown schematically in Figure 13. The major components comprising this system and their functions are,

- (1) Holding tank for blending raw waste, addition of ferric sulfate, powdered activated carbon, and subsequent adsorption operation.
- (2) Flocculator (conventional) for use in purification step.
- (3) Clarifier-Thickener Basin (conventional) for use in purification step.
- (4) Neutralization facilities, if necessary.
- (5) Diatomaceous earth filter, for polishing.
- (6) Disinfection facilities.

The design of the various components involved in this system are detailed in Appendix M. Evaluation of this system in terms of the evaluation parameters listed above is summarized in Table Z.

4.3.2.2.2 Continuous Flow System 2.3

This system is shown schematically in Figure 13. This system

is functionally identical to Continuous Flow System 2.2. The difference between the two systems is indicated in Figure 13. Whereas in Continuous Flow System 2.2, the process elements of flocculation and sedimentation-thickening are carried out in individual conventional units, in Continuous Flow System 2.3 these operations are combined in a package solids-contact unit, (Erdlator, a standard military component).

The design of the various components for System 2.3 are detailed in Appendix N. Evaluation of this system in terms of the evaluation parameters listed above is summarized in Table Z.

4.4 Evaluation of the Various Proposed Integrated Waste Treatment Systems

Evaluation of the various proposed waste treatment systems will be made using the evaluation parameters listed above as well as using other pertinent considerations. Comparison of the systems in terms of the evaluation parameters listed above may be made from the summary presented in Table Z. Referring to Table Z, definition of each of the evaluation parameters as used in this discussion is in order.

- (1) Columns (1), (2), and (3) define the treatment system being evaluated as well as the references which were used to obtain the various details involved for the treatment system in question. For example, Treatment System 1.1, Figure 10 (Appendix H) refers to the batch treatment system employing Purification Method No. 1, which is schematically shown in Figure 10 of the text and whose component design details are presented in Appendix H.
- (2) Column (4) defines the total weight of the package treatment system in question, and the figures shown are for package components fabricated of steel. If aluminum is used as the material of construction, the approximate total package weight may be obtained using the factor shown in the appropriate footnote for Column (4), Table Z. The total package weight shown in Column (4) does not include such items as the activated carbon used in the carbon column or the coal used in the coal filter, although it is conceivable that these components may be transported containing the appropriate material in order to conserve cubage and facilitate subsequent system start-up.

- (3) Columns (5) and (6) represent the total cubage of the package system for transportation and operation purposes, respectively. The operational cubage shown is the sum of the individual component cubages and does not represent the operating space volume required for a given system because the operating space volume may vary considerably with varying arrangement of the individual components.
- (4) Columns (7) and (8) show the monthly logistical support requirements necessary to sustain the operation of a given treatment system. The materials included in the logistical support, where applicable, are ferric sulfate, quicklime, activated carbon, diatomaceous earth, calcium hypochlorite, and sulfuric acid. Note that the logistical support is expressed in terms of weight (Column 7) and cubage (Column 8).
- (5) Columns (9) and (10) show the daily cost of operation (Column 9) as well as the operating cost per 1,000 gallons of product water produced. These costs were based upon the costs of the materials used for treatment, and are detailed in the appropriate Appendix for a given treatment system.
- (6) Column (11) shows the percentage water recovery expected for a given treatment system and the percentage water recovery is defined as the ratio of the product water volume to raw waste volume times 100.
- (7) Column (12) represents the expected total connected power requirements for a given system. Power consuming equipment include mixers, flocculators, pumps, chemical feeders, etc.
- (8) As noted in Table Z, the evaluation parameters in Columns (13) through (17) are rated on a 1 to 7 basis; 1 representing the most desirable system for the parameter involved and 7 representing the least desirable system for the parameter involved.
- (9) In Column (13), the treatment systems are rated from the standpoint of the operational skills required. The major factor used in the comparison of the treatment systems was the relative complexity of start-up, shut-down and operation of the systems. Relative complexity was determined by consideration of the number of components requiring attention, number of operations required, frequency of attention required, and duration of attention required.

- (10) In Column (14), the treatment systems are rated from the standpoint of maintenance requirements. Factors considered in making the ratings included the number of components requiring maintenance, frequency of maintenance, type of maintenance (mechanical, electrical, etc.), and complexity of maintenance.
- (11) In Column (15), the treatment systems are rated from the standpoint of complexity of component assembly. Factors considered in making the ratings included the number of components requiring field assembly as well as the time required for assembly and complexity of assembly.
- (12) In Column (16), the treatment systems are rated from the standpoint of the availability of fabrication materials. Common fabrication materials are used in all seven proposed systems.
- (13) In Column (17), the treatment systems are rated from the standpoint of their odor control provisions. The proposed systems were compared for their relative potential for developing odors as well as for the amount of exposable surface area from which odors may be emitted.

An examination of Table Z shows that the batch treatment systems are more desirable than the continuous flow treatment systems. (The batch treatment systems in Table Z are Treatment Systems 1.1, 1.2, and 2.1). For example, the total package weight (Column 4) of the batch treatment systems are significantly and consistently less than that of the continuous flow treatment systems. (Note in Table Z that the figures shown in Column (4) are for components fabricated of steel. The total package weight of all systems proposed may be drastically reduced if aluminum is used as the material of construction. The appropriate footnote in Table Z shows the factor, 0.358, which may be used to convert the weights in Column (4), Table Z, from that for steel to that for aluminum).

The cubage (both transport and operating) (Columns 5 and 6) of the batch treatment systems are significantly and consistently less than that for the continuous flow treatment system.

The aggregate evaluation of the batch and continuous flow treatment systems involving the parameters shown in Columns (13) through (17) in Table Z, shows that the batch treatment systems are more desirable than the continuous flow treatment systems (see Column (18) and appropriate footnotes in Table Z).

The above evaluation favors the selection of a batch system for the treatment of the waste.

Comparison of Batch Treatment Systems 1.1 and 1.2 (Purification Method No. 1) in Table Z shows that,

- (1) System 1.2 requires 38% more transport cubage (Column 5) than System 1.1.
- (2) System 1.2 requires 65% more logistical support per month (Column 7) than System 1.1.

Comparison of Systems 1.1 and 1.2 from the standpoint of the other evaluation parameters shown in Table Z indicates that the two systems are otherwise comparable. It should also be pointed out that there are more unknowns involved in the operation and performance of the coal filter (System 1.2) than there are in the operation and performance of the diatomite filter (System 1.1). From the above evaluation, the selection of System 1.1 over System 1.2 is favored.

Comparison of Batch Systems 1.1 and 2.1 may be made from Table Z. At first glance, it appears from Columns (7), (8), (9), and (10), Table Z, that the logistical requirements and operating costs for Batch System 2.1 are appreciably greater than those for Batch System 1.1. However, as pointed out in Footnote (1) of Table Z, if the BOD specification for the renovated water is relaxed slightly, the logistical requirements and operating costs for System 2.1 (as well as for Systems 2.2 and 2.3) will be appreciably reduced. Relaxation of the renovated water BOD requirements in this specific instance is reasonable, and extenuating circumstances in support of this is presented below in order that Systems 2.1, 2.2, and 2.3 not be penalized unduly. It may be recalled from the laboratory investigation that 800 mg/l powdered activated carbon was required for Systems 2.1, 2.2, and 2.3 in order to meet the renovated water BOD requirements. A powdered activated carbon dosage of 400 mg/l resulted in a product water (before chlorination) of 12 mg/l BOD. Inasmuch as chlorine is a BOD reduction agent, it is possible that the product water after chlorination may meet BOD specifications when using 400 mg/l powdered activated carbon. (In this regard, it should be pointed out that BOD analyses of the product waters after chlorination were attempted but the difficulties and interferences encountered yielded results which were not reliable and not reproducible). Using the reduced powdered activated carbon dosage for System 2.1, a comparison of Systems 1.1

and 2.1 shows that the operating costs are comparable. However, from the standpoint of the logistical support requirements, those for System 2.1 are 88% (cubage) and 33% (weight) greater than those for System 1.1.

From the standpoint of total weight of package, transport cubage, operating cubage, and water recovery (Table Z, Columns 4, 5, 6, and 11, respectively) System 2.1 appears to have a slight but not overriding edge over System 1.1.

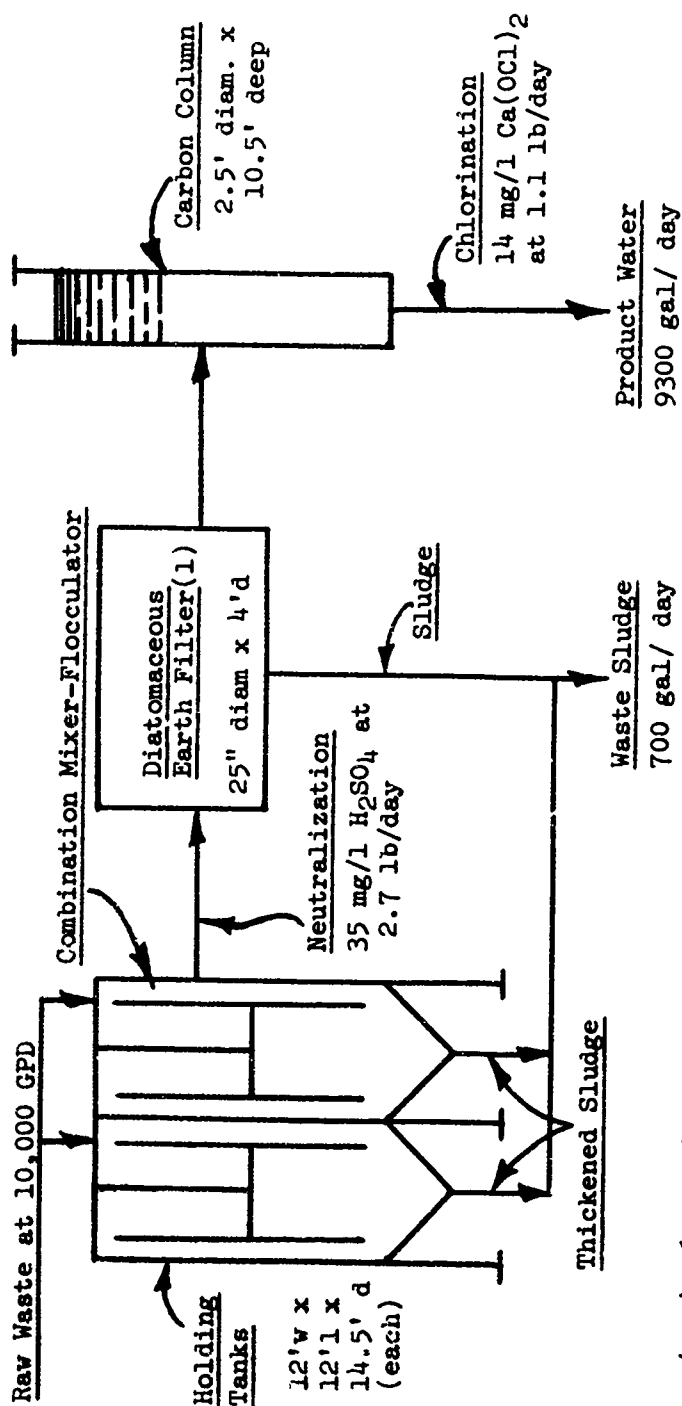
Comparison of Systems 1.1 and 2.1 from the standpoint of power requirements (Column 12, Table Z) shows that they are comparable.

Comparison of Systems 1.1 and 2.1 from the standpoint of the evaluation parameters in Columns 13 through 17, Table Z, as summarized in Column 18, Table Z, indicates a slight edge for System 2.1 (rating of 10) over System 1.1 (rating of 12). However, the advantage is felt to be negligible. For example, in regard to odor control provisions, Column 17, Table Z, Systems 2.1, 2.2, and 2.3 have inherently better odor control because powdered activated carbon (an excellent odor control agent) is used at the beginning of the treatment process, whereas in System 1.1 the treated waste does not come into contact with activated carbon until near the end of the treatment process (see Figures 12 and 10, respectively). However, System 1.1 has only one additional exposed surface (from which odors may be emitted) than System 2.1, and that is the carbon column surface, which may be effectively covered to eliminate odors, if necessary.

Another important consideration in the comparison of Systems 1.1 and 2.1 is the flexibility of the two systems. It is felt that System 1.1 has greater flexibility at an advanced base in that it may be converted to System 2.1 simply by shipping in powdered activated carbon. It is more difficult to convert System 2.1 to System 1.1 because a carbon column component would be involved in the conversion (in this regard, the difficulty may be reduced because the carbon column was intentionally designed to employ a 30 inch diameter nominal size pipe, which may be readily available).

The above evaluation and discussion favors the selection of Batch System 1.1 for the treatment of the waste. It is recommended that Batch System 1.1 be adopted for treating the raw waste described in this contract.

FIGURE 10
Purification Method No. 1
Batch Systems 1.1 and 1.2



$Fe_2(SO_4)_3 \cdot 6H_2O$ - 400 mg/l = 33.4 lb/day
CaO - 175 mg/l = 14.6 lb/day

Chemicals added, mixed, flocculated, and thickened in holding tanks

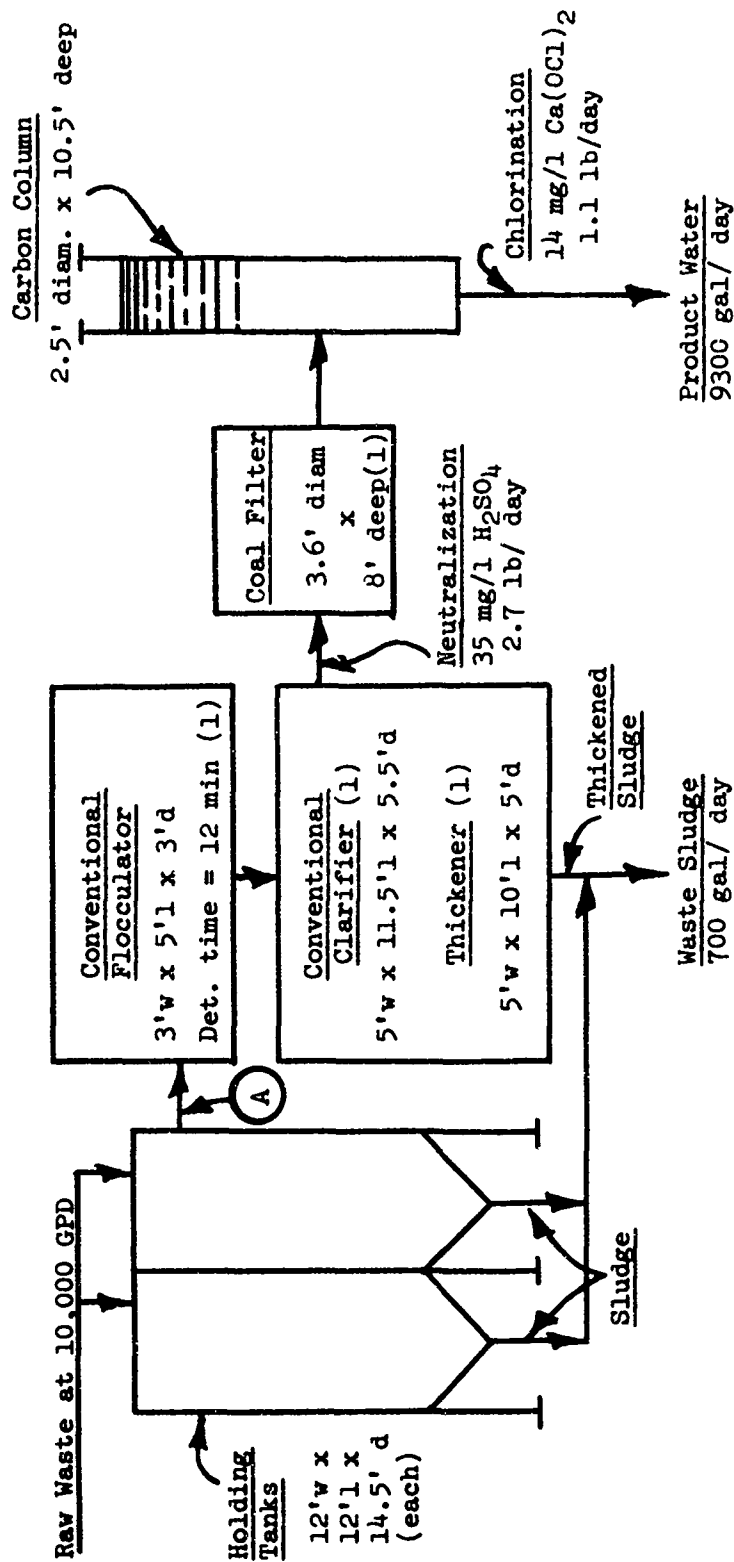
Flocculation - 12 minutes

Sedimentation - 60 to 90 minutes

Thickening - 2 hours

(1) Batch system 1.2 employs a coal filter in place of diatomaceous earth filter. Dimensions of coal filter = 3.6' diam. x 8.0' deep

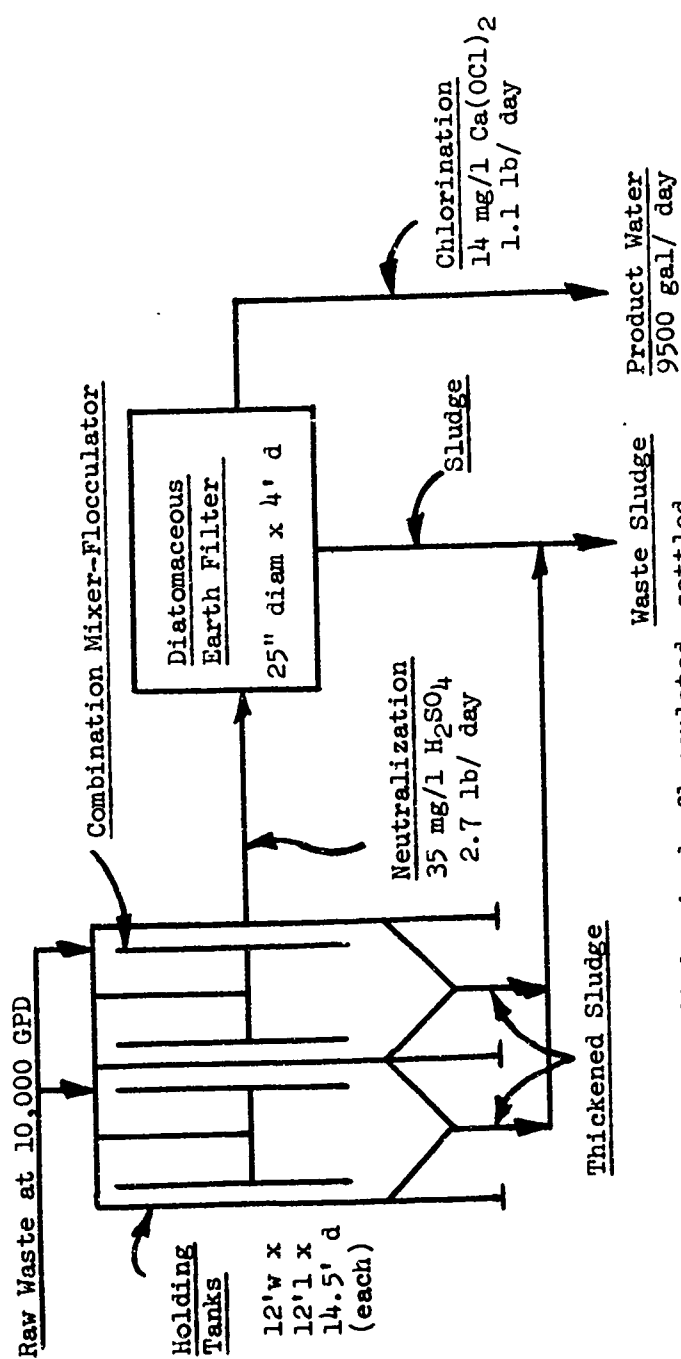
FIGURE 11
Purification Method No. 1
Continuous Flow Systems 1.3 and 1.4



(1) 1500 gph ERDLator substituted for these components in System 1.4
Dimensions of ERDLator = 8.2'w x 16.9'l x 7.3'd

(A) Following materials added at this point:
 $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$ @ 400 mg/l (33.4 lb/day)
 CaO @ 175 mg/l (14.6 lb/day)

FIGURE 12
Purification Method No. 2
Batch System 2.1

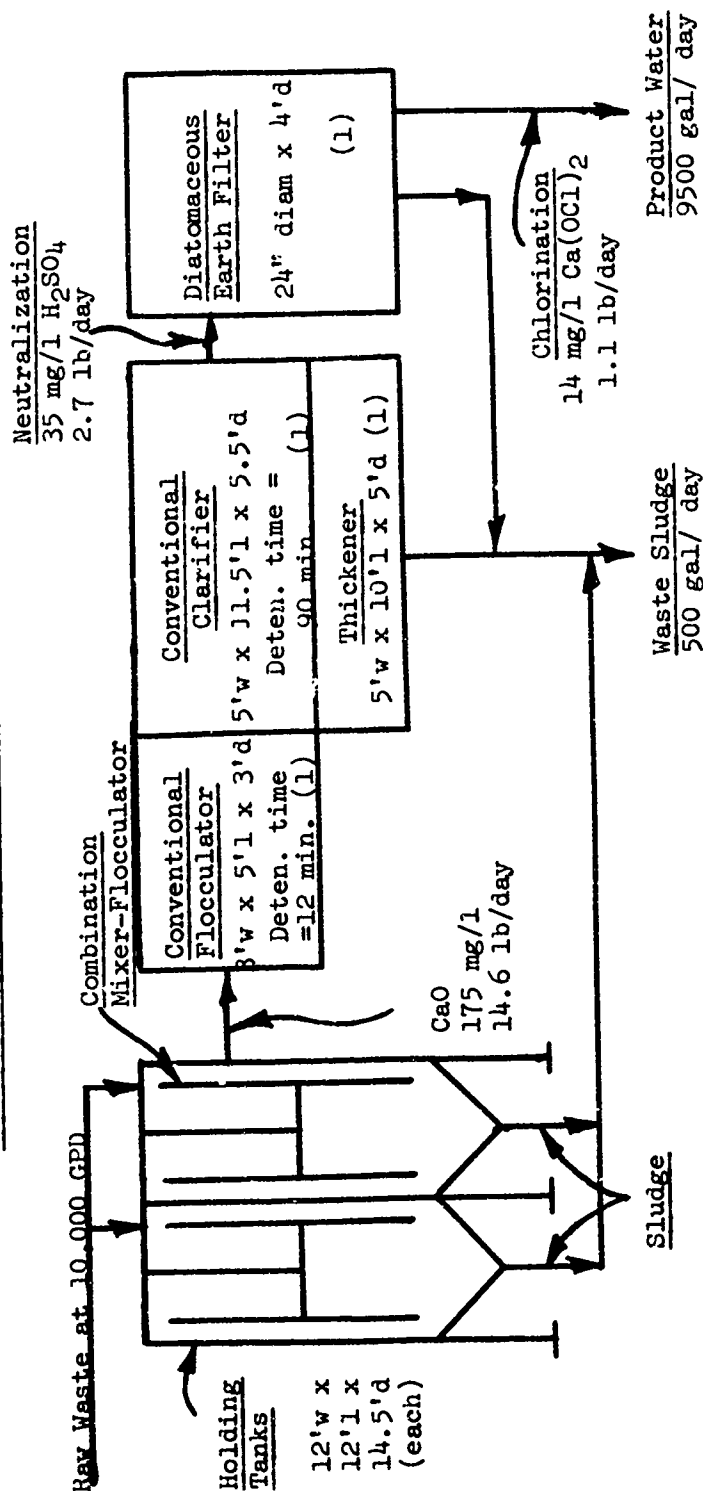


Following chemicals added, mixed, flocculated, settled, and thickened in the holding tanks:

$Fe_2(SO_4)_3 \cdot 6H_2O$ - 400 mg/l = 33.4 lb/day
Activated Carbon - 800 mg/l = 66.8 lb/day
30 minute flocculation period

CaO - 175 mg/l = 14.6 lb/day
12 minute flocculation period
60-90 minute settling period
2 hour thickening period

FIGURE 13
Purification Method No. 2
Continuous Flow Systems 2.2 and 2.3



Following chemicals added and mixed in

holding tanks:

$Fe_2(SO_4)_3 \cdot 6H_2O$ - 400 mg/l = 33.4 lb/day

Activated Carbon - 800 mg/l = 66.8 lb/day

30 minute mixing period

(1) These components replaced by a
 1500 gph ERDLator in System 2.3.
 ERDLator dimensions = 8.2'w x
 16.9'l x 7.3'd

TABLE Z - COMPARISON OF THE VARIOUS PROPOSED INTEGRATED WAS

(1) Treatment System	(2) References Figure Number	(3) Appendix Section	(4)* Total Package Weight	(5) Cubage (cubic feet) Transport	(6) Operating	(7) Logistical Support lb/month	(8) Support cu ft/mo	(9) Operating Costs \$/day	(10) Costs/ 1000 gal	(11) Water Recovery %	(12) Power Requirements (kilowatts)
1.1	10	H	11,527 lb	178.5	4,265.0	2,109	76.5	3.93	42	93%	6.15
1.2	10	I	11,413 lb	246.0	4,332.0	3,477	82.5	3.81	41	93%	4.85
1.3	11	J	13,889 lb	521.0	5,094.0	3,477	82.5	3.81	41	93%	1.87
1.4	11	K	18,727 lb	1,156.0	5,232.0	2,109	76.5	3.93	42	93%	2.42
2.1 (1)	12	L	10,643 lb	133.5	4,223.0	3,790	226.5	6.54	69	95%	6.40
2.2 (1)	13	M	13,119 lb	408.5	4,985.0	3,790	226.5	6.54	69	95%	6.60
2.3 (1)	13	N	17,813 lb	1,100.0	5,176.0	3,790	226.5	6.54	69	95%	5.00

* Weights shown in this column are for components fabricated of steel.
If aluminum is used as the material of construction, multiply figures
in this column by factor of 0.358 to obtain approximate package weight.

(1) If a renovated water BOD of 12 mg/liter (slightly higher than specified in the contract) may be tolerated, then the logistical support for these systems can be reduced to 2,800 lb/month and 144 cu ft/month respectively. The operating costs will correspondingly be reduced to \$3.76/day and 40 cents/1000 gallons of product water.

NOTE: E
b
a

** C
f
a

THE VARIOUS PROPOSED INTEGRATED WASTE TREATMENT SYSTEMS

(10) ing Costs Cents/ 1000 gal	(11) Water Recovery %	(12) Power Requirements (kilowatts)	(13) Operational Skills Required	(14) Maintenance Requirements	(15) Complexity of Assembly	(16) Availability of Materials	(17) Odor Control Provisions	(18)** Sum of Columns (13) through (17)
42	93%	6.15	2	2	4		4	12
41	93%	4.85	1	1	5		5	12
41	93%	1.87	4	4	6		6	20
42	93%	2.42	5	6	1		7	19
69	95%	6.40	3	3	3		1	10
69	95%	6.60	6	5	7		2	20
69	95%	5.00	7	7	2		3	19

NOTE: Evaluation parameters in Columns (13) through (17) inclusive are rated on a 1 to 7 basis, with 1 representing the most desirable system for the parameter involved, and 7 representing the least desirable system for that same parameter.

** Column (18) shows a gross evaluation of the systems involving the individual parameters shown in Columns (13) through (17). System desirability increases as the total indicated decreases.

4.5 Conclusions

- (1) The treatment characteristics of the synthetic waste tested varied with the age of the waste. Difficulty in treating the raw waste increased with increasing age.
- (2) Some of the solids in the test raw waste settled rapidly. These solids were removed from the waste in laboratory detention periods of five minutes or less. This sludge volume is less than 2 gal/1000 gallons raw flow.
- (3) Treatment of the waste without chemicals was not satisfactory.
- (4) The literature survey indicated that the most applicable waste purification methods for treatment of the combined wastewater were chemical treatment, adsorption, and chemical oxidation.
- (5) The laboratory investigation showed that a combination of chemical treatment and adsorption was necessary for satisfactory purification of the waste. Satisfactory results in the removal of suspended matter and soluble organic matter were achieved using ferric sulfate, lime, and activated carbon treatment. This method of treatment worked well for both fresh and aged samples of waste.
- (6) Adsorption with activated carbon is necessary to reduce BOD, COD, color, odor and surfactant contents to acceptable levels.
- (7) Filtration through diatomaceous earth is necessary to prevent a build-up of fine particles and a gradual increase in BOD, COD, and turbidity as the renovated water is reused. Filtration should precede carbon adsorption if a continuous carbon adsorption column is used and should follow purification where ferric sulfate, powdered activated carbon, and lime are used for purification. Use of the carbon column as a combined filter and adsorber is not recommended because of the decreased adsorption capacity observed.
- (8) The prescribed laboratory treatment procedure followed in treating the waste using ferric sulfate as $\text{Fe}_2(\text{SO}_4)_3 \cdot 6\text{H}_2\text{O}$, lime (as CaO), and activated carbon (powdered or granular) is shown below. Two treatment processes are described.

a. Combined chemical treatment and powdered carbon adsorption:

- 1) Settle ten minutes to remove heavy solids.
- 2) Add 400 mg/l ferric sulfate and mix to disperse.
- 3) Add 800 mg/l activated carbon and mix for thirty minutes.
- 4) Add 175 mg/l lime and mix to disperse.
- 5) Flocculate for six minutes.
- 6) Settle for a thirty minute detention period.
- 7) If necessary, reduce the effluent pH to 9.0 with acid.
- 8) Filter through diatomaceous earth.
- 9) Chlorinate with 14 mg/l calcium hypochlorite (70% available chlorine).

b. Treatment with ferric sulfate and lime followed by carbon column adsorption:

- 1) Settle ten minutes to remove heavy solids.
- 2) Add 400 mg/l ferric sulfate and mix to disperse.
- 3) Add 175 mg/l lime and mix to disperse.
- 4) Flocculate six minutes.
- 5) Settle for thirty minutes.
- 6) If necessary, reduce effluent pH to 9.0 with acid.
- 7) Filter through diatomaceous earth.
- 8) Pass through carbon adsorption column for an approximate contact period of six minutes.
- 9) Chlorinate with 14 mg/l calcium hypochlorite (70% available chlorine).

In the two processes described above, settling rates ranged from 0.08 to 0.18 fpm. Settled sludge volumes were 70 to 140 gal/1000 gal after a thirty minute detention period. Further compaction occurred on extending the sludge detention time. In both processes, final effluents met the renovated water specifications.

- (9) Seven integrated waste treatment systems were proposed for consideration in the selection of a system for treating the raw waste using the purification methods outlined in Conclusion No. 8. Three of the proposed systems were batch treatment systems and four of the proposed systems were continuous flow treatment systems.

An evaluation of the proposed treatment systems indicated that a batch treatment system would be more desirable than a continuous flow treatment system.

4.6 Recommendations

- (1) It is recommended that the purification methods developed and described in Conclusion No. 8 be adopted for treating the raw waste described in this contract.
- (2) It is recommended that Batch Treatment System 1.1 (shown in Figure 10), consisting of chemical treatment, diatomite filter polishing, and carbon column adsorption, be selected as the prototype wastewater treatment unit to be designed, fabricated and tested in the next phase of the work to be performed under this contract.

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APPENDIX A: CLARIFICATION TESTS AND RATE OF SEPARATION

The rate of separation of the suspended solids from a waste is useful in the design of industrial waste treatment equipment. Rate of separation data may be conveniently obtained in the laboratory from treatment tests performed on the waste in question. The treatment processes which will be considered are dissolved-air flotation and sedimentation. Generally, the procedure used in obtaining rate of separation data is to observe the solids-liquid interface and to record its travel with time.

A.1 Dissolved-Air Flotation

In the tests using dissolved-air flotation, the rate of rise of the major portion of the solids is recorded. At times the solids-liquid interface may be vague and good judgment may have to be exercised in following this interface. Care should be taken to avoid following the interface formed by the air bubbles alone. In general, this interface lags behind the solids-liquid interface.

A suggested procedure for the performance of laboratory flotation tests and the equipment needed is as follows:

1. Equipment

- a. Flotation pressure cell.
- b. Graduated Cylinder of one liter capacity containing an effluent sampling arm.
- c. Tire pump or source of compressed air.
- d. Gooch crucibles for suspended solids determinations.
- e. Stop watch.

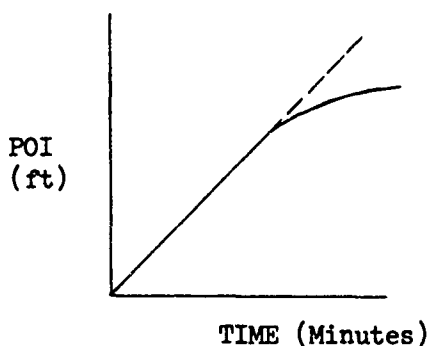
2. Flotation Test Procedure

- a. Record waste temperature, pH, operating pressure, recycle rate, and flotation detention time.
- b. Record rate of separation data. The following form is suggested in obtaining the rate of separation data.

<u>Time</u> <u>(min.)</u>	<u>Volume</u> <u>(ml)</u>	<u>POI (Position of Interface)</u> <u>(feet)</u>
0	0	0
1	100	0.115
2	350	0.411
3	500	0.589
4	650	0.766
5	800	0.946
6	950	1.122
7	950	1.122
8	950	1.122

The ultimate data desired is the position of the interface at various intervals throughout the test. The column above labeled "Volume" is used as a convenient means of obtaining the position of the interface at any given time. For example, in the hypothetical case shown above, a liter graduate was used in the test. At the beginning of the test the solids-liquid interface is at the bottom of the graduate or at zero volume. As flotation progresses, the solids-liquid interface moves progressively up the height of the graduate. The position of the interface at any given time may be conveniently obtained using the appropriate graduation mark on the liter graduate as a reference. After the flotation test, the graduation marks may be converted to feet of height by actual measurement.

The data obtained are plotted using Time as the abscissa and POI in feet as the ordinate.



The slope of the straight line portion of the curve represents the rate of particle rise.

- During flotation it should be noted whether settling of solids took place. Note observation.
- c. Record the floated scum volume obtained immediately before obtaining a sample of effluent.
 - d. Obtain sample of effluent five minutes after flotation is started for the appropriate analyses. Repeat the flotation and obtain another sample of effluent for analysis after an eight minute detention period.
 - e. If possible, a small portion of the floated scum should be analyzed for total solids content.

A.2 Sedimentation

In the tests using sedimentation, the subsidence rate of the major portion of the solids is desirable. In many cases, this may be obtained by following the solids-liquid interface formed. A suggested procedure for the performance of a laboratory settling test and the equipment needed is as follows:

1. Equipment

- a. Graduated cylinder of one liter capacity.
- b. Gooch crucibles for suspended solids analysis.
- c. Stop watch.

2. Settling Test Procedure

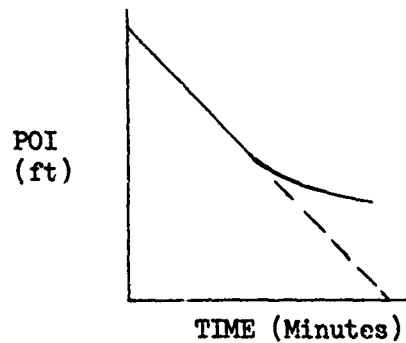
- a. Record waste temperature, pH and settling detention time.
- b. Record rate of separation data. A detention time of 30, 60, or 90 minutes may be used, depending upon the relative subsidence rate of the solids.

<u>Time (min.)</u>	<u>Volume (ml)</u>	<u>POI (Position of Interface) (feet)</u>
0	1000	1.146
1	950	1.089
2	900	1.031
3	850	0.980
4	800	0.923
5	750	0.865
8	600	0.694
10	500	0.584
12	400	0.469

<u>Time</u> <u>(min.)</u>	<u>Volume</u> <u>(ml)</u>	<u>POI (Position of Interface)</u> <u>(feet)</u>
15	200	0.240
20	175	0.213
25	175	0.213
30	175	0.213

A hypothetical example of data obtained from a settling test is tabulated above. The column labeled "Volume" is used as a convenient means of obtaining the position of the interface at any given time. At the beginning of the test the solids-liquid interface is at the top of the graduate or at 1000 ml volume. As the solids settle, the solids-liquid interface moves progressively down the height of the graduate. The position of the interface at any given time may be conveniently obtained using the appropriate graduation mark on the liter cylinder as a reference. After the settling test, the graduation marks may be converted to feet of height by actual measurement.

The data are plotted using Time as the abscissa and POI in feet as the ordinate.



The slope of the straight line portion of the curve represents the subsidence rate of the solids.

During the settling test, it should be noted whether a significant amount of solids floated. Note observation. It should be noted that some solids may be floated by the entrainment of air produced by the original shaking of the sample prior to the test. The solids in the sample should be suspended prior to the test in such a manner that no air is entrained.

- c. Record the settled sludge volume after 30, 60, and 90 minutes.
- d. Obtain sample of effluent and determine suspended solids content. Determine pH if chemical treatment is used. The effluent may be obtained by siphon.
- e. If possible, a small portion of the settled sludge may be analyzed for total solids content.

In some cases it is recognized that a solids-liquid interface may not exist or be readily apparent. In these particular instances, it is necessary to obtain the allowable suspended solids content in the effluent to be discharged. Settling tests are then conducted in which the detention time is varied. Effluent samples are obtained at the end of the selected detention times and analyzed for suspended solids. That detention time which produces an effluent containing a suspended solids content equal to or less than the allowable suspended solids content is used as a basis for the design of the sedimentation basin.

APPENDIX B: REX CHAINBELT INCORPORATED

FLOAT-TREAT DEMONSTRATION KIT PROCEDURE

The recirculation ratio is the ratio of the volume of effluent recycled to the volume of raw waste to be clarified. Assume that a recirculation ratio of 0.33/1 is to be tried.

1. Place 750 ml of a representative sample of the waste in a one liter graduated glass cylinder.
2. Fill the Float-Treat Pressure Cell approximately one-half full with liquid. (It is desirable that the operation of the Float-Treat Pressure Cell closely simulate the recirculation of effluent as used in the Float-Treat Flotation System. The returned effluent (recycle water) may be developed by repeated flotation of several different portions of raw waste. After the recycle water has been developed and used in the flotation tests, samples may then be withdrawn for chemical analyses. If recycle water is not developed and tap water is used, it is recommended that a few milliliters of raw waste or a pinch of garden variety dirt be added to the tap water. Addition of the raw waste may furnish sufficient suspended solids around which air bubbles may form.
3. Secure the cover gasket and cover of the Float-Treat Cell, making certain all the valves are closed.
4. Inject air into the Cell using compressed air or by means of an ordinary tire pump until a pressure of 40 psig is attained.
5. Shake the Cell vigorously for thirty seconds, then test for formation of air bubbles and remove air from the discharge tube.
6. Release 250 ml of the liquid which has been pressurized into the graduated cylinder. The volume of liquid in the graduated cylinder then totals 1000 ml (750 ml raw and 250 ml pressurized). The ratio of volumes of recycle water to the raw waste is termed the recycle ratio. This ratio is expressed in percent and is termed the recycle rate. Thus, the recycle rate used in this test was 33 percent. The most suitable recycle rate can be determined by repeated tests by varying rates of recycle and usually is not less than 20 percent and no more than 50 percent. To facilitate the introduction of the air-charged recycle water to the graduated cylinder, a rubber tube may be connected to the petcock on the pressure cell. After clearing the rubber tube of air, (allow some liquid to escape through the tube by opening the petcock. Sufficient liquid should be removed until it has a milky appearance) the air-charged recycle water is

introduced through the rubber tube into the graduated cylinder. The end of the tube should be placed near the bottom of the cylinder. The air bubbles attach themselves to the suspended material and rise through the liquid in a manner similar to that in the Float-Treat Flotation System.

7. Allow the contents of the graduated cylinder to come to rest and observe the flotation. Allow sufficient time for the rising solids to come to the surface of the liquid. Usually ten minutes will be sufficient time for the flotation to be completed.
8. After the flotation is completed, a sample of the raw waste and treated waste should be obtained for analysis. The treated waste should be carefully withdrawn from the graduated cylinder either through the use of the sampling arm installed in the side and near the bottom of the cylinder or through the use of a siphon inserted in the cylinder. The sampling side arm may contain some raw waste which was not exposed to flotation. Sufficient liquid should be withdrawn to complete the desired analysis.
9. Should chemical flocculation with flotation be desired, the chemical may be added into the raw waste after Step No. 1 is completed. The contents of the graduate are then vigorously agitated for 10 to 15 seconds to disperse the chemical uniformly throughout the waste (see Flocculation Test Procedure). The quick mix is then followed by flocculation. Under appropriate conditions, a floc may be formed by gentle agitation of the waste after the chemical is added. A long stirring rod may be used for this purpose. Enough time for flocculation should be allowed before introducing the air-charged recycle water.

In flotation of a particular waste, it is quite possible that the test using the recirculation ratio of 0.33/1 may not yield the best results. It may be that some other recirculation ratio would yield the results needed to work in with the economy of a final plant design and effluent requirements. Therefore, the tests described above may be repeated with other recirculation ratios until the optimum ratio is obtained. In these tests the values shown in Steps 1 and 6 will be changed accordingly.

When running flotation tests in the Rex Float-Treat demonstration kit, the observed rate of rise of the major portion of the solid material should be recorded. (See Clarification and Rate of Separation test procedure). This value can be recorded in terms of inches per minute and will be used in determining the full-scale plant requirements.

In order to insure the validity of results obtained, care should be taken that representative samples of waste are obtained before running tests.

APPENDIX C: ANALYTICAL INSTRUMENTS AND APPARATUS LISTING

Hellige Aqua Tester
Hellige Incorporated
877 Stewart Avenue
Garden City, New York

Hellige Turbidimeter, Serial No. 5666
Hellige Incorporated
877 Stewart Avenue
Garden City, New York

Coleman Universal Spectrophotometer
Model Number 11
Coleman Electric Company
Maywood, Illinois

pH Meter, Model N
Beckman Instruments Incorporated
South Pasadena, California

Analytical Balance, Type H5
Mettler Instruments Corporation
Hightstown, New Jersey

BOD Incubator, Labline No. 3554B
Labline Instruments Incorporated
Melrose Park, Illinois

Conductivity Bridge
Model RC16B2
Industrial Instruments Incorporated
Cedar Grove, New Jersey

Incubator
Model 1483
Precision Scientific Company
Chicago, Illinois

pH Meter
Beckman Model H-2
Beckman Instruments Incorporated
Fullerton, California

APPENDIX D: CARBON ISOTHERM TEST PROCEDURE

The carbon isotherm procedure followed is the one outlined by Fornwalt and Hutchins in CHEMICAL ENGINEERING, VOL. 73, April 11th, 1966, page 179. This procedure consists of the following steps:

1. Pulverize the activated carbon to minus 200 mesh.
2. Add various weights of carbon to a constant volume of chemically treated effluent. Shake the mixture for 60 to 90 minutes.
3. Remove the carbon from the waste by filtration through S&S 597 filter paper.
4. Analyze the waste for COD and/or BOD.
5. Plot the weight COD (or BOD) adsorbed per unit weight of carbon against COD (or BOD) remaining in the waste on log-log paper. Extrapolation to the initial COD (or BOD) value indicates the maximum COD (or BOD) that may be adsorbed by the carbon tested.

APPENDIX E: BENCH SCALE CARBON COLUMN TESTS

E.1 Apparatus (See Figure 14)

- a. Three foot length of plastic tubing, one inch inside diameter.
- b. Sigma-motor pump.
- c. Ring stand and clamps.
- d. Rubber stopper with glass tee and screen.

E.2 Procedure

The plastic tubing was placed on the ring stand, the bottom stopper and screen inserted and the column filled one-half full of distilled water. The carbon, which had been degassed by boiling in distilled water, was spooned into the column. The liquid level in the column was kept above the carbon level to prevent air entrapment. After the desired depth of carbon was attained, 4 to 5 bed volumes of distilled water were put through the column to wash out the fines before the column was put on line. A glass tube connected to the bottom tee allowed a direct measurement of headloss through the bed. A bed depth of 24 inches was used during the tests and a surface loading of about 2.5 gpm/ft². This represented a flow rate of 52 ml/min and a contact time of six minutes based on bed volume of carbon. The carbon used was Calgon (Filtrisorb 300) 8 x 30 mesh selected from the isotherm tests described in Appendix D.

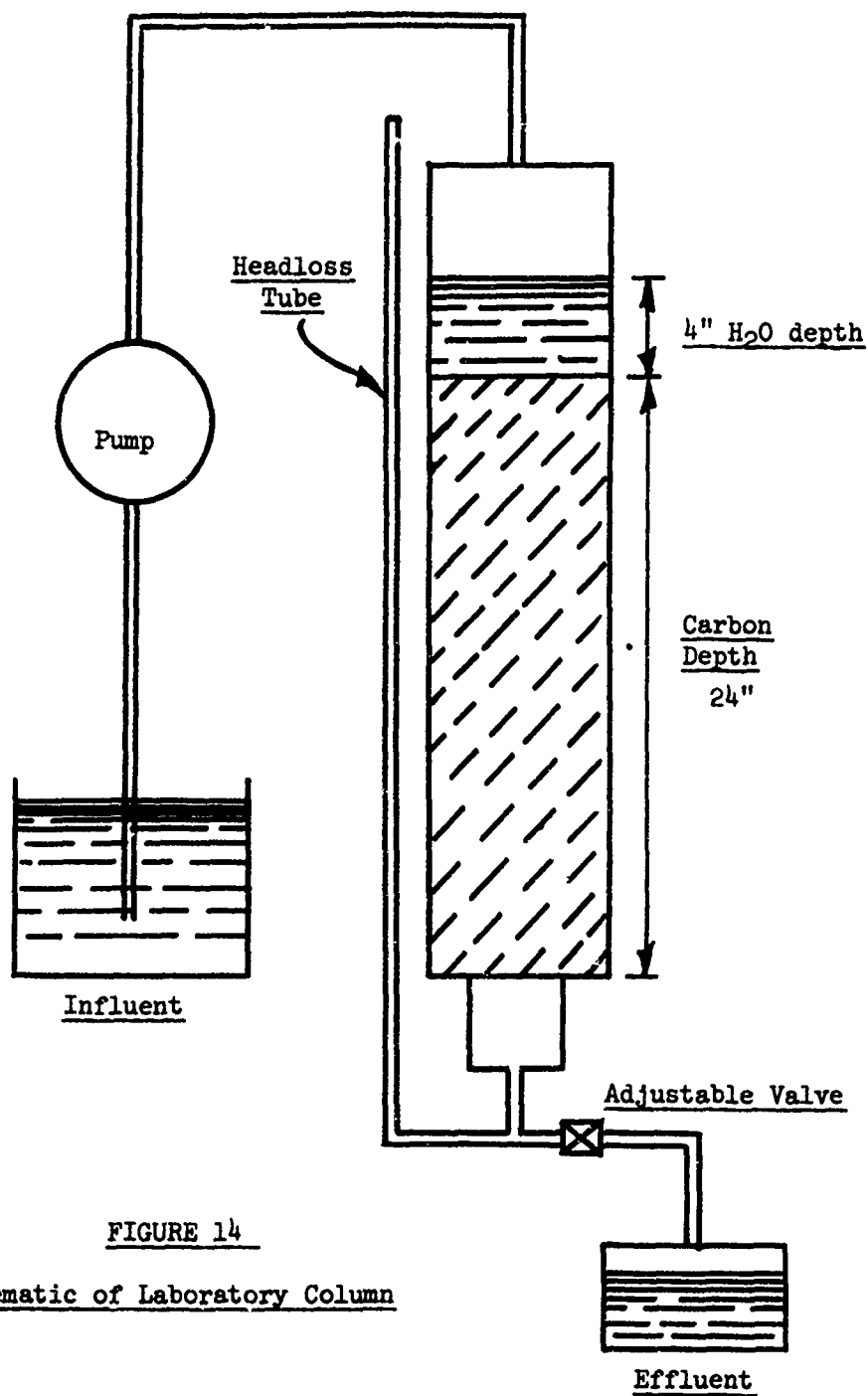


FIGURE 14
Schematic of Laboratory Column

APPENDIX F: DETERMINATION OF PROPER SEED VOLUME FOR BOD TEST

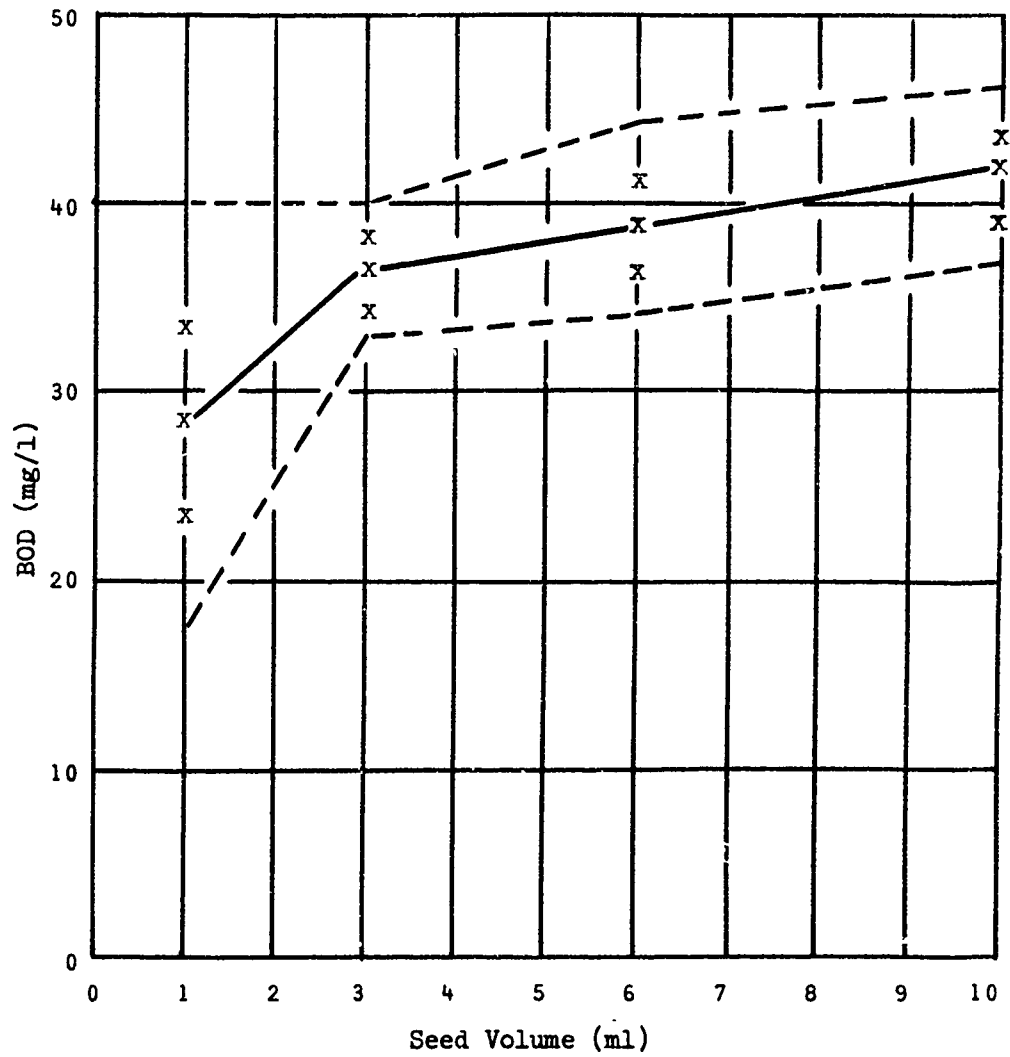
Tests were performed to determine the proper amount of seed to be used in performing BOD analyses on this wastewater. Tests were conducted on a sample of raw waste after filtration through an S&S 597 filter paper. This waste sample had a COD of 72 mg/l. The seed tested was fresh raw sewage from the Milwaukee Sewage Treatment Plant which had been allowed to settle for one day at 20°C. Volumes of seed tested were 1, 3, 6 and 10 ml per 300 ml BOD bottle. The samples were incubated at 20°C for five days. The measured BOD values and the 95% confidence interval of the mean BOD for each volume of seed tested are listed below.

<u>Seed Volume, ml</u>	<u>BOD Value, mg/l</u>	<u>Mean BOD, mg/l</u>
1	24.7, 33.5, 28.5	28.9 ± 11.0
3	36.3, 37.7, 34.8	36.3 ± 3.6
6	36.4, 40.3, 39.6	38.8 ± 5.2
10	41.8, 39.4, 42.8	41.3 ± 4.3

The data points, the mean values, and the confidence bands for the mean values are plotted in the attached figure. It is apparent that a seed volume of 3 ml per bottle resulted in the data with the least variation. In addition, the effect of seed volume on measured BOD is relatively less at seed volumes of 3 ml or more.

FIGURE 15

Graph for BOD Seed Volume



Dashed line = 95% confidence band for mean BOD
Solid line = Mean BOD
x = data points

APPENDIX G: ANALYTICAL DATA
RAW WASTE

DATE	6/15	6/19	6/20	6/21	6/24	6/26	6/29	7/11	7/12	7/14	7/18	7/19	7/25	7/2
Mixed Raw														
Total Sol., mg/l							749			740		760	685	
Sus. Sol., mg/l							193			161		233	166	
COD, mg/l							356			330		365	415	
BOD, mg/l							138			89				
LAS, mg/l														
pH								7.8		8.6			8.15	
Cond., umhos/cm							520			444				
Soluble Portion														
Total Sol., mg/l	523	438	295	548	507	567	549	576	562	538	552	559	477	
COD, mg/l	148	152	138		157	99	121		147	149	158		156	
BOD, mg/l					50		42	24		31		34		
LAS, mg/l	24													
pH									8.7	8.5	8.6			
Cond., umhos/cm	510	8.75	8.9	8.6		8.8	8.7			416				
Color, units		5	15			10	505	20	20	15		5/10	15	
After 10 min. Settling														
Total Sol., mg/l		636	389		647	701	722							
Sus. Sol., mg/l		162	0			168	183							
COD, mg/l		289	177		284	210	322							
BOD, mg/l					97		112							
LAS, mg/l							33							
pH		8.75	8.9			8.8	8.7							
Cond., umhos/cm							505							

APPENDIX G: ANALYTICAL DATA
RAW WASTE

	6/24	6/26	6/29	7/11	7/12	7/14	7/18	7/19	7/25	7/27	8/2	8/7	8/15	8/18	8/22	8/24	9/2	Average Values
21	--	--	749	--	--	740	--	760	685	--	708	--	--	734	--	845	--	746
	--	--	193	--	--	161	--	233	166	--	160	--	--	--	--	230	--	190
	--	--	356	--	--	330	--	365	415	--	376	--	--	380	--	373	--	371
	--	--	138	--	--	89	--	--	--	--	--	--	--	0	--	134	--	120
	--	--	--	--	--	--	--	--	--	--	28	--	--	41	--	32.5	--	34
	--	--	8.7	7.8	--	8.6	--	--	3.15	--	8.4	--	--	--	--	8.6	--	8.37
	--	--	520	--	--	444	--	--	--	--	--	--	--	--	--	--	--	482
8	507	567	549	576	562	538	552	559	477	--	500	584	--	562	525	515	795	534
	157	99	121	--	147	149	158	--	156	--	124	156	--	146	120	155	158	143
	50	--	42	24	--	31	--	34	--	36	--	--	--	42	--	--	42	38
	--	--	--	--	--	--	--	--	--	--	20	--	--	--	--	--	--	22
6	--	8.8	8.7	--	8.7	8.5	8.6	--	--	--	--	--	--	--	8.7	8.6	8.7	8.68
	--	--	505	540	--	416	--	--	--	--	500	--	--	--	--	--	--	494
	--	10	--	20	20	15	--	5/10	15	--	15	--	--	--	10	--	5/10	12.6
	647	701	722	--	--	--	--	--	--	--	--	--	--	--	--	--	--	676
	--	168	183	--	--	--	--	--	--	--	194	--	--	--	--	--	--	176
	284	210	322	--	--	--	--	--	--	--	--	--	--	--	--	--	--	276
	97	--	112	--	--	--	--	--	--	--	--	--	--	--	--	--	--	105
	--	--	33	--	--	--	--	--	--	--	--	--	--	--	--	--	--	32
	--	8.8	8.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.78
	--	--	505	--	--	--	--	--	--	--	--	--	--	--	--	--	--	505

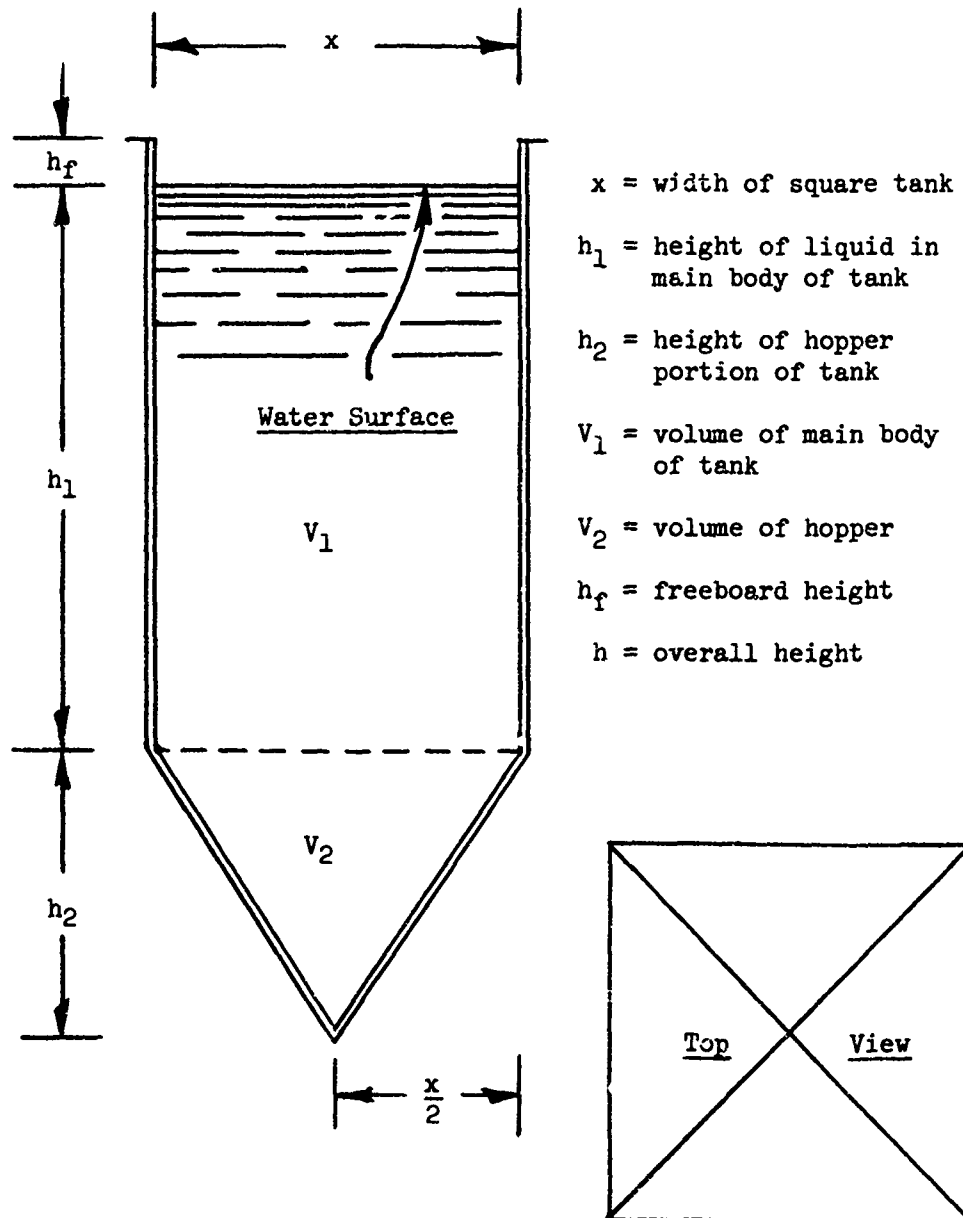
APPENDIX 4: DETAILED COMPONENT DESIGN

H.1 Treatment System 1.1

H.1.1 Accumulation and Blending Tanks

1. Assume at least two tanks
2. Assume effective capacity each tank is 10,000 gal =
1337 ft³
3. Tank configuration (see Figure 16)
4. Sizing calculations
 - let $x = 12'$ (1)
 - let $h_2 = 6'$ (2)
 - then:
 - $V_2 = (1/3)(x^2)(h_2)$ (3)
 - $V_2 = 1/3 (12')^2(6) = 288 \text{ ft}^3$ (4)
 - $V_1 = 1337 - V_2 = (x^2)(h_1)$ (5)
 - $1337 - 288 = (12')^2(h_1)$ (6)
 - $h_1 = 7.28 \text{ ft}$ (7)
 - let $h_f = 1.22 \text{ ft}$ (8)
 - $h = h_f + h_1 + h_2$ (9)
 - $h = 1.22 + 7.28 + 6 = 14.5 \text{ ft}$ (10)
5. Weight calculations
 - Assume 3/16" steel at 500 lb/ft³ (11)
 - Weight of steel
 - Main body = $(4)[(12')(8.5')(3/16'')(1/12)](500 \text{ lb/ft}^3) = 3187 \text{ lbs}$ (12)
 - Hopper = $(4)[(6')(\sqrt{2})(12')](3)(500 \text{ lb/ft}^3)/384 = 1590 \text{ lbs}$ (13)
 - Sub Total = 4777 lbs
 - Connections and miscellaneous at .1 x Sub Total = 478 lbs (14)
 - Weight each tank = 5255 lbs (15)
 - Using common wall construction (1 common wall)
 - Second tank weight = 5255 lbs - weight of (1) wall (16)
 - Weight of wall = $(12')(8.5')(3/16'')(1/12)(500 \text{ lb/ft}^3) = 797 \text{ lbs}$ (17)
 - Weight of second tank = 4458 lbs (18)
 - Total weight of (2) tanks = 9,713 lbs (19)
 6. Calculation of cubage in transport and operation (both tanks)
 - (a) Operation cubage
 - plan area is 12' x 24' (20)
 - Volume = 12' x 24' x 14.5' = 4176 ft³ (21)

FIGURE 16
Schematic of Accumulation-Blending Tank



- (b) Shipping cubage (both tanks)
 (Based on plate sections erected in field)
 Assume plate sections (must be cut in half
 to pass loading door of C 130 E)
 Main sections (7 each)
 $\text{Volume} = (7)(8.5)(12')(3/16'')(1/12) = 11.1 \text{ ft}^3$ (22)
 Hopper sections (8 each)
 $\text{Volume} = (8)[\sqrt{2} (6')(12')1/2](3/16'')(1/12) =$
 6.4 ft^3 (23)
 Miscellaneous components
 i.e. angles, struts and bolts for connection of
 sections - packing materials - volume of liner
 $\text{Total Volume} = 75 \text{ ft}^3$ for miscellaneous items (24)
 $\text{Total shipping volume} = 100 \text{ ft}^3$ (25)
 NOTE: Since two holding tanks are proposed
 for each system, the estimate of weight and
 cubage should have no effect on the final
 selection of a system. A detailed design of
 the holding tanks will be performed in Phase
 II, and various shapes and materials will be
 considered. The outcome of this design could
 effect to a great extent the weights and cubages
 estimated herein for comparison purposes.
7. Summary accumulation and blending tanks
 (a) Tank configuration shown in Figure 15
 (b) Critical dimensions (refer to Figure 15)
 $h = 14.5'$ $h_1 = 7.28'$ $h_2 = 6'$
 $x = 12'$ $h_f = 1.22'$
 $\text{Effective volume} = 10,000 \text{ gallons}$
 (c) Shipping weight = 9713 lbs (26)
 (d) Operating cubage = 4176 ft^3 (27)
 (e) Shipping cubage = 100 ft^3 (28)

H.1.2 Coagulated Water Filter

1. Diatomaceous earth-type filter
 Average rate necessary 20 - 30 gpm
 Use 50 gpm filter with rate controller to
 reduce amount of backwashing necessary
 (reference TM 5-2104)
 $\text{Volume} = [(2')^2 \pi (4')] / 4 = 12.5 \text{ ft}^3$
 Weight = 310 pounds
 Use one filter

Total weight 310 lbs + motor, pump and accessories (29)

Vol operate 12.5 ft³ (30)

Vol ship 12.5 ft³ (31)

2. Power requirements

$$Hp = \frac{(50 \text{ gpm})(40 \text{ psi})(2.31)}{(3960)(.7)(.85)} = 1.96$$

Use two horsepower electric motor (31a)

H.1.3 Carbon Column

1. Sizing of column (flow rate 20 gpm)

design contact time in column =

15 minutes (based on carbon volume)

flow rate (Calgon Bulletin 20-4) = 5 gpm/ft²

area required = 20 gpm/(5 gpm/ft²) = 4 ft² (32)

carbon volume required = (15)(20 gpm)(.1337) = 40 ft³ (33)

Use standard steel pipe 30" nominal diameter
(Chemical Engineers Handbook)

inside diameter = 29.5"

area = 4.75 ft²

flow rate = 20 gpm/4.75 ft² = 4.2 gpm/ft² (33a)

depth of carbon = 40 ft³/4.75 ft² = 8.4 ft (34)

Using Filtrasorb 300 (Calgon Bulletin No. 20-4)

H_L at 4.2 gpm/ft² = 2.1"/foot of bed depth

Total headloss through bed = 1.5 ft H₂O (35)

Use two feet of clear water above carbon surface
for distribution

Use .6' of freeboard and 6" bottom clearance

Total column height = 11.5 feet

Diameter = 30" nominal

2. Volumes and Weights

(a) Weight carbon first charge at 20 lb/ft

Weight = (40 ft³)(20 lb/ft³) = 800 lbs (36)

(b) Weight of column

Weight of pipe = 79.5 lb/ft

Weight of column = (79.5 lb/ft)(11.5') =

914 lbs (37)

shipping weight = 914 lbs (38)

volume (shipping and operating) =

$\frac{(2.5')(\pi)}{4} (11.5') = 56 \text{ ft}^3$ (39)

H.1.4 Combination mixer - flocculator

Use 40% of cross-sectional area as paddle

$$\text{X-sectional area} = (12')(7.28') + (1/2)(6')(12') = 123.4 \text{ ft}^2 \quad (40)$$

$$\text{Paddle area} = (.4)(123.4) = 49.4 \text{ ft}^2 \quad (41)$$

r = radius of rotation (feet)

N = RPM of flocculator

γ = kinematic viscosity (ft^2/sec)

P_T = total power requirements (ft-lb/sec)

C_D = coefficient of drag

A = cross-sectional area of paddles (ft^2)

ω = weight of water (lb/ft^3)

v = relative velocity of paddle (fps)

V = volume of flocculation tank (ft^3)

v_a = actual velocity of paddles (fps)

G = velocity gradient (fps/ft)

g = gravity constant (ft/sec^2)

$$P_T = \frac{C_D \omega}{2g} \sum A(v)^3 \quad (42)$$

$$G = \sqrt{\frac{C_D}{2\gamma V} \sum A(v)^3} \quad (43)$$

Let maximum tip speed = 4 fps (for mixing)

See Figure 17 for dimensions used in the following calculations

$$N = 60 v_a / 2\pi r \quad (44)$$

$$N = \frac{(60)(4)}{(2\pi)(\frac{72'' - 4''}{12})} = 6.7 \text{ RPM} \quad \text{use 7 RPM} \quad (45)$$

$$\text{Let } v = (.75)(v_a)$$

$$v_n = \frac{(7)(2)(\pi)(.75)}{60}(r_n) = K r_n$$

$$K = .5495$$

$$v_1 = (.5495)(68/12) = 3.1 \text{ fps} \quad (46)$$

$$v_2 = (.5495)(60/12) = 2.7 \text{ fps} \quad (47)$$

$$v_3 = (.5495)(52/12) = 2.4 \text{ fps} \quad (48)$$

$$v_4 = (.5495)(44/12) = 2.0 \text{ fps} \quad (49)$$

$$v_5 = (.5495)(36/12) = 1.6 \text{ fps} \quad (50)$$

$$v_6 = (.5495)(28/12) = 1.3 \text{ fps} \quad (51)$$

$$v_7 = (.5495)(20/12) = 0.9 \text{ fps} \quad (52)$$

$$v_8 = (.5495)(12/12) = 0.5 \text{ fps} \quad (53)$$

$$v_9 = (.5495)(4/12) = 0.2 \text{ fps} \quad (54)$$

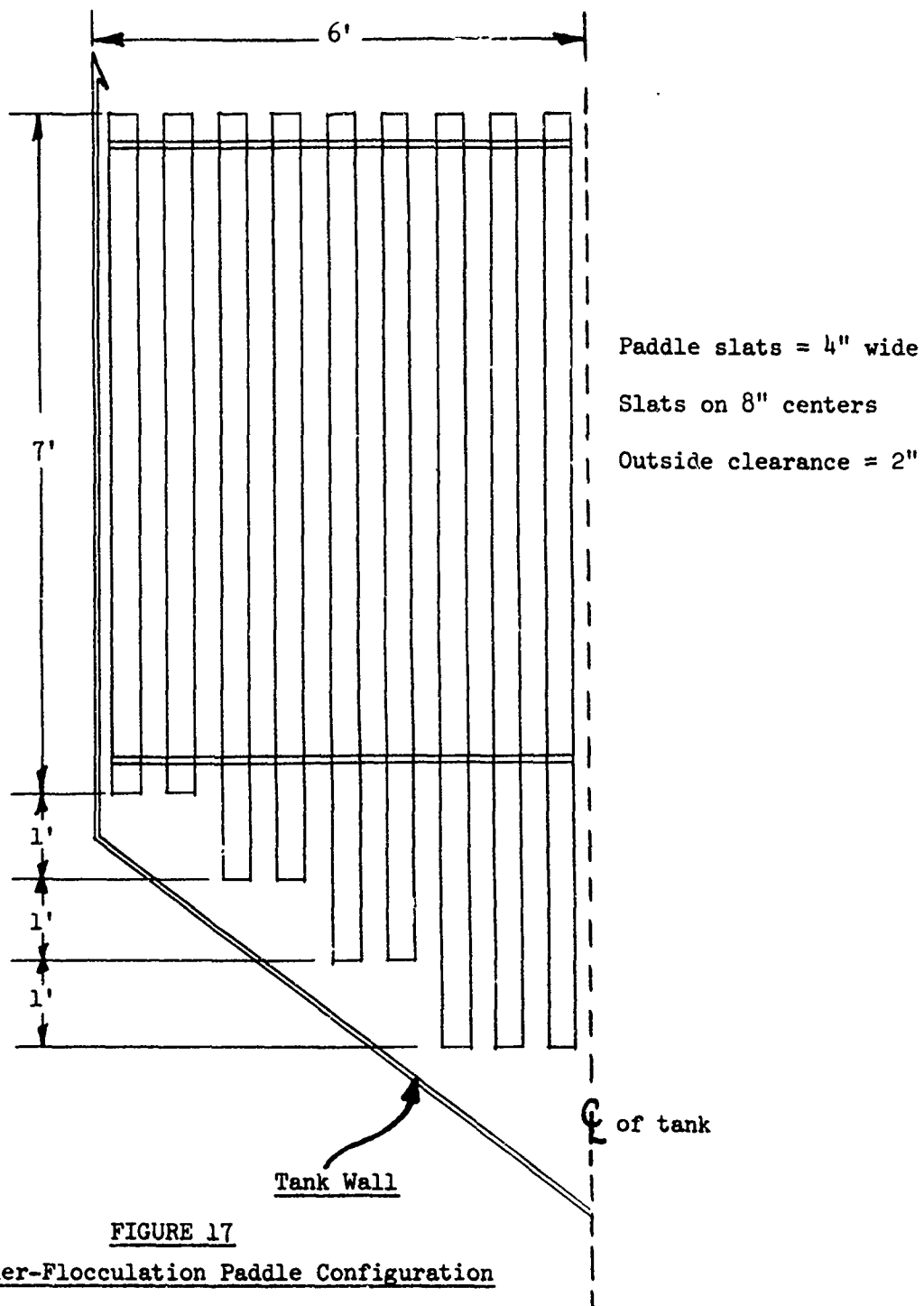


FIGURE 17
Mixer-Flocculation Paddle Configuration

$$\begin{aligned}
 A_1 &= (4/12)(7) = 2.31 \text{ ft}^2 & (55) \\
 A_2 &= (4/12)(7) = 2.31 \text{ ft}^2 & (56) \\
 A_3 &= (4/12)(8) = 2.64 \text{ ft}^2 & (57) \\
 A_4 &= (4/12)(8) = 2.64 \text{ ft}^2 & (58) \\
 A_5 &= (4/12)(9) = 2.97 \text{ ft}^2 & (59) \\
 A_6 &= (4/12)(9) = 2.97 \text{ ft}^2 & (60) \\
 A_7 &= (4/12)(10) = 3.3 \text{ ft}^2 & (61) \\
 A_8 &= (4/12)(10) = 3.3 \text{ ft}^2 & (62) \\
 A_9 &= (4/12)(10) = 3.3 \text{ ft}^2 & (63)
 \end{aligned}$$

$$\begin{aligned}
 \text{Total paddle area} &= 25.74 \times 2 = 51.48 \text{ ft}^2 \\
 51.48 &> 49.4 \text{ ft}^2 & (64)
 \end{aligned}$$

$$\begin{aligned}
 \Sigma Av^3 &= (2.31)(3.1)^3 + (2.31)(2.7)^3 + (2.64)(2.0)^3 + \\
 &\quad (2.64)(2.4)^3 + (2.97)(1.6)^3 + (2.97)(1.3)^3 + \\
 &\quad (3.3)(0.9)^3 + (3.3)(0.5)^3 + (3.3)(0.2)^3 = \\
 &\quad 193.43 & (65)
 \end{aligned}$$

$$P_T = (2) \frac{1.8(193.43)62.4}{(2)(32.2)} = 675 \text{ ft-lbs/sec}$$

$$P_T = 675/550 = 1.23 + \text{losses} \quad (66)$$

$$G = \sqrt{\frac{(1.8)(193.43)(2)}{(2)(1337)(1.41 \times 10^{-5})}} = 136 \quad (67)$$

This should cause adequate mixing. Use 50% efficiency

$$\begin{aligned}
 \text{Power required} &= 1.23/.5 = 2.46 \text{ horsepower} \\
 \text{Say } 2.5 \text{ horsepower} & & (68)
 \end{aligned}$$

H.1.5 Chemical Feeders and Stock Tanks with Pumps

$$\begin{aligned}
 1. \text{ Stock tanks and pumps for ferric sulfate and lime} \\
 \text{Fe}_2(\text{SO}_4)_3 - \text{concentration } 2 \text{ lb/gal feed/day} = \\
 35 \text{ lbs} = 17.5 \text{ gal} & (69)
 \end{aligned}$$

$$\begin{aligned}
 \text{CaO} - \text{concentration } 0.93 \text{ lb/gal feed/day} = \\
 18 \text{ lbs} = 19.4 \text{ gal} & (70)
 \end{aligned}$$

$$\begin{aligned}
 \text{Volume of stock tanks} &= 20 \text{ gallons effective} \\
 \text{Use } 25 \text{ gallon capacity stock tank} & (71)
 \end{aligned}$$

Use polyethelene or similar non-corrosive material
Reference Tamco Plastic Supplies Bulletin

$$\begin{aligned}
 \text{Use two stock tanks} \\
 \text{Volume} &= 3.5 \text{ ft each} & (72)
 \end{aligned}$$

$$\text{Weight} = 6 \text{ lbs each} = 12 \text{ lbs total} \quad (73)$$

Power requirements - 1/8 horsepower will give
5 gpm at 10 foot head -- empty tank in 4 minutes --

use two -- one each tank

For mixing need = 1/4 horsepower per tank

2. Stock Tanks and Pumps

(a) Chlorination

Ca(OCl)₂ feed 14 mg/l = 1.15 lb/day (74)

Feed solution .125 gal (75)

Volume stock tank = 1.15/.125 = 10 gal (76)

Use polyethylene tank hand mixed
volume = 1.5 ft³ (77)

weight = 3-1/2 lbs (78)

Use standard Army feeder LIQUID TYPE as
in 1500 gph erdlator

Power requirement = 1/15 horsepower (79)

volume small pack within stock tank

(b) Neutralization Step

Need 35 mg/l H₂SO₄ conc.

(.35)(8.34) = 3 bl H₂SO₄/day

Use 20 gallon tank, same as Item (71) (80)

(20)(8.34) = 167 lb = 1.8% solution or

= 0.35 N solution

for weak solutions - use polyethylene

Use standard military chemical feeder capable
of 1 gal/hr

power requirement = 1/15 horsepower (81)

3. Diatomite Slurry Feeder

Use standard military feeder

power = 1/4 horsepower

weight = 50 lbs

volume = packed within chemical storage tanks

4. Summary (Volume, Weights, and Power)

(a) Total volume (shipping) = 10 ft³

(b) Total volume (operating) = 20 ft³

(c) Total weight (motors, feeders, pumps, etc.) =
100 lbs

(d) Power total requirement (mixers and feeders) =
1-1/4 horsepower

H.1.6 Miscellaneous Piping, Valves, Switches, etc.

These items will be approximately the same for all
systems and hence will not effect the evaluation.

H.1.7 Logistical Support Requirements and Costs

		lb/day	ft ³ /day
1. Fe ₂ (SO ₄) ₃ ·5-6H ₂ O	400 mg/l =	33.2	1
2. CaO	175 mg/l =	14.6	

	lb/day	ft ³ /day
3. Diatomaceous earth (coagulated water filter) Actual quantities needed are not known at this time. Use 8 lb/day precoat---.4 lb/day body feed	8.4	.8
4. Carbon column		
COD required		
55 mg/l removed by 8.34	9.2	} 10 0.5
.5 (adsorption capacity)100		
BOD		
(18 mg/l removed)(8.34)	10.0	
.15 (adsorption capacity)(100)		
5. Chlorine		
Dose at 15 mg/l	1.2	} 0.25
6. Acid H ₂ SO ₄		
Dose at 35 mg/l	2.9	
Totals per day	70.3	2.55
Totals/month	2109	76.5

7. Costs

	\$/day	lb/day	¢/lb	
(a) Fe ₂ (SO ₄) ₃	.567	33.2	1.7	(1)*
(b) CaO	.183	14.6	1.25	(1)*
(c) Carbon	2.600	10.0	26.0	(2)*
(d) Ca(OCl) ₂	.265	1.2	22.0	(1)*
(e) H ₂ SO ₄	.060	2.0	2.0	(1)*
(f) Diatomaceous earth	.252	8.4	3.0	(3)*
Total	<u>\$3.93</u>			

Sources

- (1)* Chemical Engineering News Quarterly Report on Current Prices (1963)
- (2)* Calgon Corporation
- (3)* Grefco (Dicalite Division)

H.1.8 Water Recovery

Normal water recovery with two hours settling will be 93%.

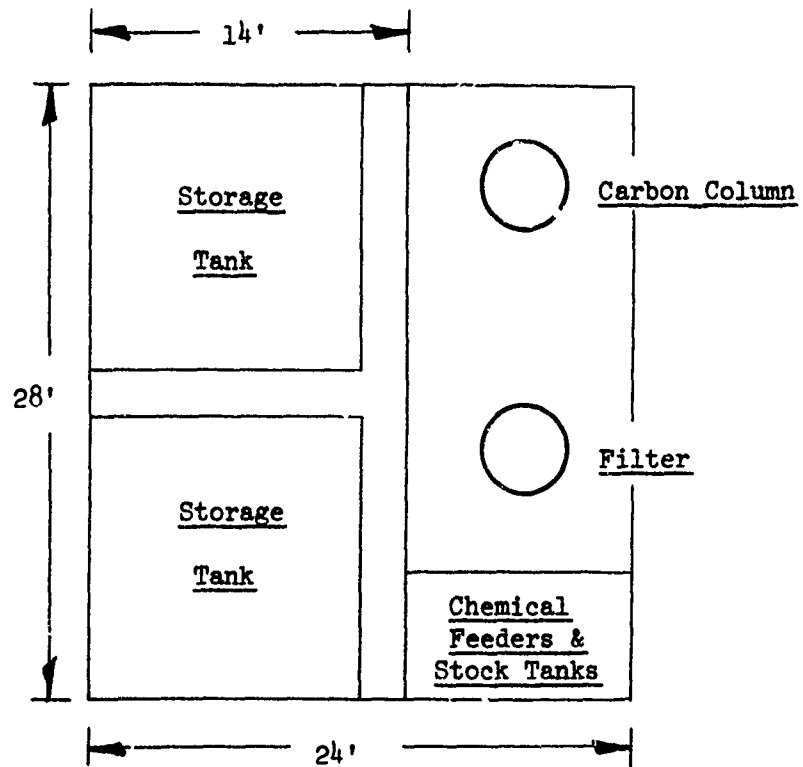
H.1.9 Summary of Treatment Method

1. Accumulation and blending tanks
12' square tank
Body of tank 8.5' high
Hopper bottom 6' high
Effective volume 10,000 gal each
Shipping cubage - 100
Operating cubage - 4176 ft³
Shipping weight - 9713
2. Diatomaceous earth filter
1 filter rated at 50 gpm -- Power 2 horsepower
Total shipping weight 310 lbs + motor and pump and
miscellaneous = 800 lbs
Total shipping and operating volume = 12.5 ft³
3. Carbon Column
2.5' diameter - 11.5' high
Shipping and operating cubage = 56 ft³ - weight =
914 lbs
4. Mixer flocculator
Volume - small
Weight - small - See Item D, this section
5. Chemical feeders and stock tanks
3 each 25 gallon stock tanks for Fe₂(SO₄)₃, lime
and sulfuric acid
1 each 10 gallon stock tank for Ca(OCl)₂
Total shipping - 10 ft³
Total weights including motors and feeders -
100 lbs
Power total = 1-1/4 horsepower
6. Logistical support requirements
Total lb/month = 2109
total cubage/month = 76.5 ft³
7. Cost of operation
Total cost per 10,000 gallons, i.e., daily cost =
\$3.93/10,000 gallons
Cost per 1,000 gallons product water
$$\phi = \frac{\$3.93 \times 100}{10 \times .93} = 42\phi/1,000 \text{ gallons}$$
8. Total power connected
 - (a) Flocculator 2 at 2.5 horsepower 5 horsepower
 - (b) Filter 2 horsepower
 - (c) Miscellaneous pumps, feeders, etc. 1.25 horsepower

8.25 horsepower =
6.15 KW

9. Operating area and volume

$$\underline{\underline{28 \times 24 = 670 \text{ ft}^2}}$$



OPERATIONAL LAYOUT PLAN

APPENDIX I: DETAILED COMPONENT DESIGN

I.1 Treatment System 1.2

I.1.1 Accumulation and Blanding Tanks

Same as Method 1.1 -- See Appendix H

I.1.2 Coal Filter

1. General information

If a coal filter is to be used, some basic development work will be necessary. Parameters such as:

- a. Headloss - flow rate values
- b. Size of coal most effective
- c. Necessary filter depth
- d. Method of cleaning bed
 - (1) backwash
 - (2) scraping top of bed
 - (3) combination

For this preliminary design and estimate of sizes and weights, data from the following sources will be utilized.

- Reference (81) Investigation of the Use of Coal for
Treatment of Sewage and Waste Waters (1)
(Rand Corporation)
- Reference (70) Factors Affecting Filtration Rates (2)
Laboratory Carbon Column Data (3)

2. Design of filter

It is assumed in this design that scraping will be used as the method of floc removal from the bed thus eliminating backwashing.

An average design flow rate of 1.0 gpm/ft^2 was indicated if the bed surface was renewed every two hours when filtering raw or settled sewage (Rand Report). Since we will be filtering a water much cleaner than sewage, a flow rate of 2 gpm/ft^2 would seem reasonable. Reduction of scraping time also seems possible but will have to be determined during development work.

$$\text{Area of filter} = \frac{20 \text{ gpm}}{2 \text{ gpm/ft}^2} = 10 \text{ ft}^2 \quad (4)$$

$$\text{Depth of filter} = 30 \text{ inches (Rand Report)} \quad (5)$$

- Foundation support of coarse coal 12" (6)
- Total bed depth 42" = 3.5' (7)
- Liquid level above bed 30" (Rand Report) (8)
- Freeboard - 12"
- Legs and under-piping = 12"
- Total filter height = 2.5 + 1 + 2.5 + 1 + 1 = 8 feet (9)
- Diameter of filter = $\sqrt{\frac{(4)(10 \text{ ft}^2)}{\pi}} = 3.58 \text{ ft}$
- Use 3.6 fcet (10)
- Volume of coal = (10)(3.5) = 35 ft³ (11)
- Weight of coal at 50 lb/ft³ = (50)(35) = 1750 lbs (12)
- The Rand Report indicates that it is necessary to scrape off the top 1/18 inch every 20 minutes.
- The depth removed daily would be
- $(1/18") \frac{8 \text{ hours} \times 60 \text{ minutes/hr}}{20 \text{ minutes}} = 1.3"$ (13)
- Weight of coal used per day would then equal
- $(10 \text{ ft}^2)(1.3/12)(50 \text{ lb/ft}^3) = 54 \text{ lb/day}$ (14)
- This amount could vary because Rand was filtering sewage and the waste to be filtered for this project is cleaner than sewage.
- Size of coal (in the range of - 20 + 100 mesh) will have to be determined experimentally.
3. Weights and volumes
- (a) Weight of each filter tank (3/16" steel)
- Weight = $(\pi)(3.58')(8')(3/16")(1/12)(500 \text{ lbs/ft}^3) = 686 \text{ lbs}$ (15)
- (b) Weight in transport and operation
- 80 ft³ (16)
- (c) Logistics
- Need 54 lb/day coal (17)
- or 1620 lb/month (18)

I.1.3 Carbon Column

- Same as Method 1.1 (See Appendix H)
- Shipping weight = 914 lbs (19)
- Operational volume = 56 ft³ (20)
- Shipping volume = 56 ft³ (21)

I.1.4 Combination Mixer Flocculator

- Same as Method 1.1 (See Appendix H)
- Horsepower = 2.5 - 2 required (22)

I.1.5 Chemical Feeders, Stock Tanks and Miscellaneous Pumps, Power

1. Pumps from holding tank to coal filter and from coal filter to carbon column
$$P = \frac{(20 \text{ gpm})(8.34 \text{ lb/gal})(20')}{(33,000)(.7)(.85)} = .17 \text{ horsepower} \quad (23)$$

Use 1/4 horsepower - need two pumps (24)
2. Chemical feeders, agitators, pumps, stock tanks
From Appendix H
For ferric sulfate, lime, acid, and chlorine
Total power for pumps, feeders, etc., is 1 horsepower (25)
weight 100 lbs
operating volume 20 ft³
shipping 10 ft³

I.1.6 Summary of Method 1.2

1. Accumulation and blending tanks
Same as Method 1.1 (Appendix H)
Shipping 100 ft³
weight 9713 lbs
operating volume 4716 ft³
2. Coal filter
Round column diameter = 3.5 ft
Height - 8.0 feet (total)
Volume shipping 80 ft³
Shipping weight 686 lbs
Coal volume = 35 ft³
Weight = 2750 lbs
3. Carbon column
Same as Method 1.1
Shipping weight 914 lbs
Shipping volume 56 ft³
4. Mixer Flocculator
Same as Method 1.1
Volume and weight small
2 units at 2.5 horsepower = 5 horsepower
5. Chemical feed tanks
Same as Method 1.1
Operating volume 20 ft³
weight 100 lbs
Shipping volume 10 ft³

6. Logistical Support and Cost

	lb/day	ft ³ /day	\$/day ⁽¹⁾
(a) Fe ₂ (SO ₄) ₃	33.2	1	.567
(b) CaO	14.6		.183
(c) Coal at 1/4¢/lb	54.0	1	.135
(d) Carbon	10.0	0.5	2.500
(e) Chlorine	1.2	0.25	.264
(f) Acid	2.9		.060

	115.9	2.75	\$3.81
Per Month	3477 lbs	82.5	

(1) Cost figures shown in Appendix H.1.7,
Step 7

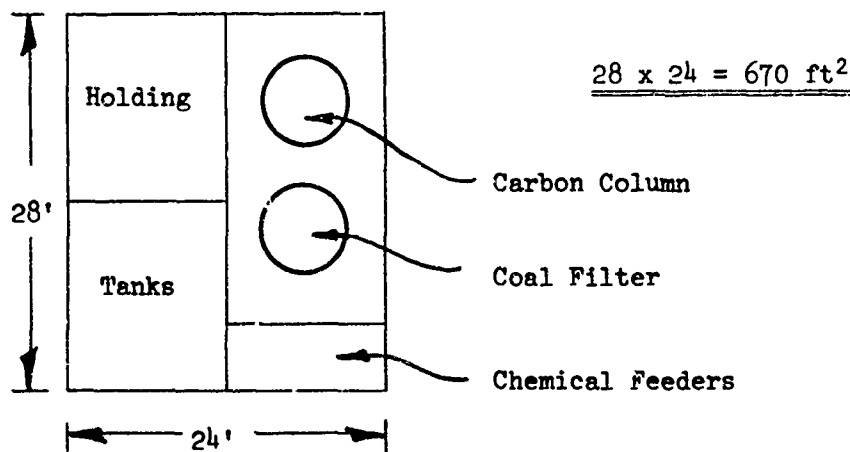
Cost per 1,000 gallon product

$$\phi = \frac{(3.81)100}{(10)(.93)} = 41\phi/1,000 \text{ gallons}$$

7. Water Recovery

With 2 hour settling = 93%

8. Operating Area



9. Power Requirements

	Horsepower
Flocculator Mixer	5.0

	horsepower
Flow pump	0.5
Chemical feed and agitators	1.0
	6.5 = 4.85 KW

APPENDIX J: DETAILED COMPONENT DESIGN

J.1 Treatment System 1.3

J.1.1 Accumulation and Blending Tanks

Same as Method 1.1 - See Appendix H - Part H.1.1

J.1.2 Flocculator - Settling Basin

1. Settling Basin Design (Rectangular Tank)

(a) Sedimentation Zone

Lab settling shows

$$\text{settling velocity} = .1 \text{ fpm} \quad (1)$$

$$\text{Sludge volume} = 10\% \text{ at 1 hour} \quad (2)$$

Use .05 fpm for design settling velocity

$$\text{O/F rate} = 20 \text{ gpm} - (.1)(20) = 18 \text{ gpm} \quad (3)$$

$$\text{Surface area} = \frac{18 \text{ gpm} \times .1337 \text{ ft}^3}{(.05 \text{ fpm})} = 48 \text{ ft}^2 \quad (4)$$

Use 90 minutes settling time

$$\text{Volume} = (20 \text{ gpm})(90)(.1337) = 240 \text{ ft}^3 \quad (5)$$

$$\text{Effective depth } (D_E) = 240 \text{ ft}^3 / 48 \text{ ft}^2 = 5 \text{ ft} \quad (6)$$

Let length = 2 w then

$$48 = 2w^2 \quad w = 4.9 \text{ ft} \text{ -- use 5 feet} \quad (7)$$

$$L = 9.7 \text{ ft} \text{ -- use 10 feet} \quad (8)$$

$$V_n = \frac{20 \text{ gpm}(.1337)}{25 \text{ ft}^2} = .1 \text{ fpm} < 1 \text{ fpm O.K.} \quad (9)$$

(b) Thickening Zone

Sludge flow rate = 2.2 gpm based on 30 minutes lab settling tests

Based on two-hour detention

$$\text{Thickener volume} = (2.2 \text{ gpm})(120 \text{ min})(.1337) = 35 \text{ ft}^3 \quad (10)$$

Use pyramid shaped bottom with 45° slope

Depth = 5 feet

$$\text{Volume} = (1/3)(10)(5)(\pi) = 83 \text{ ft}^3 > 35 \text{ O.K.} \quad (11)$$

2. Flocculation Basin

Laboratory flocculation time = 6 minutes

Use 12 minute flocculation time for design (12)

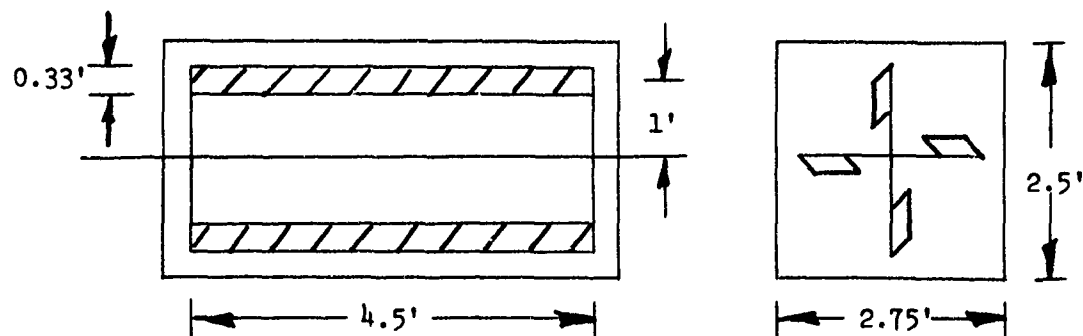
Tank Sizing

$$\text{Volume} = (20 \text{ gpm})(12) = 240 \text{ gal} = 32 \text{ ft}^3 \quad (13)$$

Use width of 5 feet (width of sedimentation tank) (14)

$$\text{Length} = 32 / (2.5)(5) = 2.56 \text{ Use 2.75 feet} \quad (15)$$

Effective size of tank 5' wide x 2.75' long x 2.5' deep (16)



Configuration

$$\text{Paddle area} = (.4)(5')(2.5') = 5 \text{ ft}^2 \quad (17)$$

$$\text{Total actual paddle area} = (4)(.33')(4.5') = 5.9 \text{ ft}^2 > 5 \text{ O.K.} \quad (18)$$

Use tip speed of 2 fps = v_a

$$\text{RPM} = \frac{(60)(2)}{(2\pi)(1')} = 19 \text{ RPM} \quad (19)$$

$$v = (.75)(v_a) = (.75)(2) = 1.5 \text{ fps} \quad (20)$$

$$P_T = \frac{(1.2)(62.4)}{(2)(32.2)} = [(5.9)(1.5)^3] = 23.1 \text{ ft-lb/sec} \quad (21)$$

(See Appendix H for Nomenclature)

Assume .50 efficiency total

$$\text{Hp} = \frac{23.1 \times 2}{550} = .084 \text{ Hp} \quad (22)$$

Use 1/4 horsepower for flocculator (23)

$$G = \sqrt{\frac{(1.2)(19.9)}{(2)(34.4)(1.41 \times 10^{-5})}} = 157 \text{ too high} \quad (24)$$

at maximum of 1 fps actual = .75 relative v

$$G = \sqrt{\frac{(1.2)(.75)(5.9 \text{ ft})}{(2)(34.4)(1.41 \times 10^{-5})}} = 55 \text{ O.K.} \quad (25)$$

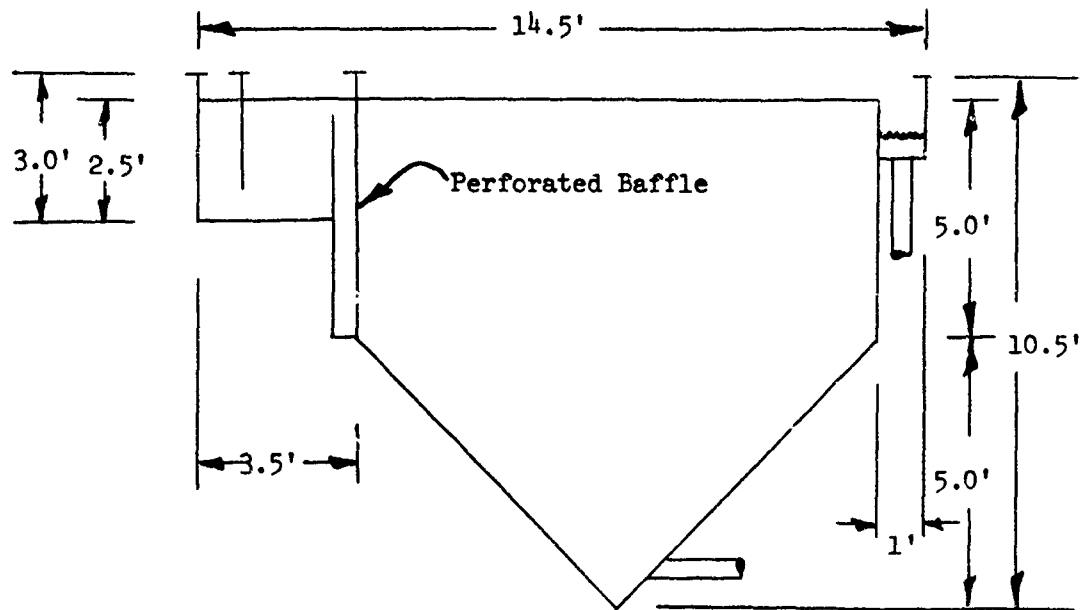
3. Final Overall Sizing and Weights

Inlet velocity to flocculation tank

$$V = \frac{(20 \text{ gpm})(.1337)}{(3'/12)(5')} = 2.1 \text{ fpm} < 5 \text{ O.K.} \quad (26)$$

Inlet velocity to sedimentation tank

$$V = \frac{(20 \text{ gpm})(.1337 \text{ ft}^3/\text{g})}{(.5')(5')} < 5 \text{ fpm O.K.}$$



(Width of unit = 5.0')

Overall Size and Configuration
(Operating Conditions)

Operating volume

$$V = (5')(14.5')(10.5') = 762 \text{ ft}^3$$

Shipping volume

The flocculation tank and sedimentation tank can be shipped disassembled in the same manner as the holding tanks. This, however, will increase erection times since both the holding tanks and the flocculation tanks must be assembled. In light of the above discussion, the flocculation tank will be broken into major sections.

Section 1: Flocculation tank and flocculator assembly

Shipped as a unit

Shipping volume = $(3.5')(3')(5') = 52.4$

Shipping weight (3/16" steel)

$[(2)(3.5)(3) + (2)(5)(3) + (5)(3.5)](3/16)(1/12)(500) = 535 \text{ lbs}$

Connections, flocculation assembly = 100 lbs

Total weight = 635 lbs

Section 2: Settling tank

Bottom hopper section removed

Shipping volume = $(10)(5.5)(5) = 275 \text{ ft}^3$

Weight tank proper =

$[(2)(10)(5.5) + (2)(5)(5.5)](1/12)(3/16)(500) = 1289 \text{ lbs}$

Weight bottom hopper section

$(4)[(\sqrt{2})(5)(5)(1/2)](3/16)(1/12)(500) = 552 \text{ lbs}$

Flocculator section, bottom hopper plates, chemical stock tanks, pumps, feeders, miscellaneous, to be shipped inside sedimentation tanks.

Shipping volume = 275 ft^3 Weight = 2476 lbs

J.1.3 Coal Filter

Same as Method 1.2 (Appendix I, Part I.1.2)

Shipping volume = 80 ft^3 - Shipping weight = 686 lbs

J.1.4 Carbon Column

Same as Method 1.1 (Appendix H)

Shipping and operating volume = 56 ft^3

Shipping weight = 913 lbs

J.1.5 Flow Pumps, Chemical Feeders, Stock Tanks

1. Flow pumps

1/8 horsepower from holding tank to flocculator

1/4 horsepower from settling tank to coal filter

1/4 horsepower from coal filter to carbon column

2. Chemical feeders and stock tanks

Same as Method 1.2 (Appendix I)

Operating volume = 20 ft^3

Shipping volume = 100 ft^3

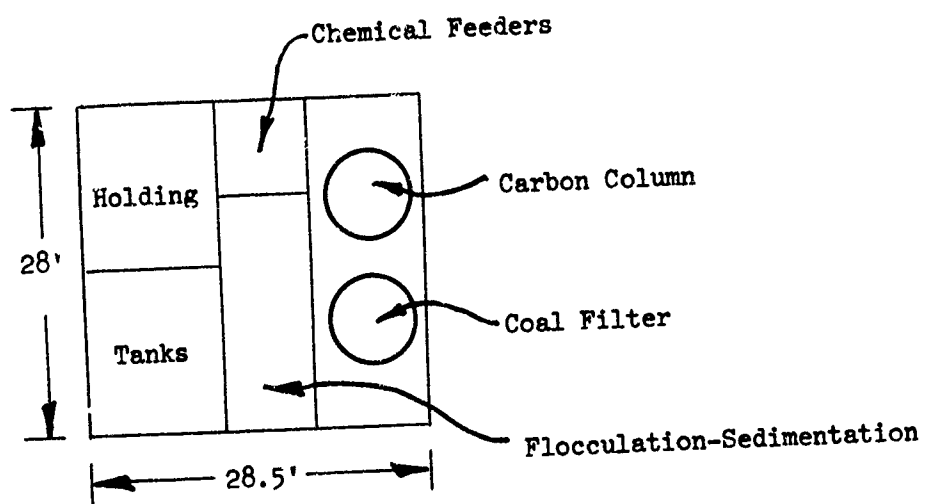
Weight = 100 lbs

Horsepower = 1 horsepower

3. Total Power Required
1.87 horsepower = 1.4 KW

J.1.6 Summary of Method 1.3

1. Accumulation and blending tanks
Shipping cubage = 100 ft³
Weight = 9713 lbs
Operating volume = 4176 ft³
2. Flocculation and sedimentation tank and chemical storage tanks and pumps
 - (a) Flocculation and sedimentation
shipping cubage = 275 ft³
operating volume = 762 ft³
weight = 2476 lbs
 - (b) Chemical stock tanks, etc.
operating volume = 20 ft³
shipping volume = 10 ft³
weight = 100 lbs
power = 1 horsepower
3. Coal Filter
shipping cubage = 80 ft³
weight = 686 lbs
4. Carbon column
shipping cubage = 56 ft³
weight = 914 lbs
5. Power requirements
Total horsepower connected = 1.62 horsepower =
1.2 KW
6. Water recovery
Normal = 93% - 2 hour settling
7. Logistical support and cost
Same as Method 1.2 (Appendix I)
lb/month = 3477
ft³/month = 82.5
cost/1,000 gal product = 41¢
cost/day = \$3.81
8. Operating Area
See next page



$$(28')(28.5') = 800 \text{ ft}^2 \text{ area}$$

APPENDIX K: DETAILED COMPONENT DESIGN

K.1 Treatment System 1.4

K.1.1 Accumulation and Blending Tanks

Same as Method 1.1 - See Appendix H - Part H.1.1

K.1.2 Erdlator Assembly

From TM 5-4610-204-12

Shipping cubage = 1,000 ft³

Shipping weight = 8,100 lbs

K.1.3 Carbon Column

Same as Method 1.1 - See Appendix H

Shipping volume = 56 ft³

Shipping weight - 913 lbs

K.1.4 Total Connected Horsepower

TM 5-4610-204-12

1. Slurry and chemical feeders 1/2 horsepower

2. Agitator motor 1/2 horsepower

3. Filter 2.0 horsepower

4. Pump from holding tank to
Erdlator

1/4 horsepower

3-1/4 horsepower = 2.42 KW

K.1.5 Summary of Method 1.4

1. Accumulation and blending tanks

Operating volume 4176 ft³

Shipping volume 100 ft³

Weight 9713 lbs

2. Erdlator unit

Operating and shipping

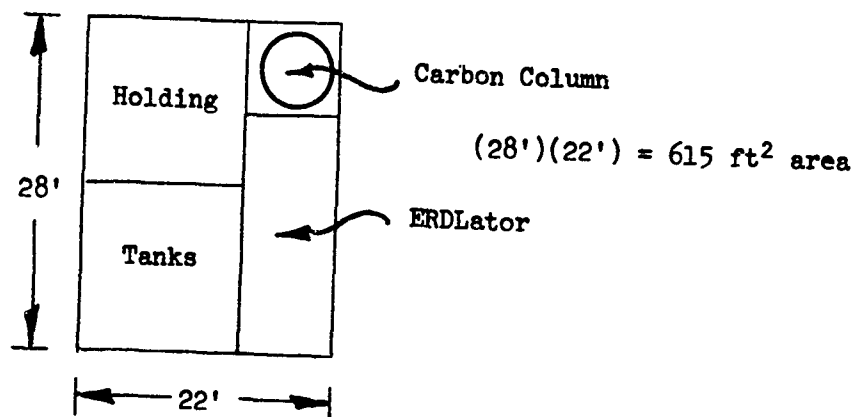
1000 ft³ - weight 8,100 lbs

3. Carbon column

Operating and shipping

561 ft³ - weight 914 lbs

4. Power
Total = 2.42 KW
5. Water recovery
93%
6. Logistical Support and cost
Same as Method 1.1 - See Appendix H
2109 lb/month
76.5 ft³/month
Cost 3.93 \$/day
42¢/1,000 gallons product
7. Operating Area and Volume



APPENDIX L: DETAILED COMPONENT DESIGN

L.1 Treatment System 2.1

L.1.1 Accumulation and Blending Tanks

Same as Method 1.1 See Appendix H

L.1.2 Mixer - Flocculator

Same as Method 1.1 See Appendix H

L.1.3 Diatomaceous Earth Filter

Same as Method 1.1 See Appendix H

L.1.4 Chemical Feed Tanks, Slurry Feeders, Pumps

Same as Method 1.1 (Appendix H) except one more stock tank, agitator and slurry feeder is needed for the powdered carbon.

Carbon slurry concentration = 1 pound/gallon

feed 67 lbs/day Volume tank needed = 67 gallon effective use 75 gallon tank and slurry pump

weight = 22 lbs

Volume = $(27/12)^2(\pi/4)(34/12) = 11.25 \text{ ft}^3$ operating and shipping

Use 1/4 horsepower agitator motor -- 1/8 horsepower slurry pump

L.1.5 Summary Method 2.1

1. Accumulation and blending tanks

Operating volume = 4176 ft^3

Shipping volume = 100 ft^3

Weight = 9713 lbs

Power (flocculator) = Total 5 horsepower

2. Filter

Operating and shipping volume = 12.5 ft^3

Weight = 800 lbs

Motor = 2 horsepower

3. Chemical feeders, stock tanks, motors

	Weight pounds	Operating Volume ft ³	Shipping Volume ft ³	Power horse- power
From Method 1.1	100	20	10	1.25
Added	30	15	11	.37
TOTAL	130	35	21	1.62

4. Logistic support and cost

	lb/day	ft ³ /day	\$/day
a. Fe ₂ (SO ₄) ₃	33.2	1.0	0.567
b. CaO	14.6		
c. Diatomaceous Earth	8.4		
d. Powdered Carbon [(8-1/4¢/lb) West Va. Pulp and Paper]	66.0	5.5	5.460
e. Chlorine	1.2	2.5	0.265
f. Acid	2.9		
Daily	126.3	7.55	6.535
Per Month	3790	226.5	\$6.54/ day

If a BOD of 12 can be tolerated, the carbon dosage can be reduced to 33 lb/day and the logistics and cost are reduced to 2800 lb/month 144 ft³/month \$3.76/day for Methods 2.1, 2.2, and 2.3.

5. Water recovery

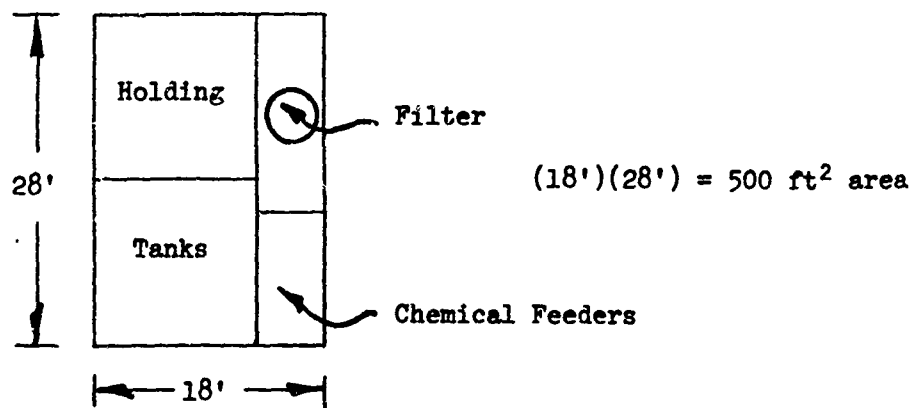
Water recovery will be 95% with 2 hour sludge compaction

6. Cost per 1,000 gal product water

with 66 lb carbon = 69¢/1,000 gal

with 33 lb carbon = 39.6¢/1,000 gal

7. Operating area



APPENDIX M: DETAILED COMPONENT DESIGN

M.1 Treatment System 2.2

M.1.1 Accumulation and Blending Tanks

Same as Method 1.1 See Appendix H

M.1.2 Flocculation - Sedimentation Tanks

Same as Method 1.3 See Appendix J

M.1.3 Diatomaceous Earth Filter

Same as Method 1.1 See Appendix H

M.1.4 Chemical Feeders and Stock Tanks

Same as Method 2.1 See Appendix L

M.1.5 Summary Method 2.2

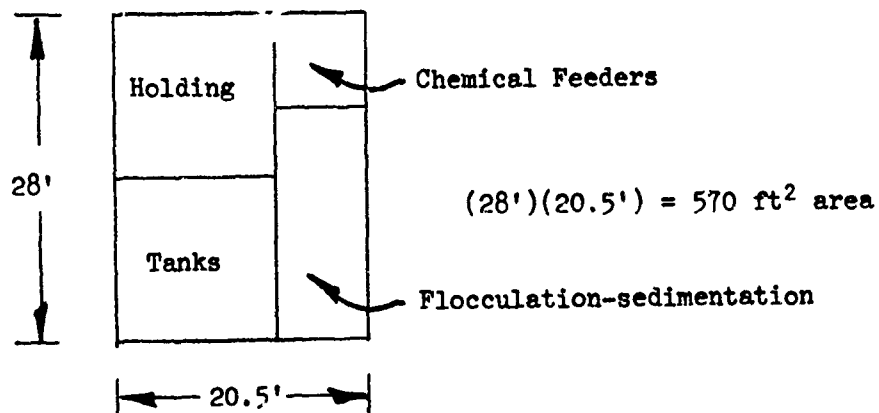
1. Accumulation and Blending Tanks
shipping volume = 100 ft³
operating volume = 4176 ft³
weight = 9713 lbs
flocculator power = 5 horsepower
2. Flocculation - Sedimentation Tank
operating volume 762 ft³
shipping volume 275 ft³
weight = 2476 lbs
flow pump = 1/4 horsepower
3. Diatomaceous Earth Filter
operating and shipping volume = 12.5 ft³
weight = 800 lbs
power = 2 horsepower
4. Chemical Feeders and Stock Tanks
operating volume = 35 ft³
shipping volume = 21 ft³
weight = 130 lbs
power = 1.6 horsepower
5. Logistic Support
Same as Method 2.1 See Appendix L

6. Total Power

Flocculator - Mixer	5.0 horsepower
Filter	2.0 horsepower
Flow pump	0.25 horsepower
Chemical feed, etc.	1.62 horsepower

8.87 horsepower = 6.6 KW

7. Operating Area



APPENDIX N: DETAILED COMPONENT DESIGN

N.1 Treatment System 2.3

N.1.1 Accumulation and Blending Tanks

Same as Method 1.1 See Appendix H

N.1.2 Erdlator Unit

Same as Method 1.4 See Appendix K

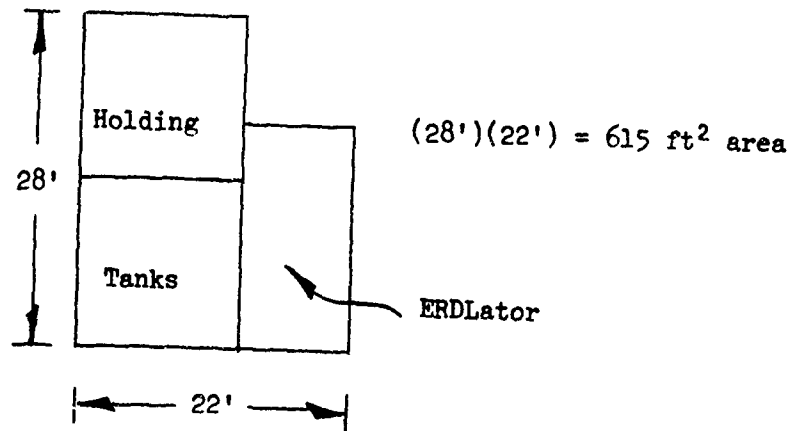
N.1.3 Summary Method 2.3

1. Accumulation and Blending Tanks
operating volume = 4176 ft³
shipping volume = 100 ft³
weight = 9713 lbs
2. Erdlator Unit
shipping and operating cubage = 1,000 ft³
weight = 8,100 lbs
3. Total Connected Horsepower
TM 5-4160-204-12
 - a. Mixer - Flocculator 5.0 horsepower
 - b. Pumps, Motors, etc. 1.62 horsepower
 - c. Filter 2.0 horsepower

8.62 horsepower = 6.42 KW
4. Water Recovery
= 95% with 2 hour sludge compaction
5. Logistical Support and Cost
Same as Method 2.1 See Appendix L

lb/month	ft ³ /month	cost/day
3790	226.5	\$6.54

6. Operating Area and Volume



Unclassified

Security Classification

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11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army Mobility Equipment Research and Development Center Fort Belvoir, Virginia 22060	
13. ABSTRACT This report documents the Engineering Design Study phase of an overall effort to develop and test a prototype wastewater treatment system for renovating a combined advanced military base wastewater consisting of kitchen, laundry, and shower wastewaters for reuse purposes other than drinking and food preparation. The objective of this phase with respect to the overall effort was to develop a number of integrated wastewater treatment systems which may be used to treat satisfactorily the combined raw wastewater. The work performed during this phase consisted of a literature survey, a laboratory investigation, and an engineering design evaluation. The literature survey was conducted to evaluate existing individual waste treatment processes which may be applicable in rendering the combined wastewater in question amenable to the required treatment. The laboratory investigation was performed on a synthetic wastewater to determine process applicability and to demonstrate the feasibility of the most promising treatment systems uncovered in the literature survey. The engineering design evaluation was carried out to design and evaluate a number of prototype integrated wastewater treatment systems using the data obtained from the laboratory investigation. The seven proposed systems emerging from the engineering evaluation were arrived at with consideration for the following parameters: total package weight, transport and operational cubage, logistical support requirements, operational skills required complexity of assembly, power requirements, availability of fabrication materials, water recovery capability, odor control provisions, and cost per unit volume of product water produced.		

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