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REMOTE TACTICAL AREAS.

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RECLAMATION OF URINE FOR FLUSH WATER
IN REMOTE TACTICAL AREAS

APPROVED BY

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DISSERTATION COMMITTEE

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DEDICATION

To My Wife Elva and Son Henry.

ABSTRACT

The objective of this research is to establish unit process design criteria so that a process will treat the urine liquor to meet technical quality criteria of odor, color, turbidity, organic matter and bacteria content to be used as flush water.

The design criteria was developed by employing the following treatment processes: (a) Ozonation, (b) Combination of Ozonation and Ultraviolet (UV) Radiation, (c) Activated Carbon Adsorption, (d) UV Radiation, and (e) Regeneration of Carbon by Ozonation. Data is collected and presented to evaluate alternatives of the above treatment processes.

The method of evaluating the various alternatives is a decision weighting model which seeks a measure of objectivity by delineation of the physical performance characteristics of the various treatment processes. The objectives are quantified by physical performance measures or direct worth estimates for each alternative. This is followed by weighting each of the criteria to reflect its overall contribution to the objective. Then the criteria are aggregated to provide a single measure of the alternatives' overall worth through a total utility index. The principal criteria used to evaluate the alternatives in this study are: health hazard, user acceptability, operation reliability, maintainability, safety, power requirement, space requirement, weight and shelf life. Cost per unit effectiveness was finally achieved by utilizing the cost data and effectiveness data.

Activated carbon adsorption is the most cost effective treatment process to reclaim urine for flushing water in remote tactical areas.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

Page

LIST OF TABLES

RECLAMATION OF URINE FOR FLUSH WATER IN REMOTE TACTICAL AREAS

CHAPTER I

INTRODUCTION

The conflict in Southeast Asia has forcefully illustrated that existing sanitation facilities and methods such as cat holes, straddle trenches, pit latrines, and burn-out heads are no longer adequate for the Marine Corps (MARCORPS) expeditionary operations, expecially in a fire base environment. The MARCORPS' mission of rapid response for crisis control, requires the development of adequate fail-safe water and sanitation systems to support deployed marine units for effective and successful combat operations. Manpower losses to secondary (non-combat or housekeeping) activities can have an adverse impact on MARCORPS' primary mission. Self-contained, self-operating sanitation modules that are compatible with (a) the scope of available manpower, skills, materials and resources of the primary mission, and (b) the present and future MARCORPS' logistics system are needed.

The field sanitation practices that statisfically had significant impact on non-combat casualties resulting from personnel leaving shelter to use sanitation facilities, and from suffering diseases induced by poor physical hygiene and living environment sanitation, include field head, shower, laundry, liquid and solid waste handling procedures.

Among them, development of a field head module has been selected by MARCORPS to be first priority effort, and the Civil Engineering Laboratory (CEL) of the Naval Construction Batallion Center (NCBC), Port Hueneme, California, was tasked to perform the research, development, test and evaluation (RDT & E) work (1).

At present, human waste in many military combat/noncombat field operations is disposed of into pit latrines, 1-2-3 trenches, cat holes, and burn-out heads, which are labor intensive requiring constant maintenance and supervision. These sanitation practices (burn-out heads and pit latrines) require ideal environmental conditions such as low water table, low rainfall, good climate, constant vector (flies/mosquitoes) control, sufficient manpower to provide daily maintenance, and a tactical situation allowable to tolerate daily plumes of black smoke, flame and obnoxious odors.

The expeditionary field head module being developed by CEL includes two mini-water flush commodes, a thermal waste destructor, and two independent mini-water flush urinals. Water flush closets and urinals were selected for their self-cleaning characteristics and their seal that isolates and contains gases and odors. Figures 1 and 2 in Appendix 1 depict the front and rear views of the expeditionary head module.

It is apparent that any type of wastewater reclamation and reuse would result in minimizing the logistic burden for water importation, manpower for disposal of liquid waste, and enhance the head module applicability. Flush water may be reclaimed from the urinals. The problem of paramount importance, yet to be resolved, is the process for reclaiming the urine for flush water that will use minimum or no chemical/material resupply.

The constituents of urine, in descending order of quantity, are water, urea, sodium chloride, other inorganic salts, organic ammonium salts, amines, and non-nitrogen containing organic compounds. The objectionable color and odor of normal urine (from healthy persons) is due to excretion of urochromes and other catabolic ammoniated compounds respectively. Urochromes are nitrogen containing organic compounds produced by endogenous metabolism of the nitrogenous substances of cells and tissues. Ammoniated compounds, which undergo decomposition in urine upon standing, contribute to the unpleasant ammoniacal odor. Thus, the color and odor, together with bio-nutrients, are most important parameters in developing urine reclamation processes.

The available treatment processes utilized during this research effort in reclaiming urine for flush water were the following: (a) Ozonation, (b) Combination of Ozonation and Ultraviolet (UV) Radiation, (c) Activated Carbon Adsorption, (d) UV Radiation, and (e) Regeneration of Carbon by Ozonation.

The objective of this study was to establish unit process design criteria so that the process will treat the urine liquor to meet technical quality criteria of odor, color, turbidity, organic matter and bacteria content to be used as flush water.

A cost-effective analysis was prepared utilizing the design criteria obtained from each of the treatment unit processes. The objective in this analysis was to select the most cost-effective treatment unit process that will best meet U.S. Navy and Marine Corps needs, using the Navy's overall system evaluation criteria of (a) health hazard potential, (b) user acceptability, (c) operation reliability, (d) maintainability, (e) safety, (f) power requirement, (g) space requirement, (h) weight, and (i) shelf life.

Background and Related Research

The requirements for developing an incinerating tiolet, including a urinal with minimum water flush, has been established. For the successful operation of such a system water and chemical resupply, liquid waste disposal problems, and manpower and skill requirements had to be considered. Water requirements showed that a self-contained and self-operating urine reclamation method needed to be developed. The processes recommended will be subjected to advanced development and future application. The agency which has been engaged in recovering potable water from urine for a number of years is the National Aeronautics and Space Administration (NASA).

Investigation indicates that electrolysis (2) and freeze drying processes (3) have been evaluated in the past. Specific application of these treatment technologies has been for reclaiming water from urine to potable quality for space missions. Nichols (4) concluded that a distillation method was the most practical means of water recovery on manned space missions of greater than a few days duration. His conclusions were based on the state-of-the-art in 1965. The power requirement of his system was very high. Metzger et al. (5) also utilized a distillation method of recovering water from urine for potable use in an actual aerospace mission. Activated carbon was used as a means of polishing the final product in terms of color, odor and taste. During 1967 Metzger et al. (6) continued to evaluate urine reclamation alternatives. The alternatives included: (a) Vacuum Distillation, (b) Vapor Compression, (c) Electrolysis, (d) Ultrafiltration, (e) Membrane Permeation, (f) Electrodialysis, (g) Unfiltered Condensate, (h) Filtered Condensate, (i) Thermoelectric Distillation and (j) Fuel Cell. Test results indicated considerable variations in the composition of water recovered from the same system from day to day. Investigators claim that these variations were usually the result of variations in the raw material rather than in the water reclamation system or in the operation thereof. In most cases the recovered water met the 1962 drinking water standards set by U.S. Public Health Service (USPHS). In some cases some constituents exceeded the standards but they were within allowable limits for aerospace use. The conclusions of this study showed that thermoelectric distillation, electrodialysis and vapor compression water reclamation devices are suitable systems for use during an extended aerospace mission.

Metzger et al. (7) utilized radioisotopes to provide thermal energy needed for vacuum distillation and vacuum distillation-vapor pyrolysis. Their results were very encouraging and radioisotopic heat sources are recommended for space vehicle life support systems. Both systems produced potable and sterile water from urine.

Different problems have been encountered during the development stages of electrolysis and freeze drying processes, such as system complication, high capital cost, corrosion of electrode and salts formation, and the skill requirement of operating the reclamation system. These problems indicated that additional basic research is required. Since this was an applied research effort, only state-of-the-art technologies that showed high potential for cost-effective urine treatment were investigated.

Development of a physical or electrochemical process and/or a chemical-physical process in which the chemical to be used is either generable or regenerable at application site, and uses only electricity as an energy source, was the primary requirement for this research effort. The four unit treatment processes selected for this study have been satisfactorily demonstrated in the domestic water reclamation programs. The Army Medical Research and Development Command and NASA Headquarters have contracted out the development of a UV-ozone water purification process to destroy selected microorganisms and organic contaminants (8). Zeff et al. (8) did preliminary laboratory studies in reclaiming water from urine by applying Ozone-UV. Although his results were not quantitative, he stated that flush water could be obtained from ozonation of urine with UV radiation.

See, Yang and Kacholia (9) conducted a study for the U.S. Army

Medical Research and Development Command on the development and preliminary characterization of a modified ozone contactor system as a post-Reverse Osmosis treatment process for the Water Processing Element in a Medical Unit, Self-Contained, Transportable (MUST) complex. The unit treatment process treated a wide variety of hospital wastes. Their conclusions state that their system succeeded in reducing the organic solute concentrations to meet their specifications. Furgason (10) employed ozonation in the treatment of kraft paper pulp waste. He observed that the wastewater was satisfactorily decolorized and deodorized by the ozone. In addition the treated effluent appeared to be more biodegrabable than before ozonation. This is due to the dissociation of complex organic molecules by ozone exidation to simpler organic molecules. Considerable work has been performed on the oxidation of various wastes by ozone. Researchers have proven that, at the required ozone levels for elimination of bacteria and viruses, phenols and similar wastes are readily decomposed. Unpleasant characteristics like taste, odor and toxicity are greatly reduced. Ozone has effectively lowered the chemical oxygen demand (COD) and total organic carbon (TOC) content of effluents from wastewater treatment plants (11, 12, 13).

Prengle et al. (14) have performed studies on the oxidation rate of refractory chemical species with ozone and ultraviolet radiation using ethanol, acetic acid, glycine, glycerol, and palmitic acid. These organics were selected as representative refractories found in municipal and industrial wastewater. Their conclusions were (a) for refractory compounds, the use of UV enhances reaction with ozone 10^2 to 10^4 fold, and drives the reaction to completion, CO_2, H_2O, etc.; whereas without UV the final products, in some instances, are stable compounds, e.g., ozonides, (b) based on the results obtained, a properly designed reactor system, with ozone and UV can accomplish essentially complete removal of refractory materials.

The activated carbon adsorption process has been used in different types of applications and has proven to be an effective, simple and economic means of removing tastes, odors and other organic contaminants. In the adsorption process, removal of organic contaminants occurs as the thin layer of molecules of the impurities contact and adhere to the surface of the adsorbent. In several studies (15, 16, 17) granular activated carbon beds have offered dependable removal efficiencies of organic contaminants from industrial and municipal wastes. During these applications activated carbon has been used in cases where the treatment objectives varied from pollution abatement to complete water reclamation. In most cases, granular activated carbon beds have been utilized in a final adsorption step to remove any remaining adsorbable organic contaminants (18).

Ultraviolet radiation has been tested for its disinfection capability with respect to meeting Remote Base Water/Wastewater Treatment System design criteria (19). In addition to bactericidal effect UV radiation produces small amounts of hydrogen peroxide which oxidizes some refractory organics. Disinfection of a raw wastewater does not seem to be complete. Lory (19) showed that when UV was applied to the raw waste having high content of color and turbidity, E. coli was not completely killed, due to their forming natural barrier to the penetration of ultraviolet radiation. UV radiation has been employed as a disinfecting agent in many industrial applications (20, 21, 22). Monogram Company has developed a chemical which masks the odor and color very efficiently. This chemical agent has been tested in urine with positive results (1).

As one may observe the processes investigated in this study are well established treatment unit processes but not many researchers have attempted to use them in recovering flush water from urine. Therefore, the amount of literature in this particular subject was very limited, and that stimulated the author's interest to conducting this research.

CHAPTER II

EXPERIMENTAL PROCEDURES AND METHODOLOGIES

Experimental procedures and methodologies used for development of the urine reclamation method are described in the following.

A. Experimental Parameters

1. Physical Parameters

The physical parameters measured during experiments of the bench-scale models for urine reclamation are listed as follows:

a. Odor - The objectionable color and odor of normal urine are due to excretion of urochromes and other catabolic ammoniated organic compounds respectively. The intensity and offensiveness of the odor varies with the amount of catabolic ammoniated organic compounds left in the urine after treatment. According to a Department of Interior report (23), six odor units is considered an acceptable standard for flushing water. Odor is a very important parameter since it relates to user acceptability. This parameter is so readily detectable that any trace of detectable odor in the flushing water affects significantly the user's acceptance. It is generally agreed that the user has a high sensitivity to odor than to color or any other pollutional parameter.

b. Color - Urochromes in the urine have been found to cause the typical yellowish color in normal urine. The Department of Interior has suggested 30 color units to be the maximum acceptable value for flushing water. Color intensity reflects the activity of biodegradation and significantly affects users' acceptance in terms of aesthetics. Color adversely affects UV radiation efficiency.

c. Temperature - The rate of many water-related chemical reactions increases as temperature increases. During disinfection, for example, chemical reactions are involved, and its efficiency generally increases with an increase in temperature. Changes in temperature have been observed to affect activated carbon adsorption (25).

d. Turbidity - Measures light-transmittance which is related to the concentration of colloidal matter in a liquid. Colloidal matter adversely affects carbon adsorption, and UV radiation. Turbidity reduces the effectiveness in water disinfection. Twenty Jackson Turbidity Units (JTU) have been recommended, by the Department of Interior, as acceptable for flushing water.

2. Chemical Parameters

The chemical parameters that are significant to flush water reclamation from urine were measured during testing bench-scale models and are the following:

a. Chemical Oxygen Demand (COD) - This parameter measures the total amount of organic matter (biodegradable and nonbiodegradable) in the urine sample. The reduction of COD is related to the removal of color, odor, and oxidizable organic matter in the samples. The reason for selecting COD was the short time required for its evaluation. This permitted, in a relatively short period, the making of any adjustments necessary to obtain the results required.

b. Total Kjeldahl Nitrogen (TKN) - This parameter measures ammonia and organic nitrogen content in urine samples. Since urine contains urochromes (nitrogen-containing organic compounds) and ammoniated organic compounds, TKN concentration measurement quantifies those principal color and odor causing chemical compounds in urine, and also indicates the status of the degradation of these chemicals.

c. pH - This parameter is important because pH changes tend to significantly affect carbon adsorption (25), disinfection and ozonation (26). A study showed that ozonation rendered best results at pH values of 5 to 7.

3. Bacteriological Parameter

A bacteriological parameter must be measured to ensure user health and hygiene and to reduce or eliminate biodegradation of urine that causes odor and other associated problems.

a. Total Coliform Count - Microorganism commonly found on the anterior urethra of healthy human subjects (28) are: (a) *Escherichia coli*, (b) *Klebsiella aerogenes*, (c) *Proteus mirabilis*, (d) *Pseudomonas aeruginosa* , and (e) *Alcaligens faecalis*. Due to the involved bacteriological techniques of culturing these organisms the decision was made to only culture *E. coli*. This organism may be cultured very easily and does provide a good indication of the effectiveness of disinfection. The coliform group of bacteria has been used as the principal indicator of the suitability of a particular water. Researchers have established the significance of coliform group densities as criteria of the degree of pollution and thus of sanitary quality of the water sample under examination. Ten thousand coliform colonies per 100 milliliters (ml) of water has been recommended for flushing water (23). The Table below summarizes the parameters considered.

SUMMARY OF EXPERIMENTAL PARAMTERS

Physical	Chemical	Bacteriological
Odor	COD	Total Coliform
Color	TKN	
Temperature	pH	
Turbidity		

B. Experimental Procedures and Test Set Up

1. Ozonation

Pooled urine samples were collected. A one liter of diluted urine (with demineralized water, 1:1 by volume) was prepared from the pooled urine batch and placed under ozonation for 30, 90, 180 and 300 minutes contact time respectively. Tests were performed in a batch of a 1:1 dilution urine solution. The pH of the diluted urine was not adjusted since it did not vary considerably (6.20 - 6.55). To prepare the second and third batch a 1:1 (by volume) solution was prepared with the treated diluted urine. The objective was to investigate any build up of impurities. Table 1 in Appendix 2 shows the experimental set-up and operational characteristics of the ozonation system. Figure 3 in Appendix 1 depicts the physical arrangement of the system. A flow diagram reflecting the operation of the system is shown in Figure 4 in Appendix 1.

Ozone is a relatively unstable gas and is generated by the reaction of an oxygen containing gas (air or pure oxygen) in an electric discharge called a corona. The instability of the ozone molecule with respect to decomposition back to oxygen requires an on-site production. Rosen (29) states that currently all large-scale commercial ozone generators operate on the corona discharge principle. He also comments on the fact that the only viable technique which may compete with corona ozone production is the use of nuclear power to convert oxygen to ozone.

During this study the feed gas employed was commercially available oxygen. The pressure and flow were kept constant. The author performed ozone production tests and found that 10 psig pressure and an oxygen flow of 0.20 l/min. were optimum for producing ozone.

The concentration of ozone applied was 81 mg/l. Samples were taken at the end of each designated contact time and analyzed for their physical, chemical and biological parameters. The gas line going to the ozonator had a control valve by which the gas flow rate was controlled. The experiment was performed at room temperature.

For the detection of leaks in the gas lines of the experimental system, a filter paper coated with a 10 percent aqueous potassium iodide solution was used. A color change of the filter paper from white to brown indicated the ozone leakage.

The ozone production was performed by placing a porous diffuser (50 microns) into a glass cylinder so that the gas stream was forced through the potassium iodide (KI) solution in the form of fine bubbles. The ideal amount of the gas to pass through the KI solution was generally about 60 liters. The solution then was transferred to a one liter flask, and was acidified to a pH below 2 with 1 N sulfuric acid. Grace Pollution Control Systems (3) shows that one molecule of ozone liberated equimolar amounts of oxygen and iodine when the pH medium is 2 according to the classical equation.

$$O_3 + 2H^+ + 2I^- \rightleftharpoons O_2 + I_2 + H_2O \qquad (1)$$

After the aliquots were acidified with sulfuric acid, the solution was titrated with 1N sodium thiosulfate solution with starch as the indicator. The end point was detected by a color change, the color going from blue-black to colorless.

A second glass cylinder equipped with a porous diffuser

(50 microns), containing 400 milliliters of potassium iodide was installed at the end of the gas line carrying ozone residual from the reactor. A foam trap was placed ahead of this glass cylinder to collect any foam produced.

2. Ozonation - Ultraviolet Radiation

This experiment was conducted with the same set up and in the same manner as the ozonation (See Figure 1), except that the UV lamp (Westinghouse Sterilamp 637T6VH) was turned on during the specified ozone contact times. Figure 5 in Appendix 1 illustrates the location of the UV lamp in relation to the rest of the system. Table 2 in Appendix 2 lists the experimental set-up and operational characteristics of the Ozone-UV system.

3. Activated Carbon Adsorption

Activated carbon adsorption isotherms were performed using 800 milliliters (ml) of diluted urine (1:1 by volume). The carbons tested were (a) NUCHAR WV-L, (b) NUCHAR WV-G, (c) DARCO HD-3000, and (d) FILTRASORB 300. These isotherms experiments provided information on how effectively a specific carbon adsorbed impurities contained in the diluted urine, and whether it was worth conducting the time-consuming carbon column studies. Six beakers were filled with 800 ml of diluted urine each. Five contained different amounts of carbon (325 mesh). The sixth beaker was the blank (without carbon). The carbon-urine solutions were agitated simultaneously for 10, 20, 30 and 60 minutes. At the end of the above contact time a sample was taken from each beaker, filtered (to remove trace carbon) and analyzed for the parameters described previously. The adsorption isotherms were performed at room temperature.

The adsorption isotherm shows the distribution of organic contaminants (adsorbate) between the adsorbed and the solution phases. A plot of the amount of impurity adsorbed against the amount of impurity remaining in solution was obtained. In this case (liquid phase) one generally obtains straight line plots by making use of the empirical line plots by making use of the empirical Freundlich (32) equation which relates the amount of impurity in the solution phase to that in the adsorbed phase by the expression:

$$X/M = kc^{1/n} \qquad (2)$$

where X = amount of contaminant adsorbed

M = weight of carbon

X/M = concentration in the adsorbed state (i.e., the amount of contaminant adsorbed per unit weight of carbon)

c = remaining contaminant concentration in solution

k,n = constants

In logarithmic form:

$$\log X/M = \log k + 1/n \log c$$

$1/n$ represents the slope of the straight line isotherm.

An adsorption isotherm was not performed using FILTRASORB 400 because Sulick (31) had used it for the same application with satisfactory results. The types of carbons selected were NUCHAR WV-L and FILTRASORB 400.

Activated carbon adsorbs organic contaminants in water. In the adsorption process, removal of organic contaminants occurs when the impurities contact the surface of the carbon (adsorbent). The large surface area is due to the great number of pores within each activated carbon particle. Carbon powder has larger surface area than the same volume of granular carbon. However, separating carbon powder after adsorption process from water is very difficult and expensive.

a. Carbon Columns

(1) NUCHAR WV-L

The carbon column study consisted of two plexiglass columns connected in series. Figure 6 and 7 illustrate the physical arrangement and flow diagram of the column system respectively in Appendix 1. Table 3 in Appendix 2 lists the construction and operational characteristics of the activated carbon adsorption system using NUCHAR WV-L.

Pooled urine samples were collected in 1 liter wide-mouth plastic bottles and stored in 8°C refrigerator. Once 12 liters of raw urine were collected, this volume was diluted with deminerilized water (1:1 dilution by volume).

The required amounts of carbon were placed in deionized water and left overnight to ensure that all the gases entrapped in the carbon pores were forced out. Each column was filled half full with deionized water, then the carbon was carefully poured into the column, making sure that the liquid level remained above the surface of the carbon. Backwash of the carbon followed with deionized water to remove entrained air and fines. The carbon was then allowed to settle while allowing the water to drain to a level about 1 inch above the carbon bed. The depth of the bed was measured and its volume calculated. Retention time for the diluted urine to be treated was calculated.

$$\text{Retention Time} = \frac{0.4 \times \text{Carbon Bed Volume}}{\text{Flow Rate}} \qquad (3)$$

where: 0.4 is the void fraction in the carbon bed

The diluted urine was placed in the influent storage containers and pumped at the given flow rate (see Table 3 in Appendix 2). Samples were collected at certain time intervals and analyzed for the parameters listed, until the carbon was exhausted. When the impurity concentration in the effluent from the second column became greater than the standard concentration allowed, the carbon column was considered to have breakthrough. Flow measurements were performed at regular intervals, at the influent and effluent ends. When the flow at the effluent was less than at the influent the columns were backwashed with distilled water for 15 minutes. The reason for having two pumps to pump diluted urine was to alternate the pumping since the operation was carried out continuously, day and night.

Two different flow rates were used to determine how much flow rate would affect the adsorption rate. Generally, increasing the flow rate will reduce the volume of acceptable effluent produced at any given bed depth (31). This data is usually obtained by experiment. Records were kept for the total volume of diluted urine processed.

(2) FILTRASORB 400

During the adsorption studies with FILTRASORB 400, the same column system, as used with NUCHAR WV-L was utilized (see Figures 4 and 5 in Appendix 1). Table 4 in Appendix 2 illustrates the experimental set-up and operational characteristics of the carbon adsorption system. The operational procedures were the same as NUCHAR WV-L except the flow rate of 4 ml/min. was changed to 14 ml/min.

4. Ultraviolet Radiation

One liter of diluted urine was placed in an Aquafine Electronic Liquid Sterilizer (Model SL-1), see Figure 1 and Table 1 in Appendix 1 and 2 respectively. The diluted urine was exposed to UV radiation for 30, 90, 180 and 300 minutes respectively. Samples were taken at the end of each contact time and analyzed for the water quality parameters. The percent of UV intensity applied was 85. The intensity of radiation, generally means the rate of supply of radiation energy, to a unit area of flat surface, for example a square centimeter, perpendicular to the direction of radiation (33). Although UV is primarily used as a disinfecting agent, the author was interested to know if there were significant photochemical reactions induced by UV radiation that would affect on dissolved organics reduction. Results show that there may be photochemical reactions because there was some reduction in the parameters.

5. Carbon Regeneration by Ozonation

In order to perform the experiment, two experimental apparatus were fabricated; (a) a plexiglass column, and (b) a plexiglass carbon-ozone contactor. Figure 8 in Appendix 1 shows the apparatus. The carbon-ozone contactor had two sections connected by drilled flanges and associated handware to facilitate the cleaning of the porous diffuser. Table 5 in Appendix 2 depicts the construction and operational characteristics of the carbon regeneration system and Figure 9 in Appendix 1 illustrates the ozone flow diagram.

The carbon (free of entrained gases) was placed in the column and backwashed with deionized water to clean the carbon and remove the fines. Diluted urine was then pumped through the column. Samples were taken at regular intervals and analyzed for the required parameters until breakthrough was reached. The carbon was then taken out from the column and washed with demineralized water to remove solids. The carbon was placed in the carbon-ozone contactor, filled with deionized water. First, the exhausted carbon was submitted to aeration with oxygen for 300 minutes. The purpose of submitting the carbon to aeration was to investigate if the mechanical action would affect the regeneration of the carbon. After the aeration time the carbon was placed in the column and diluted urine was pumped through the bed. After 30 minutes the effluent was sampled and analyzed. The carbon was discarded.

A second column, with virgin carbon was submitted to diluted urine until breakthrough was reached. This carbon was washed with deionized water and placed in the carbon-ozone contactor filled with deionized water. Ozone was applied for a period of 300 minutes. During both experiements (Aeration and Ozonation) carbon particles were suspended in the water.

After the 300 minutes had elapsed the carbon was taken out and placed in the column. Diluted urine was pumped through the carbon bed. Samples were taken and analyzed.

C. Analytical Measurements and Methods

The measurements made during this study include those on the untreated and treated liquid samples for COD, TKN, Color, Odor, Turbidity concentrations and pH. Temperature was monitored. Disinfection experiments were conducted separately. Samples were taken in sterilized 50 ml test tubes for coliform test. Samples for measurement of other parameters were taken in 150 ml plastic bottles.

During Ozonation, Ozonation - Ultraviolet Radiation and Ultraviolet Radiation experiements samples were taken when the specified contact times had elapsed. During the Carbon Adsorption Column experiments samples were taken at adequate regular time intervals and filtered to remove any carbon particles since these tend to give false COD results.

1. Chemical Oxygen Demand (COD)

Since COD concentration of diluted urine was quite high (maximum of 6000 mg/l) dilution of the sample was necessary before preparation of the COD sample. Dilutions of the influent samples were prepared at 1:100 (by volume), and effluent samples at 1:10 (by volume). COD samples were prepared according to the procedure described in Standard Methods (34).

Urine strength varies considerably depending on the diet of the contributing individual (6). Sulick (31) was involved in experiments to recycle urine for human consumption and stated that longer digestion time (3 to 4 hours) gave them more uniform COD results. Since the author experienced great variations in COD results a decision was made to experiment with 3 and 4 hours of digestion time. After the COD tests were performed results showed little difference between 3 and 4 hours digestion, therefore, 3 hours was used. COD test results after 3 hours digestion were observed to be more uniform. The results are reported in milligrams per liter (mg/l).

2. Total Kjeldahl Nitrogen (TKN)

Due to the lack of proper equipment to run TKN at CEL the samples were sent to a local water chemical laboratory, BTC Laboratories in Ventura, California.

The samples were taken, diluted 1:4 (by volume) and preserved with Sulfuric Acid in accordance with Standard Methods (34). These samples were refrigerated until they were transported to the BTC laboratories. The refrigeration never exceeded 3 days. Results are reported in milligrams per liter (mg/l).

3. Color and Turbidity

These parameters were performed by means of a HACH DR-IR Colorimeter. Twenty-five milliliters (ml) sample of the treated and untreated urine were placed in a colorimeter bottle. A colorimeter bottle filled with deionized water was used as reference to zero the instrument before each reading was performed. The proper color meter scale and color filter was placed in the instrument before each reading.

Since the diluted urine influent samples had a high color and turbidity values they were filtered through a 0.45 micron Millipore filter. The filtered diluted urine sample was used as a blank to zero the instrument when the burbidity of the influent sample was measured.

Color values are reported in "Color Units". Turbidity values are reported as Jackson Turbidity Units (JTU).

4. Odor

This parameter was measured according to the procedure described in Standard Methods (34). A panel of three persons was employed to determine the threshold of odor in the samples. Dilutions were prepared, according to Table 217 (1) of Standard Methods, before the panel would arrive. The dilution flasks were coded to avoid any bias tendencies. Odor-free water was prepared by passing deionized water through a carbon packed column and collected in a sealed container before being used in the dilutions.

Odor tests were performed immediately after the samples were taken. Results are reported as Odor-Intensity Index (OII).

5. pH

pH value of the samples were determined with a Beckman Digital (Model 3500) pH meter.

6. Temperature

Temperature of the collected samples were measured using a conventional Mercury thermometer.

7. Bacteriological Analysis

Disinfection experiments were performed separately from other previous experiements. One liter of diluted urine sample was inoculated with E. coli and submitted to 5, 15, 20, and 30 minutes of Ozonation and Ozonation-Ultraviolet Radiation respectively. When UV Radiation alone was experimented the inoculated urine was submitted to 30, 90, 180 and 300 minutes of exposure time.

The E. coli inoculum was prepared by aclimating a stock culture of pure E. coli to the diluted urine. Each day, a fresh inoculum (18 hours of incubation) was prepared. Fifteen milliliters of the inoculum were placed in one liter of diluted urine sample and placed in the disinfection reactor.

A control sample (inoculated diluted urine not submitted to disinfection treatment) was kept at room temperature. Whenever a sample was taken from the disinfecting unit, a sample was taken from the control. This was done to investigate natural death rate.

Membrane filter technique for Coliform Bacteria outlined in Standard Methods (34) was employed to determine the effectiveness of the disinfection processes. This technique was selected due to its high reproducibility and ability to yield definite results more rapidly than the standard dilution method.

Triplicates of every sample were analyzed for better data interpretation.

8. Ozone

The ozone concentration in the influent gas flow was determined at six different times during the experiment using iodometric method described in Standard Methods (34). Since gas flow rate and pressure did not change the average value of these six determinations was used as constant ozone concentration in the gas. The Table below shows a summary of experimental procedures and methodologies.

SUMMARY OF EXPERIMENTAL PROCEDURES AND METHODOLOGIES

Methods	Parameters	Analytical Techniques
Ozonation*	Odor	Dilution
	Color	Colorimetric
	Temperature	Conventional Thermometer

SUMMARY OF EXPERIMENTAL PROCEDURES AND METHODOLOGIES (Continued)

Methods	Parameters	Analytical Techniques
	Turbidity	Turbidimeter
	COD	Potassium Dichromate
	TKN	Digestion
	Total Coliform	Millipore Filtration
Ozonation-UV*	Same as above	Same as above
Ultraviolet	Same as above	Same as above
Carbon Adsorption	Odor	Dilution
	Color	Colorimetric
	Temperature	Conventional Thermometer
	Turbidity	Turbidimeter
	COD	Potassium Dichromate
	TKN	Digestion
Carbon Regeneration* bu Ozonation	Odor	Dilution
	Color	Colorimetric
	Temperature	Conventional Thermometer
	Turbidity	Turbidimeter
	COD	Potassium Dichromate
	TKN	Digestion

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* Ozone was analyzed by the Potassium Iodide technique.

CHAPTER III

EXPERIMENTAL RESULTS

The results presented herein include those resulting from all the unit treatment processes studied.

A. Ozonation

Three different experiments were conducted to investigate the removal rates of COD, Color, Odor, Turbidity and TKN. Effects of pH and temperature were evaluated. The procedure for conducting these experiments has been described in previous sections. The conditions and data collected during the experiments are tabulated in Appendix 3. The Tables below show the percent remaining and initial concentration of impurities for each run after each contact time and before ozonation respectively. TKN was analyzed only after 300 min. of contact time. Figures 10-14 in Appendix 1 illustrate the rate of reduction of COD, Color, Odor, Turbidity, and TKN respectively.

Disinfection of diluted urine was conducted separately but under the same operational conditions as the other Ozonation experiments. The data obtained during the disinfection experiment by Ozonation is given in Appendix 4. The Table below gives the percent of _E. coli_ remaining after being subjected to Ozonation.

PERCENT INPURITIES REMAINING AFTER OZONATION

Run	Cum. Contact Time,min.	Percent Remaining				
		COD	Color	Odor	Turbidity	TKN
1	30	65	90	80	102	
	90	58	20	70	12	
	180	53	5	60	0	
	300	48	11	60	6	94
2	30	93	82	80	100	
	90	84	31	64	33	
	180	79	15	64	11	
	300	68	3	55	0	100
3	30	84	58	73	46	
	90	81	25	64	25	
	180	78	12	55	11	
	300	67	7	45	14	100

INITIAL IMPURITIES CONCENTRATION BEFORE OZONATION

Run	COD mg/1	COLOR Units	ODOR OII	TURBIDITY JTU	TKN mg/1
1	5808	455	10	83	3920
2	3816	390	11	75	3400
3	5724	430	11	104	5400

PERCENT E. coli REMAINING AFTER OZONATION

Contact Time, min.	Control*	Sample**
5	98	73
15	82	1
20	91	0
30	72	0

* Initial E. coli concentration 1.14 x 10^8

** Initial E. coli concentration 1.14 x 10^8

B. Ozonation - Ultraviolet Radiation

Three different experiments were conducted to investigate the efficiency of impurities removal using the combination of Ozonation and Ultraviolet Radiation. The procedure for conducting these experiments is described in the previous section. Conditions and data of the experiments are given in Appendix 5.

The Tables below show the percent remaining and initial concentration of impurities for each run after each contact time and before ozonation-UV respectively. TKN was analyzed only after 300 minutes of contact time.

PERCENT IMPURITIES REMAINING AFTER OZONATION - ULTRAVIOLET RADIATION

Run	Cum. Contact Time, min	Percent Remaining				
		COD	COLOR	ODOR	TURBIDITY	TKN
1	30	65	97	73	100	
	90	62	13	64	0	
	180	58	10	64	0	
	300	46	8	45	14	97
2	30	84	71	82	77	
	90	72	0	64	77	
	180	67	0	55	0	
	300	49	12	55	13	98
3	30	71	76	82	56	
	90	61	46	64	56	
	180	52	30	55	7	
	300	40	6	45	0	99

INITIAL IMPURITIES CONCENTRATION BEFORE OZONATION-UV

Run	COD mg/1	COLOR Units	ODOR OII	TURBIDITY JTU	TKN mg/1
1	5034	380	11	70	3488
2	5221	340	11	62	3672
3	4819	330	11	70	5600

Figures 15-19 in Appendix 1 illustrate the rate of reduction of COD, Color, Odor, Turbidity and TKN respectively.

Disinfection of diluted urine was conducted separately but under the same operational conditions as the other Ozonation -UV Radiation experiments. The data obtained during the disinfection experiment by Ozonation-UV Radiation is given in Appendix 4. The Table below gives the percent of E. coli remaining after being subjected to Ozonation-UV Radiation.

PERCENT E. coli REMAINING AFTER OZONATION - ULTRAVIOLET RADIATION

Contact Time, min.	Control*	Sample**
5	92	55
15	66	0
20	60	0
30	59	0

* Initial E. coli concentration 11.3 x 10^7

** Initial E. coli concentration 11.3 x 10^7

C. Ultraviolet Radiation

Although primarily a disinfection agent, UV can cause some reduction in organic matter content in the diluted urine. Two different experiments were conducted to investigate the degree of reduction. In each experiment, one liter of diluted urine was subjected to UV Radiation. The procedure for conducting these experiments is described in Chapter II. Conditions and data of the experiments are provided in Appendix 5. The Tables that follow show the percent remaining and initial concentration of impurities for each run after each contact time and before UV respectively. TKN was analyzed only after 300 minutes contact time. During the second run TKN was not analyzed because the results of the other parameters indicated that it was not necessary.

PERCENT IMPURITIES REMAINING AFTER ULTRAVIOLET RADIATION

Run	Cum. Contact Time, min.	COD	COLOR	ODOR	TURBIDITY	TKN
1	30	64	95	92	78	
	90	61	97	83	76	
	180	61	108	83	72	
	300	63	114	92	68	91
2	30	65	87	90	91	
	90	62	88	80	77	
	180	61	109	80	71	
	300	64	113	90	67	-

INITIAL IMPURITIES CONCENTRATION BEFORE ULTRAVIOLET RADIATION

Run	COD mg/l	COLOR Units	ODOR OII	TURBIDITY JTU	TKN mg/l
1	3956	370	12	50	4500
2	4064	300	10	75	-

Figures 20-23 Appendix 1 illustrate the reduction rates of COD, Color, Odor, and Turbidity respectively.

Disinfection of diluted urine was conducted separately but using the same operational conditions as the other UV Radiation experiments. The data obtained during the disinfection experiments with Ultraviolet Radiation is given in Appendix 6. The Table below presents the percent _E_. _coli_ remaining after being subjected to Ultraviolet Radiation.

PERCENT _E_. _coli_ REMAINING AFTER ULTRAVIOLET RADIATION

Contact Time, min.	Control**	Sample†
30	67	69
90	57	U*
180	56	U
300	52	U

* Undetermined, unable to count the plates using lower dilution rates than control

** Initial _E_. _coli_ concentration 9.7×10^7

† Initial _E_. _coli_ concentration 9.7×10^7

Researchers (33) have recognized that the influent treated with Ultraviolet Radiation must be reasonably clear and free from excessive color to allow penetration of the UV light. In view of the results obtained the author decided to conduct an experiment with clear tap water inoculated with E. coli. Appendix 7 gives the data obtained. The COD of the inoculated tap water was 160 mg/l, Color was 35 units, and Turbidity was 3 Jackson Turbidity Units (JTU). The disinfection of the inoculated tap water was conducted under the same conditions as the disinfection of the inoculated diluted urine. The Table below gives the percent E. coli remaining after the inoculated tap water was exposed to Ultraviolet Radiation. Appendices 8-9 give the data obtained during the disinfection of inoculated diluted urine and tap water respectively.

PERCENT E. coli REMAINING AFTER ULTRAVIOLET RADIATION

Contact Time	Control**	Sample*+
5	88	69
20	81	63
35	81	31
50	94	13
65	81	25
75	75	0

* Inoculated tap water

** Initial E. coli concentration 16 x 10^7

\+ Initial E. coli concentration 16 x 10^7

D. Carbon Adsorption

Four different types of carbon were tested by conducting adsorption isotherms. The procedure for conducting these adsorption isotherms has been described in Chapter II. The conditions and data for NUCHAR WV-L, NUCHAR WV-G, DARCO HD 3000, and FILTRASORB 300 isotherms are given in Appendices 10-13 respectively. The isotherm plots for the above carbons are illustrated in Figures 24-27 of Appendix 1 respectively. NUCHAR WV-L isotherm characteristics were far superior to the other carbons tested, and for this reason was employed in the column experiments. The conditions and data of the column experiments for NUCHAR WV-L and FILTRASORB 400 are listed in Appendixes 14-21. The procedure for conducting the column experiments has been described in Chapter II. Breakthrough curves (for each required parameter) for NUCHAR WV-L and FILTRASORB 400 were attained and plotted. Figures 28-36 in Appendix 1 illustrate the breakthrough curves for NUCHAR WV-L in columns 1 and 2 at Q/A = 1.0 gpm/sq. ft. TKN was analyzed in the column 2 effluent, therefore, breakthrough curve for this parameter is only shown for column 2. Figures 37-45 in Appendix 1 illustrate breakthrough curves for NUCHAR WV-1 in columns 1 and 2 at Q/A = 0.5 gpm/sq. ft. The percent impurities remaining, calculated from the results obtained during carbon adsorption using NUCHAR WV-L at Q/A = 1.0 and 0.5 gpm, are summarized in Tables 6 and 7 respectively in Appendix 2.

Figures 46-54 in Appendix 1 illustrate breakthrough curves for FILTRASORB 400 in columns 1 and 2 at Q/A = 1.0 gpm/sq. ft.

Breakthrough curves in columns 1 and 2 at Q/A = 1.75 gpm/sq. ft. for FILTRASORB 400 are illustrated in Figures 55-63 in Appendix 1. The percent impurities remaining during the column experiment using FILTRASORB 400 at Q/A = 1.0 and 1.75 gpm/sq.ft., for columns 1 and 2 are given in Tables 8 and 9 respectively in Appendix 2.

E. Carbon Regeneration by Ozonation

Two different experiments were conducted to regenerate a fixed amount of exhausted FILTRASORB 400 (14 grams). The procedure for conducting these experiments was described in Chapter II. One of the experiments was conducted by applying commercial oxygen to the exhausted carbon. The objective was to determine the degree of regeneration without ozone. Conditions and data for the regeneration of FILTRASORB 400 by means of Oxygenation and Ozonation are given in Appendix 22. The Table below gives the percent impurities remaining during the carbon regeneration experiments.

PERCENT IMPURITIES REMAINING DURING CARBON REGENERATION

		COLUMN*			
Cum. Vol. Liters	COD	COLOR	ODOR	TURBIDITY	TKN
0.69	50	38	60	64	95
9.61	70	63	70	73	
12.35	85	93	100	100	111
The results below were obtained after 5 hours of OXYGENATION					
0.69	91	69	100	71	98

PERCENT IMPURITIES REMAINING DURING CARBON REGENERATION (Continued)

		COLUMN*			
Cum. Vol. Liters	COD	COLOR	ODOR	TURBIDITY	TKN
0.35	75	30	70	63	78
6.24	72	90	90	80	
8.55	75	77	90	74	
10.40	98	91	100	100	
11.78	104	103	100	100	91
The results below were obtained after 5 hours of OZONATION					
0.46	92	76	100	81	91

* Average initial impurities concentration
COD = 3555 mg/l
COLOR = 340 units
ODOR = 10 OII
TURBIDITY = 74 JTU
TKN = 3190 mg/l

Appendix 23 gives the volume of diluted urine processed by the regenerated carbon before acceptable values were exceeded.

The Table that follows summarizes the average range of percent removal of impurities by the unit treatment processes studied.

SUMMARY OF AVERAGE RANGE OF PERCENT IMPURITIES REMOVAL

Method	COD	COLOR	ODOR	TURBIDITY	TKN	COLIFORMS
Ozonation	19-39	23-93	22-46	18-93	0-6	27-100
Ozonation-UV	26-55	18-91	21-51	22-91	0-2	45-100
UV	35-36	0- 9	0- 9	15-32	0-9	0- 31

SUMMARY OF AVERAGE RANGE OF PERCENT IMPURITIES REMOVAL (Continued)

Method	COD	COLOR	ODOR	TURBIDITY	TKN	COLIFORMS
Carbon Adsorption						
NUCHAR WV-L	66-83	69-78	45-60	21-88	19-74	-
Filtrasorb 400	65-80	86-95	39-60	75-90	45-80	-

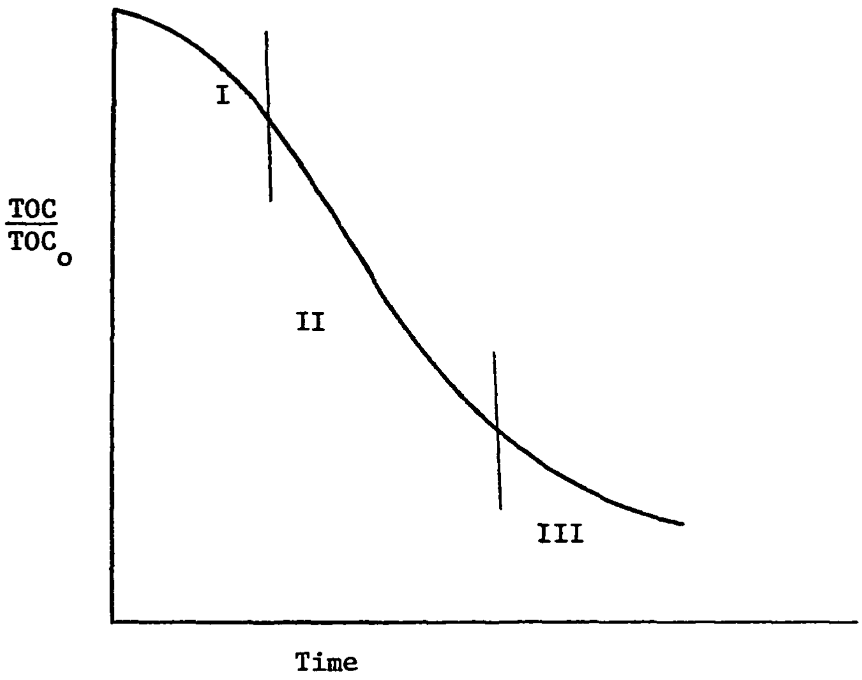
CHAPTER IV

DISCUSSION OF EXPERIMENTAL RESULTS

The reclamation of flushing water from diluted urine by Ozonation, Ozonation-UV Radiation, UV Radiation and Carbon Adsorption was conducted. Effectiveness of these processes was evaluated in terms of removing rates of COD, Color, Odor, Turbidity, E. coli and TKN in the urine sample. The experimental conditions and data are given in Appendix 3-23.

A. Ozonation

The materials with which ozone reacts during the experiment were primarily organic substances. Among these substances living organisms, toward which disinfection is directed, are included. Investigators (36) have concluded that ozone is a powerful oxidizing agent and has an electronegative oxidation potential exceeded only by flouride. Ozone reduces or eliminates organic compounds causing color, odor, and oxidizes many toxic chemicals. The overall reaction rate of ozone with organic matter in diluted urine covers three phases. The initial phase, I (mass transfer control) is a fast reaction which involves the transfer rate of ozone from the gaseous phase to the liquid phase. Phase II, major reaction, involves the combination of mass transfer and the reaction rate of the transferred ozone with the organics. The final phase, tail end, Phase III, is called reaction rate controlled (37). The Figure below illustrates the sequence of the above phases.



The efficiency of phase I is a function of the porosity of the gas diffusion device. The optimum bubble size has been found to be 0.25 centimeters (0.1 in.) (9).

From data on ozonation of diluted urine shown in Table 6 one can observe that the compounds causing color and turbidity were oxidized more readily. TKN, which includes both organic nitrogen and free ammonia, was not oxidized in the last two runs. In the last run only 5 percent (%) was removed. The TKN increase may possibly be attributed to the BTC laboratories experimental error which was out of the author's control.

Odor was decreased to an odor intensity index (OII) of 5 in 300 minutes of ozonation (Appendix 3). This is two units above (more odorous) the recommended value for flushing water described by a report of the U.S. Department of Interior (23) which indicates 3 OII as an acceptable odor level for flushing water. Through careful observations by the author and a panel of individuals used to evaluate the odor threshold of treated and untreated samples, a value of 7 OII was designated an acceptable value, for a field head unit. At this odor intensity value, turbidity ranged from 10 to 26 JTU which based on the Department of Interior flushing water standards is satisfactory. The recommended value is 20 JTU. The color does not comply with the standards since it ranged from 90 to 120 units, after 90 min. ozonation (30 units is recommended). This is not a major problem, however, since stainless steel commondes and urinals will be used, and slight color differences will not be as readily seen. This was tested by placing 500 ml of treated sample with a color value of 130 units in a stainless steel pan next to another stainless steel pan containing the same volume of tap water. There was no difference in the appearance of the samples. Based on this observation flushing water could be recovered from diluted urine with only 90 minutes of ozonation.

All the parameters in the untreated (influent) diluted urine fluctuated to some extent, and was expected, since the strength of urine fluctuates with the diet and liquid intake habits of the individuals (6). However, the value of the concentrations of the parameters did not seem to fluctuate considerably with the exception of COD and TKN which ranged from 3200 to 6000 mg/1.

Multiple correlation analysis was performed to investigate the relationship between the parameter values obtained during the Ozonation experiment. This statistical analysis was performed by means of a pre-programmed tape and a Hewlett Packard programmable calculator (Model 9815A). The Table that follows gives the correlation coefficients obtained. The closer the value of a correlation coefficient to 1.0 the better correlation exist between the two parameters, and this means that if one parameter cannot be measured by knowing the other a close approximation of the former may be derived. In this case color and turbidity correlate very closely; therefore color could be estimated from turbidity. The next highest degree of correlation is color and odor.

At the beginning of each run considerable foaming occurred during the first 15 minutes of ozonation. The color of diluted urine was a light straw-like yellow. After 30 minutes of ozonation the color was very faint yellow. The color after 90 minutes was not yellow but a cloudy white.

CORRELATION COEFFICIENTS
(OZONATION)

Correlated Parameters*	Coefficients
1 & 2	0.66
1 & 3	0.67
1 & 4	0.65
2 & 3	0.87
2 & 4	0.94
3 & 4	0.86
1 & 5	0.06
2 & 5	-0.31
3 & 5	-0.43
4 & 5	-0.20

* 1 = COD
2 = Color
3 = Odor
4 = Turbidity
5 = TKN

As stated in Chapter II, to investigate any build-up of impurities, diluted urine to be treated on the second run was prepared by a 1:1 dilution (by volume) with treated effluent from the first run. The third run batch was prepared with treated effluent from the second run. The treated effluent used to dilute the urine had been subjected to Ozonation for 300 minutes. The build up of impurities may be noticed in Figures 10 - 14 in Appendix 1. Generally, the percent of impurities remaining in the effluent during the first run was lower than subsequent runs.

During the disinfection experiment _E. coli_ was completely killed after 30 minutes of ozonation. These results were obtained in triplicate to insure experimental accuracy.

B. Ozonation - Ultraviolet Light Radiation

Jain (38) has found that the introduction of UV during ozonation under certain conditions enhances the oxidation effect. The experimental results clearly showed however that odor intensity did not improve with addition of UV radiation to ozonation after 90 minutes contact time. Theoretically, the odor should have improved. The color and turbidity reduction values were greater than the values obtained using ozone without UV. The color, of the effluents, especially during the first two runs was clear. The TKN was not easily oxidized. COD reduction improved with the addition of UV by about 12 to 20 percent.

In this experiment diluted urine inoculated with _E. coli_ was disinfected in 20 minutes (10 min. less than with Ozone without UV).

The build up of impurities due to the use of previous test effluent to dilute the new urine batch is not noticeable from the data obtained.

A significant point of interest, since the reduction of organics was not considerably greater than the reduction obtained by ozonation alone, is that the gas-liquid contact was not very thorough in both experiments (O_3 and O_3-UV). The same contactor was used for both O_3 and O_3-UV experiments but only during the O_3-UV tests was the UV lamp turned on. The fact that the diffusers, as described in Chapter II, were not very large (small surface area) due to the configuration of the contactor used may have been a contributing factor in the poor ozonation.

Having diffusers with a greater surface area could have cause more turbulence. This was observed by the author before installing the diffusers in the ozone contactor (stainless steel).

The author's hypothesis is that there was probably not enough turbulence in the ozone contactor. Gas-liquid contact must be very thorough in order for ozonation to operate satisfactory and this is accomplished by providing a high degree of turbulence (high shear rate) within the contactor. Such conditions must exist in order to have an efficient mass transfer of ozone. The UV lamp was new. The liquid surrounded the lamp on all sides but the thickness of the active reaction zone due to UV may have been affected by the presence of dissolved solids, organic matter, and high color. Perhaps multipoint introduction of ozone could increase the mass transfer efficiency by minimizing loss of ozone due to the auto-decomposition reaction (breakage of ozone molecule).

Temperature of the diluted urine (18°C) increased to 30°C in 300 minutes of UV Radiation. The solubility of ozone in 40°C water is about 30 percent (8) of that in 20°C water. Therefore, temperature niether lowered the rate of oxidation nor added to the destruction of test microorganisms.

The Table below gives the correlation coefficients of the parameters tested during this experiment.

CORRELATION COEFFICIENTS
(OZONATION - ULTRAVIOLET RADIATION)

Correlated Parameters*	Coefficients
1 & 2	0.75
1 & 3	0.93
1 & 4	0.76
1 & 5	-0.10
2 & 3	0.88
2 & 4	0.99
2 & 5	-0.03
3 & 4	0.87
3 & 5	0.00
4 & 5	-0.00

*
1 = COD
2 = Color
3 = Odor
4 = Turbidity
5 = TKN

COD, Color, Odor and Turbidity during both experiments (Ozonation and Ozonation-UV) seem to be well correlated. TKN values, however did not correlated with the other paramters.

C. Ultraviolet Radiation

UV is a disinfection agent. Therefore, tests were conducted to investigate other possible effects, directly/indirectly, by UV Radiation. There was some reduction on some parameters. Odor was not reduced to any significant level and the Color increased substantially as the UV contact time increased. The UV evidently caused a reaction or reactions which resulted in the formation of highly colored products. There was a 13 to 14 percent increase in Color at the end of 300 minutes contact time. This would decrease the depth of UV penetration thus reducing the UV efficiency. Investigators have found that water must be reasonably clear and free from excessive color to allow the penetration of Ultraviolet Radiation (38, 33, 22).

During the disinfection experiment with UV Radiation a reduction in _E_. _coli_ was observed after 30 minutes of exposure time. The plates corresponding to 90, 180 and 300 minutes of contact time could not be counted. The dilutions were carried out to 10^{-4} in triplicate but the colonies were still too numerous to be counted. Disinfection experiments were only performed twice. These results reinforce the findings of investigators that in order to achieve a high transmission of UV water must be free from color and suspended matter which acts to shield bacteria from the radiation. Koller (33) points out that most organic liquids have such low Ultraviolet transmission that the depth of penetration is very small. He also suggests that in such liquids irradiation is only possible in very thin layers. An experiment was conducted to verify the above statements. Tap water was inoculated with _E. coli_ and subjected to UV radiation. The procedure has been described in Chapter II. Results clearly indicate a stready reduction of _E. coli_ as contact time increased. After 75 minutes the water was disinfected. This supports Koller's statement. The Table that follows presents the correlation coefficients among the parameters during the UV experiment. Correlation was poor.

CORRELATION COEFFICIENTS
(ULTRAVIOLET RADIATION)

Correlated Parameters*	Coefficients
1 & 2	-0.16
1 & 3	0.44
1 & 4	0.55
2 & 3	0.46
2 & 4	-0.74
3 & 4	-0.41

* 1 = COD
2 = Color
3 = Odor
4 = Turbidity

D. Carbon Adsorption

The adsorption isotherm results of the different carbon types considered as candidates for this study are summarized in Appendix 10 - 13. From Figures 24 - 27 in Appendix 1 the capacity of these carbons was determined as X/M (pounds of COD removed/pound of carbon) at the initial concentration C_O. The curves clearly show that NUCHAR WV-L has a higher adsorption capacity than the other carbons tested and therefore the NUCHAR WV-L was selected for the column experiments. The isotherm curve of NUCHAR WV-L is steeper than the other carbons. This generally indicates that NUCHAR WV-L has a greater rate of adsorption than the others. This is usually desirable for maximum carbon efficiency and long service life. A common organic matter removal rate has been 0.5 pounds per pound of carbon (32). FILTRASORB 400 was the second type of carbon tested. No isotherm was performed with this carbon as previous experiments by Sulick (31) have given positive results.

1. Carbon Column Tests

Although the treatability of diluted urine by carbon and the relative capacities of the carbons tested were estimated from carbon performance in adsorption isotherms. However, isotherms do not measure the potential effects of biological activity which may take place in the column during actual use (18, 25). The design criteria for carbon column should be determined by flow through carbon column tests.

The information desired from the carbon column test include:

(a) Type of carbon

(b) Contact time

(c) Bed depth

(d) Carbon dosage in terms of pounds of carbon per liters of diluted urine or pounds of organic material per pound of carbon.

(e) Breakthrough characteristics.

NUCHAR WV-L

As described in Chapter II, the column tests using this carbon were performed at two different flow rates (1.0 and 0.5 gpm/sq. ft.). The first set of breakthrough curves describe the breakthrough characteristics of the carbon under a flow rate of 1.0 gpm/sq.ft. for columns 1 and 2.

At the beginning of this Chapter (under Ozonation) the reason was explained for selecting odor parameter as limiting factor in determining carbon dosage and contact time. For this reason closer attention will be given to the odor breakthrough curve.

The first run (at 1.0 gpm/sq. ft.) was terminated when the Odor level in the effluent was the same as the influent, even though the other parameters in the effluent had not reached the influent concentration level. In subsequent runs, however, the carbon was completely saturated/exhausted (effluent concentration of all the parameters was the same as the influent concentration).

The odor level of the influent ranged from 9 to 12 units on the odor intensity index (OII). An OII of 12 will be used to evaluate all the treatment systems. An OII of 7 units was determined to be satisfactory for the head units flushing water. Therefore only a 42 percent reduction in Odor is needed. According to Figures 28 and 32 about 2.6 and 4.8 liters were processed with columns 1 and 2 respectively before exceeding the Odor value of 7 OII. At this level of Odor the levels of Color and Turbidity were still acceptable.

The second set of breakthrough curves illustrate the breakthrough characteristics of NUCHAR WV-L under a flow rate of 0.5 gpm/sq. ft. for columns 1 and 2. In Figures 37 and 41 the best fitted straight line does not intersect the 58 percent remaining mark (42 percent reduction). However by intersecting the observed curve (from test results) at the 58 percent mark, only 2.6 and 2.4 liters can be processed by columns 1 and 2 respectively before the acceptable Odor level (7 OII) is exceeded.

Changing the influent flow rate to provide a longer retention time did not increase the volume production of acceptable flushing water. Theoretically an increase in flow retention time should have extended the time before breakthrough occurred (25). TKN reduction was minimal but certainly better than with Ozone and Ozone-UV.

The Table that follows gives the correlation coefficients during adsorption with NUCHAR WV-L. Parameters in Column 2 seemed to correlate better than in Column 1.

CORRELATION COEFFICIENTS
(NUCHAR WW-L)

Flow Rate gpm/sq.ft	Correlated Parameters*	Coefficients	
		Column 1	Column 2
1.0	1 & 2	0.84	0.97
	1 & 3	0.18	0.62
	1 & 4	0.74	0.86
	1 & 5	-	0.96
	2 & 3	0.37	0.78
	2 & 4	0.91	0.95
	2 & 5	-	1.00
	3 & 4	0.19	0.94
	3 & 5	-	0.82
	4 & 5	-	0.97
0.5	1 & 2	0.71	0.95
	1 & 3	-0.04	0.95
	1 & 4	0.46	0.94
	1 & 5	-	0.43
	2 & 3	-0.23	1.00
	2 & 4	0.78	0.79
	2 & 5	-	0.69
	3 & 4	-0.21	0.79
	3 & 5	-	0.69
	4 & 5	-	0.09

*
1 = COD
2 = Color
3 = Odor
4 = Turbidity
5 = TKN

FILTRASORB 400

During the column study using FILTRASORB 400, flow rates of 1.0 and 1.75 gpm/sq. ft. were used. The breakthrough curves shown in Figures 46 - 54 in Appendix 1 illustrate the breakghrough characteristics of this carbon under a flow rate of 1.0 gpm/sq. ft. Looking at the best fitted straight lines in Figures 48 and 52 it is noted that the odor exceeds acceptable values very quickly. Furthermore the lines do not intersect the 58 percent mark. By intersecting the observed curve (from test results), Column 1 processed 2 liters and Column 2, 4.8 liters before acceptable values were exceeded. As shown previously with the NUCHAR WV-L, when the treated effluent had an acceptable odor value, color and turbidity was also at an acceptable value. TKN was poor. However this may be explained by the fact that urine has a relatively high content of inorganic nitrogen which is difficult to remove.

The second set of breakthrough curves shown in Figures 55 - 63 of Appendix 1 illustrate the breakthrough characteristics under a flow rate of 1.75 gpm/sq. ft. In Figures 57 and 61 the best fitted straight line does not intersect the 58 percent remaining mark. By referring to the observed curve at intersection of the 58 percent mark 2.0 and 4.8 liters were processed by columns 1 and 2 respectively before accepted values were exceeded.

The decrease in flow retention time did not decrease the volume of acceptable flushing water produced as shown in Figures 48, 52, 57 and 61. The Table below gives the correlation coefficients during adsorption with FILTRASORB 400.

Correlation between parameters appears to vary considerably in the first column tests.

Appendix 23 gives the volume treated by both types of carbons before acceptable values of Turbidity, Color and Odor were exceeded.

CORRELATION COEFFICIENTS
(FILTRASORB 400)

Flow Rate gpm/sq. ft.	Correlated Parameters*	Coefficients	
		Column 1	Column 2
1.00	1 & 2	0.75	0.34
	1 & 3	0.71	0.89
	1 & 4	0.51	0.83
	1 & 5	-	0.79
	2 & 3	0.66	-0.13
	2 & 4	0.91	0.66
	2 & 5	-	0.55
	3 & 4	0.53	0.52
	3 & 5	-	0.52
	4 & 5	-	0.92
1.75	1 & 2	0.92	0.98
	1 & 3	0.83	0.95
	1 & 4	0.91	0.96
	1 & 5	-	0.90
	2 & 3	0.76	0.95
	2 & 4	0.93	0.89
	2 & 5	-	0.86
	3 & 4	0.78	0.90
	3 & 5	-	0.96
	4 & 5	-	0.93

* 1 = COD
2 = Color
3 = Odor
4 = Turbidity
5 = TKN

Carbon Regeneration by Ozonation

The efficiency of regenerating FILTRASORB 400 with ozone is shown Appendix 22. Some regeneration was evident after using ozone, however, oxygenation alone caused some regeneration. This was attributed to the force of the flowing oxygen gas resuspending some organics entrained within the pores of the carbon. The reason for this theory is from the observation that the ozone gas did not regerate the carbon any better than the oxygen gas. The ozone once in solution did not penetrate the pores to oxidize the organics. The regeneration accomplished by ozone was minimal as shown by the fact that odor in the effluent (treated with carbon that was ozonated) was the same as in the influent.

Design Criteria

As mentioned in Chapter I, the objective of this research effort was to establish unit process design criteria so that the process will treat the urine liquor to meet technical quality criteria of odor, color, organic matter and bacteria content to be used as flush water. The criteria used in the design of the twenty-men flush water purification systems is the following:

1. Capacity

   20 men

2. Volume of diluted urine to be treated

   Six urinations/man/day (1 for commode and 5 for urinals)

Urine to commode will be evaporated

Urine to urinals will be treated

a. (5 urinations/man/day)(20 men/day) = 100 urinations/day

b. at 250 ml urine/urination

(250 ml urine/urination) (100 urinations/day)

= 25,000 ml urine/day

c. Flushing water, 500 ml/flush

(500 ml/flush) (100 flushes/day)

= 50,000 ml/day

d. Total diluted urine for 20 men/day

25,000 ml urine/20 men/day

50,000 ml flush water/20 men/day

75,000 ml diluted urine/20 men/day or

75.0 liters diluted urine/20 men/day (20.0 gal.)

3. Normal strength of diluted urine

a. COD = 6000 mg/l

b. Color = 400 units

c. Odor = 12 OII

d. Turbidity = 100 JTU

e. TKN = 5900 mg/l

4. U.S. Department of Interior flushing water standards

a. Odor = 3 OII

b. Color = 30 units

c. Turbidity = 20 units

d. Coliform Bacteria = 10,000 colonies/100 ml

5. Effluent standards used in design of the twenty-men flushing water purification system
    a. Odor = 7 OII
    b. Color = 120 units
    c. Turbidity = 50 JTU
    d. Coliform Bacteria = 0 colonies/100 ml

A. Ozonation
    1. Ozone generator required
        a. LINDE OZONE GENERATOR MODEL SG - 4060
        b. Specifications
            (1) Ozone production (maximum)
            From air: 0.454 kg/day (1 lb/day @ 1% concentration by weight
            (2) Maximum concentration of ozone
            From air: Approximately 3%
            (3) Flow rates
            4.72 to 47.2 slm (10 to 100 scfh)
            (4) Dimensions
            43 cm x 38 cm x 66 cm (17" x 15" x 26")
            (5) Weight 77.2 kg (170 lbs.)
            (6) Power requirements
            120 volts AC, 60 Hz, 400 watts
            (7) Power consumption
            2.4 kWh/day

c. Cost

$4,000

d. Contact time

6 Hours

e. Mass of ozone needed to treat 75 liters (20 gallons) of diluted urine per day

110 grams O_3

2. Air preparation unit

a. Air compressor

(1) Air production

0.17 - 1.6 SCFM (10-100 SCFH)

(2) Power requirements

115 volts, 60 Hz

(3) Dimensions (Overall)

12" x 10 1/8" x 5 7/8"

(4) Type

Piston type air cooled

¼ HP

(5) Cost

$400

b. Dehumidifier

(1) Type

Self-Regenerating

(2) Model

4434 N 11 (McMaster-Carr Supply Company)

(3) Cost

$500

3. Holding tank and O_3 contactor

    a. Capacity

    83 liters (22 gallons)

    b. Dimensions

    Diameter 16.5"

    High 24.0"

    c. Cost

    $600

4. Pumps

    a. Type

    Rotary gear

    b. Number

    Two

    c. Capacity

    2 gpm

    d. Power requirements

    115 volts, 60 Hz

    e. Motor

    ¼ HP

    f. Power consumption

    g. Cost

    $100, each

10. Residual Ozone decomposer
    a. Activated carbon filter
11. Total Capital Cost

    $7,625

Figure 64 in Appendix 1 illustrates the twenty-men Ozone flush water purification system.

B. Ozonation - Ultraviolet Radiation

1. Ozone generator required

   Same as the one for the Ozone system

2. Air preparation unit

   Same as the one for the Ozone system

   Holding tank and O_3-UV contactor

   a. Capacity

      83 liters (22 gallons)

   b. Dimensions

      diameter 16.5"

      high 24.0"

   c. UV lamps

      Ten (10) 59 watt low pressure UV lamps

   d. Cost

      $1300

3. Pumps

   Same as those for Ozonation system

4. Residual Ozone decomposer

   Activated carbon filter

5. Total Capital Cost

   $8,750

Figure 65 in Appendix 1 illustrates the twenty-men Ozone-UV flushing water purification system.

C. Activated Carbon Adsorption

1. Holding Tank
   a. Capacity

      83 liters (22 gallons)
   b. Dimensions

      diameter 16.5"

      high 24.0"
2. Types of Carbons
   a. FILTRASORB 400

      Bulk density = 25 lbs/cu.ft.

      Size = 12 x 40

      (1) Quantity of carbon for 20 men based on 42.2 grams required to treat 2 liters of diluted urine to flushing water quality

      For 1 month = 47.50 Kg (105 lbs)

      For 3 months = 142.47 Kg (314 lbs)

      For 6 months = 284.94 Kg (628 lbs)

(2) Volume of contactor needed for the above carbon quantities

For 1 month = 4.2 cu. ft.

For 2 months - 12.6 cu. ft.

For 6 months = 25.1 cu. ft.

(3) Cost

100 to 500 lbs = $0.80/lb

500 to 2000 lbs = $0.67/lb

2000 to 10000 lbs = $0.62/lb

30000 to 40000 lbs = $0.57/lb

40000 to 100000 lbs = $0.55/lb

b. NUCHAR WV-L

Bulk density = 26 lbs/cu. ft.

Size = 8 x 30

(1) Quantity of carbon for 20 men based on 43.7 grams required to treat 2.6 liters of diluted urine to flushing water quality

For 1 month = 49.16 Kg (108 lbs)

For 3 months = 147.50 Kg (325 lbs)

For 6 months = 295.20 Kg (651 lbs)

(2) Volume of contactor needed for the above carbon quantities

For 1 month = 4.2 cu. ft.

For 3 months = 12.5 cu. ft.

For 6 months = 25.0 cu. ft.

(3) Cost

One carton contains four 40 lbs bags.

Breaking up one carton to purchase 1-3 bags, there is a $0.2½ surcharge per pound

1-3 cartons (1,600 - 4,800 lbs) = $0.41½/lb

4-11 cartons (6,400 - 17,600 lbs) = $0.48½/lb

12 or more cartons (19,200 lbs or more) = $0.47½/lb

4. Ultraviolet Radiation Sterilizer

a. UV Lamp

(1) Number

Three 59 watt lamps

b. Dimensions

10" x 36"

c. Weight

100 lbs

d. Cost $500 lbs

5. Surface Loading

1.0 gpm/ft^2

6. Contact Time

5 minutes

7. Total Capital Cost

$3,089

The activated carbon will be placed in easily replaceable cartridges.

Figure 66 in Appendix 1 illustrates the twenty-men Activated Carbon Adsorption flushing water purification system.

CHAPTER V

COST-EFFECTIVENESS ANALYSIS

In the past, economic analyses of engineering systems were based primarily on cost considerations. Least-cost solutions meeting fixed requirements/constraints were initially used to compare system alternatives. Economic efficiency was measured by cost minimization without consideration of the total scope of a system's economic impact when in operation. Later, evaluations centered about a net cost or net savings which represented the difference between total cost and any resultant savings or benefits which could be expressed in dollars and cents. Experience has shown, however, that combining costs and benefits into a single measure may not necessarily indicate the most economically efficient alternative. Benefit-cost analyzes in some cases may be satisfactory if the benefits are expressed in terms of dollars. However in evaluating wastewater treatment and disposal systems for use at advanced (remote) military bases this has shown to be not applicable (39). It is not a true representation of a system's cost when equipment resupply and manpower expenditures are so costly as in the case of a remote military base.

A subjective process may be suitable if the decision is rather simple. However a subjective decision cannot be tolerated when a complex problem is encountered. A complex problem possesses many performance consequences which must first be ascertained and assessed with reasonable accuracy before a final decision can be reached. A point of interest is that the use of a explicit, logically consistent, and replicable procedure does not exclude the user in employing subjective judgement. In the decision model employed during this study the assessment of an alternative's relative worth was performed in a subjective manner. Subjective judgement must be used in assigning measures of worth to various performance consequences among various criteria.

The method for evaluating the twenty-men flushing water purification systems in this study is a decision weighting model. The model assesses the effectiveness (in measures of worth) for each of the various system alternatives in relation to the Navy's requirements. The decision weighting model used for this study has been developed, tested and reported by Miller (40). Facets of this model have also been employed by Drobny (39) and tested for reliability by Eckenrode (41).

In performing cost-effectiveness analyzes the individual is confronted with two types of evaluations. The first is the cost analysis. Generally this is a straight forward evaluation which consists of identifying all major system components and developing capital and operating cost estimates for these items. The second evaluation is the effectiveness evaluation where by a single cardinal measure or indicator of effectiveness is generated based upon multiple considerations. The objective of a complete cost-effectiveness analysis is to compare monetary cost with effectiveness in order to identify the most cost-effective alternative.

Cost Evaluations

Assumptions and criteria employed in the cost analyses are outlined below. Some data were supplied by CEL; others were supplied by equipment manufacturers. Throughout the analysis, retail or catalog list prices of equipment were employed.

Specific cost parameters and assumptions are outlined below:

1. Capital cost amortization parameters
    a. Interest rate: 10 percent (CEL estimate)
    b. Equipment life: 5 years (CEL estimate)
2. Power: $0.05 KWh (CEL estimate)
3. Manpower: $12.00/hr (CEL estimate)

Shipping costs are not included in the analysis since the flush water purification system is a component system of a larger field sanitation unit. Tables 10-13 in Appendix 2 give the unit capital and operating costs for the Ozone, Ozone-UV and Activated Carbon (FILTRASORB 400 and NUCHAR WV-1) flush water purification systems respectively.

Effectiveness Evaluations

Earlier the author specified that the procedure employed assessed the effectiveness or worth of each of the various system alternatives in relation to Navy's requirements. Prior to a detailed explanation of the procedure the author wishes to clarify this concept of effectiveness or worth. In this case effectiveness or worth of any object, activity or situation referes to the extend of which the object is perceived by a decision maker or group of decision makers as satisfying a group or range of clearly defined objectives. In other words, the effectiveness of an alternative within a specific job context would be defined in terms of how well that alternative satisfied the job's stated objectives. The above statements imply that the worth notion arises from the human decision maker's internal assessment. The effectiveness of an alternative fulfilling an objective is here conceived as inherent within the perceptual structure of the decision maker himself.

There are three psychological states which reflect the decision maker's choice and are fundamental to the concept of effectivensss. These states are: (a) preference (positive affective response), (b) aversion (negative response), and (c) indifference (possessing neither a preference for nor aversion toward that object or activity). When dealing with the concept of effectiveness usually positive preferences prevail. That is, when an object or activity is said to possess some measure of effectiveness, this usually means that someone possesses a positive preference for it and/or its consequences. The task here is to ensure the assessment of all factors in such a manner that the true conceptual effectiveness of all alternatives is revealed. The procedure is summarized below. Figure 67 in Appendix depicts the model outline; reference to this outline will aid in understanding the procedure.

Assessment Procedure

The assessment procedure assumes a decision maker has a series of alternative systems (A_1, A_2, A_3, . . . A_n) which must be evaluated in terms of several measures of effectiveness (M_1, M_2, M_3, . . . M_n). The following rules must be followed when assessing the overall effectiveness of a set of alternatives:

1. The list of alternatives should be complete;
2. All items listed should be mutually exclusive (i.e., no objective should encompass or be encompassed by any other objective listed);
3. The alternative list should contain only objectives of highest order of significance.
4. Interdependence of effectiveness should prevail among the objectives listed.

Having observed these rules, the next step is to assign relative weights (w) to each of the "n" measures of effectiveness. The author wishes to emphasize that explicitness, logical consistency, and replicability do not preclude the use of judgment. However, an effort must be made to make the judgments in an objective manner rather than in a subjective one. The ultimate purpose of judgment is to compare relative importance among effectiveness criteria and to assess measures of effectiveness for various performance levels.

The weights assigned merely reflect the relative importance of each measure of effectiveness. Generally in deriving these relative weights, it is convenient to have each effectiveness measure objective add up to 1. By doing this the resulting overall effectiveness ratings (computed as the sum of weighted individual effectiveness ratings) may be subjected to the same interpretation as the effectiveness ratings or scores assigned to each individual effectiveness measure.

Next, the decision-maker assigns a score or rating which reflects the degree to which each alternative satisfies each of the effectiveness measures (or requirements). In Figure 67, r_{ij} is the rating or score of alternative A_i with respect to effectiveness measure M_j. The overall effectiveness can be calculated by summing the products of each rating and its relative weight as shown in Figure 67.

The use of the above decision model requires that the decision maker formulates judgment at two critical steps. The first is in the assignment of weights depicting relative importance and the second is in the assignment of ratings or scores. These two steps cannot be avoided and as a consequence reflect the decision- maker's opinion (as opposed to an absolute measure) on the relative importance of the measures and on how the alternatives measure up to the expectations. The accuracy of this model is a function of the validity of the specific judgments required to assign the effectiveness ratings or scores (40).

Effectiveness Analysis

In accordance with discussions and a review of pertinent documented material at CEL, nine measures of effectiveness were selected, ranked (in order of decreasing importance), and weighted. To facilitate understanding of the effectiveness analysis model, a complete description of the Navy's measures of effectiveness are listed below:

M_1 - Health Hazard (1). The system alternative must collect, process, and store product water without contributing any health problems to personnel. Flush water should have a maximum odor intensity index of 7, and color of 130 units. Disinfection of flushing water must reduce fecal coliform count to 10,000 MPN/100 ml (23). Waste and flush water containers must be sealed from vectors such as rodents or flies.

M_2 - User Acceptability (1). The system alternative must meet designated design and operating requirements and still be acceptable to the user. Waste processing must not interrupt continuous usage by personnel (one use every 3 minutes is considered continuous use). Waste treatment should not create user discomfort in the form of odor, noise or hot temperature. Operation should be simple. Complicated devices are not compatible within the field environment. No offensive odor should be transmitted to immediate area (50 odor units maximum three feet from system components). No additional heat must be transmitted to the immediate area (70°F radiant heat 3 feet from all components). Continuous noise level maximum is 65 dB detectable from a distance of 3 feet from any component.

M3 - Operation Reliability (1). The system alternative must be capable of sustaining adverse handling, transportation, and operation conditions. Construction must be durable for all types of transportation (Module must withstand a 6-inch drop for helicopter transport). Simplicity and fail-safe mechanisms are required.

M4 - Maintainability (1). Maintenance must be compatible with a field environment. Major maintenance must not be required within a six-month period. Trained personnel must not be required for field maintenance. No tool unique to field environment should be required (tools no more complex than flat head screw driver). System operation must not depend on a continuous logistic supply of special materials. If standard stock materials are used, a quantity sufficient for six months per 20 men must be supplied with the system. Modular components should facilitate ease of replacement and cannibalization

M5 - Safety (1). Personnel must not be exposed to any danger from system alternative use. Equipment malfunction must not be potentially dangerous to user or personnel in the immediate area. Exposed parts must not be capable of causing burns or electrical shock (maximum temperature of exposed parts is 130°F).

M_6 - Power Requirement (1). A single, standard power source is required. A multifuel logistic burden is undesirable. Electricity is the accepted and recommended source of operation.

M_7 - Space Requirement (1). The area required for a given system alternative should be as minimal as possible.

M_8 - Weight (1). The maximum weight of the system alternative is 500 pounds.

M_9 - Shelf Life (1). Equipment made for field use must be capable of remaining inactive for periods of time before usage. The equipment should require no unique environmental conditions for storage. A five-year storage life before use is required. A five-year service life encompassing a minimum of three six-month deployments is also required.

The Figure below gives the summary of the nine measures of effectiveness selected, ranked, and weighted. In Column 2 (with respect to next item on list) one can say that weight is 1.5 times more important as shelf life and space requirement is 1.1 times as important as weight. In other words, the following Figure Effectiveness Criteria and Relative Weights) shows the relative importance of each measure of effectiveness with respect to the one immediately below it on the list. By a simple multiplication the importance of each item becomes relative to the last one on the list as shown on the third column of the following Figure. This in turn makes them relative to each other. For example power is over three times as important as shelf life and operation reliability is over

EFFECTIVENESS CRITERIA AND RELATIVE WEIGHTS FOR EVALUATION OF FLUSH WATER PURIFICATION SYSTEMS FOR REMOTE TACTICAL AREAS

Effectiveness Measures	Relative Importance		Normalized Relative Weights
	With Respect to Next Item on List*	With Respect to Last Item on List	
M_1 Health Hazard	1.50	15.929	0.304
M_2 User Acceptability	1.50	10.619	0.202
M_3 Operation Reliability	1.10	7.079	0.135
M_4 Maintainability	1.30	6.435	0.123
M_5 Safety	1.50	4.950	0.094
M_6 Power Requirement	2.00	3.300	0.063
M_7 Space Requirement	1.10	1.650	0.031
M_8 Weight	1.50	1.500	0.029
M_9 Shelf Life	-	1.000	0.019
		52.462	1.000

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* Value judgment in this column represent averages of independent evaluations conducted by three individuals.

seven times (1.10 x 6.435 = 7.079) as important as shelf life and so on. Health hazard is almost sixteen times as important as shelf life. By normalizing this third column (i.e., the sum of the individual values is 1), one can derive the relative weights (w) for each of the measures of effectiveness; colum 4 shows these values. The validity of these values depends upon the decision maker's ability to provide accurate judgments in making the previous comparisons.

Having derived the relative weights (column 4 of the above Figure, Effectiveness and relative Weights) in a consistent and explicit manner, a similar procedure is employed to derive the respective rating scores (rij). Assignment of ratings to the three alternative systems with respect to each of the effectiveness measures is conducted. Reference to Figure 68 in Appendix 1 will aid in understanding the following discussion. Successive paired comparisons are made between adjacent alternatives on the list, starting at the bottom and working up. For each comparison the decision maker makes a judgment about the relative degree to which each of the alternatives satisfies the effectiveness measure under consideration. Similar to the procedure of assigning weights to the effectiveness measures (Figure on Effectiveness Criteria and Relative Weights) the decision maker is required to indicate, in terms of a ratio, the degree to which one alternative (A_1) is superior to another (A_2 in terms of its effectiveness with respect to the measure (Mn) being considered. Since this decision making procedure is primarily subjective, the author quantified the measurable criteria in order to make the assigned weights more objective. Appendix 24 gives the criteria used to assign the relative weights. In Figure 67 the values in column 3 are then multiplied to obtain the relative effectiveness of each alternative within each effectiveness measure category ($M_1 \ldots M_n$). This is shown in column 4. Column four's numbers are then averaged by dividing by their sum as shown in the fifth column. These are the respective ratings of the alternative systems with respect to the measures of effectiveness. The reason for averaging the ratings is to place all of the ratings derived for the various measures of effectiveness on the same basis, i.e., in the range of zero to one (although any other common range could similarly be used).

Once the respective weights for the nine measures of effectiveness and the respective ratings for each of the alternative systems is obtained, the decision maker has all the data necessary to perform the calculations outlined in Figure 67. Figure 69 in Appendix 1 shows the data and calculations of overall effectiveness. As can be noted alternative A_1 has an effectiveness of 0.299, alternative A_2 has an effectiveness of 0.324, and alternative A_3, an effectiveness of 0.373. These results show that activated carbon and UV disinfection has greater potential in fulfilling the requirements in terms of effectiveness measures set forth by the U.S. Navy. Also the cost of this system is substantially lower than the other two systems evaluated. These two parameters are evidence that activated carbon and UV disinfection are better suited for recovering flush water from diluted urine in a remote field environment

The Table that follows shows the summary of Cost-Effectiveness Analysis. In this Table the cost and the effectiveness are considered together to provide a final determination of the most cost effective treatment process. Activated carbon adsorption has the smallest cost per unit effectiveness indicating again that carbon adsorption is better suited to recover flush water from diluted urine. Ozonation is the second best with Ozonation-UV being the third best.

SUMMARY OF COST-EFFECTIVENESS ANALYSIS

System Alternatives*	Total Effectiveness	Total Unit Cost ¢/man-day	Effectiveness Per Unit Cost	Cost Per Unit Effectiveness	Normalized Cost Per Unit Effectiveness
A_1	0.299	6	4.983	0.201	0.435
A_2	0.324	5	6.480	0.154	0.333
A_3	0.373	4	9.325	0.107	0.232

* A_1 = Ozonation-UV

A_2 = Ozonation

A_3 = Activated Carbon & UV Disinfection

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to extablish unit process design criteria for reclaiming flushing water from urine at military field bases. The alternatives investigated include: (a) Ozonation, (b) Combination of Ozonation and Ultraviolet (UV) Radiation, (c) Activated Carbon Adsorption, (d) UV Radiation, and (e) Regeneration of Carbon by Ozonation. These urine treatment processes were tested and evaluated. The results were analyzed and a cost-effectiveness analysis was performed employing the following effectiveness measurement criteria: (a) Health Hazard, (b) User Acceptability, (c) Operation Reliability, (d) Maintainability, (e) Safety, (f) Power Requirement, (g) Space Requirement, (h) Weight, and (i) Shelf Life. The definition of these effectiveness measures are defined in Chapter V.

Conclusions

As a result of this investigation the following conclusions are drawn:

1. Activated carbon adsorption was the most cost-effective alternative in recovering flush water from urine. Changing the flow

rate from 1.0 gpm/sq. ft. to 0.5 gpm/sq. ft. did not produce a better quality effluent or increase adsorption capacity. Carbon columns (in cartridge form) were relatively easy to operate and maintain. Additional advantages of using carbon adsorption process are: (a) removing chemicals and (b) reducing capital investment. A carbon filter may also retain bacteria thus rendering an effluent with relatively low bacteria content. Disadvantages of using activated carbon are: (a) causing logistic burden for resupply, and (b) requiring some skill to check if there is short-circuiting in the carbon column.

One important observation was the shape of the breakthrough curves. There was a great variation in the adsorption pattern. This perhaps could have been caused by secondary adsorption sites in the carbon particles. The selection of a straight line regression model was based on a careful analysis of the adsorption models presented by Culp (32) and the data obtained by the author.

Carbon adsorption could be better if the influent would be ozonated, since ozone oxidizes the large organic molecules quite readily. This would leave smaller organic molecules which could be better adsorbed by the carbon.

2. Ozonation was also a cost-effective alternative in producing an acceptable flush water. The major disadvantages of this process are that it (a) requires longer contact time, (b)

needs more maintenance, (c) demands the air or oxygen gas entering the ozone generator be very dry or it will severely damage the generator, and (d) the capital cost is high. An important observation made during the ozonation study was that bubble size is an important factor in obtaining high mass transfer efficiency.

3. Ozonation-UV Radiation can also effectively treat the diluted urine to a flush water quality. Results showed that treatment did not improve appreciably as compared to Ozonation alone which is conflicting with theory and other researcher's findings. A contributing factor to the poor efficiency of the Ozonation-UV radiation appeared to be not having optimum ozone bubble size in the ozonator. As far as the field application is concerned, this alternative stands equally as Ozonation.

4. Cost-Effectiveness analysis, employing cost analysis and a decision weighting model for three alternatives described previously was performed. Results of this analysis show that the cost/unit effectiveness for the three alternatives were as follows:

a. Carbon Adsorption = 0.107
b. Ozonation = 0.154
c. Ozonation-UV = 0.201

The alternative with smaller number is the more cost-effective process. Therefore, the Carbon Adsorption is the best alternative.

Recommendations

In addition to the findings of this research the areas which are worthwhile for further research are:

a. Extension of service life of the carbon column by pretreating the diluted urine. Current experiences at Cleveland Westerly Plant, Cleveland Regional Sewer District have demonstrated that Ozonation of the wastewater before carbon adsorption has improved the carbon service life. Ozone breaks down large molecule organics, making them more adsorbable to the carbon. It also restricts to some extent the biogrowth on the carbon. Thus ozonation pretreatment appears to extend to some degree the carbon life. Further research on this technology being applied to treat urine would have academic interest.

b. Electrolysis of diluted urine could be a good treatment method. Previous researchers have encountered various problems. The objective of those researchers has been to recover potable water from urine. Recovering flush water from urine by this method may reduce the magnitude of the problem. Additional basic reasearch will have merit.

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APPENDIX 1

FIGURES

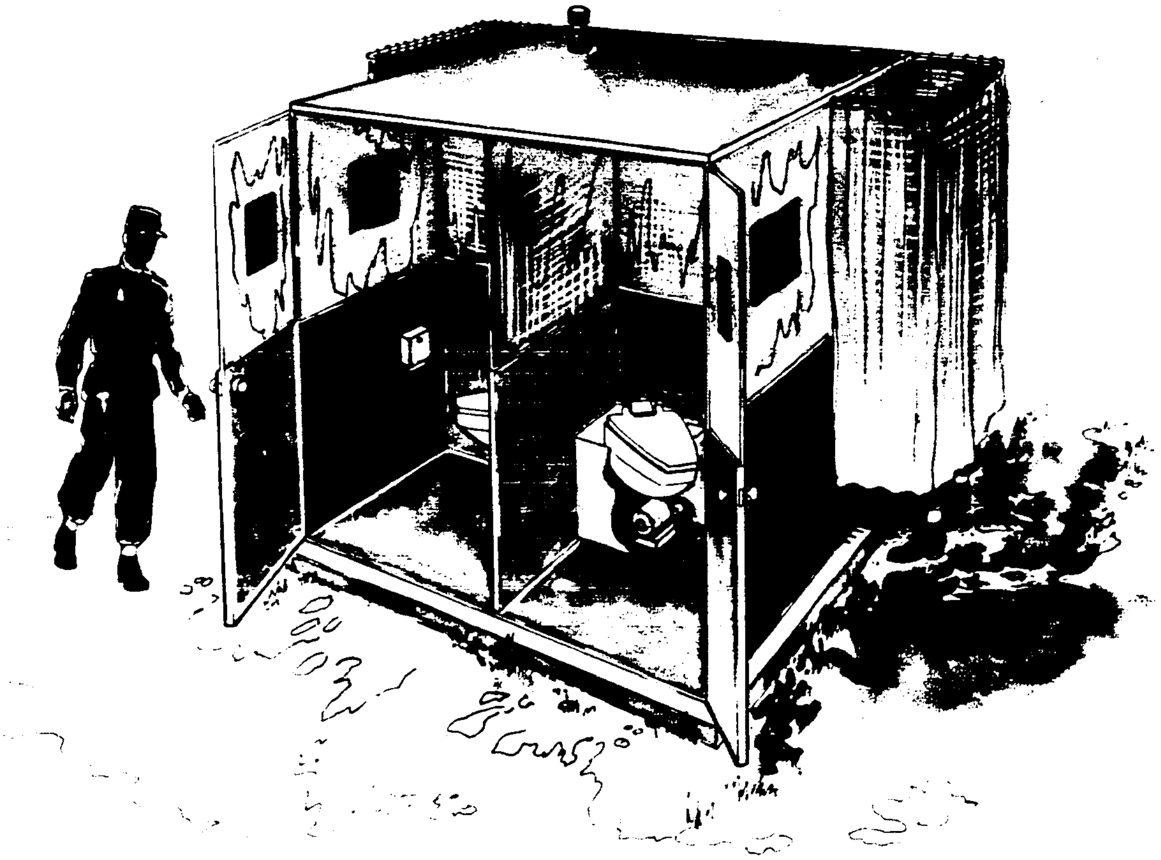


FIGURE 1. FRONT VIEW OF EXPEDITIONARY FIELD HEAD MODULE.

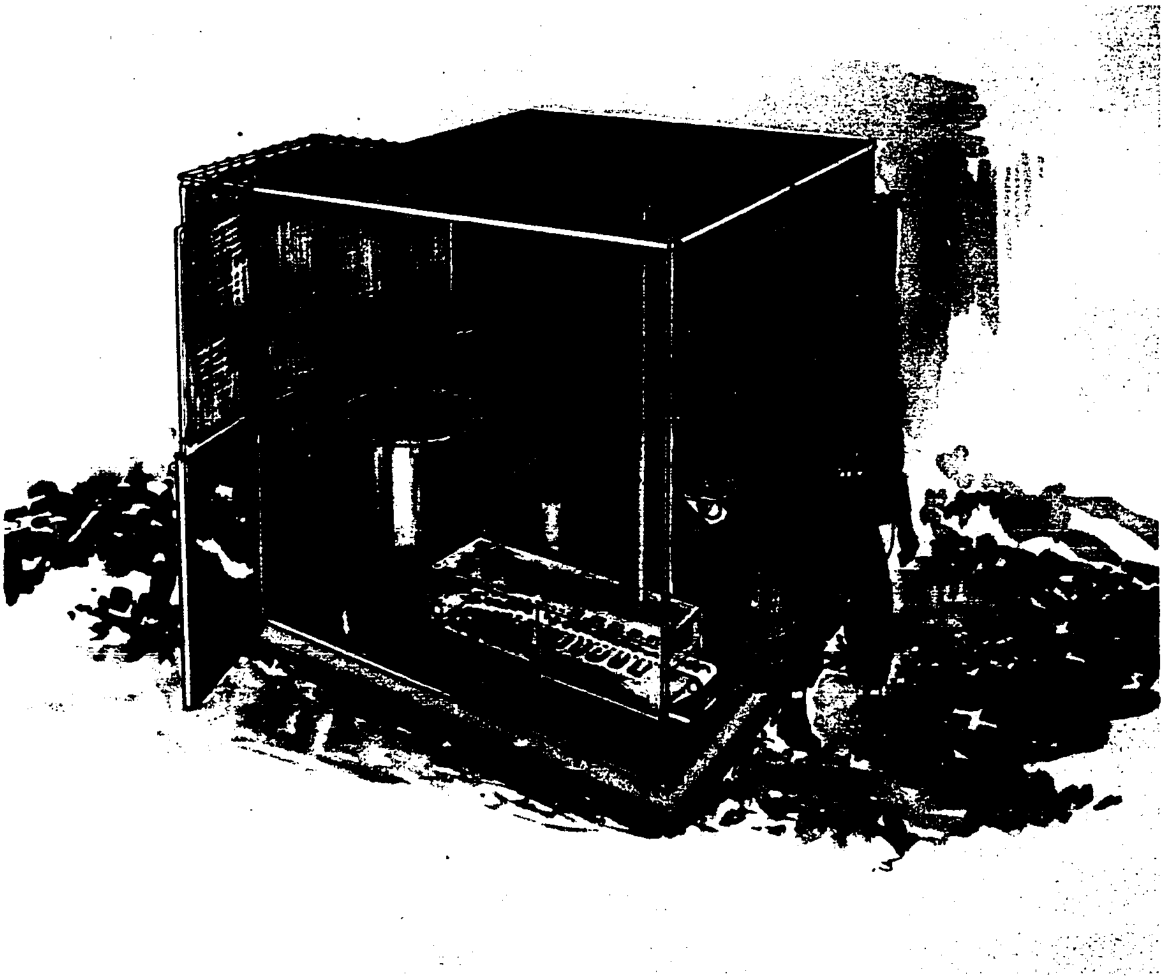


FIGURE 2. REAR VIEW OF EXPEDITIONARY FIELD HEAD MODULE.

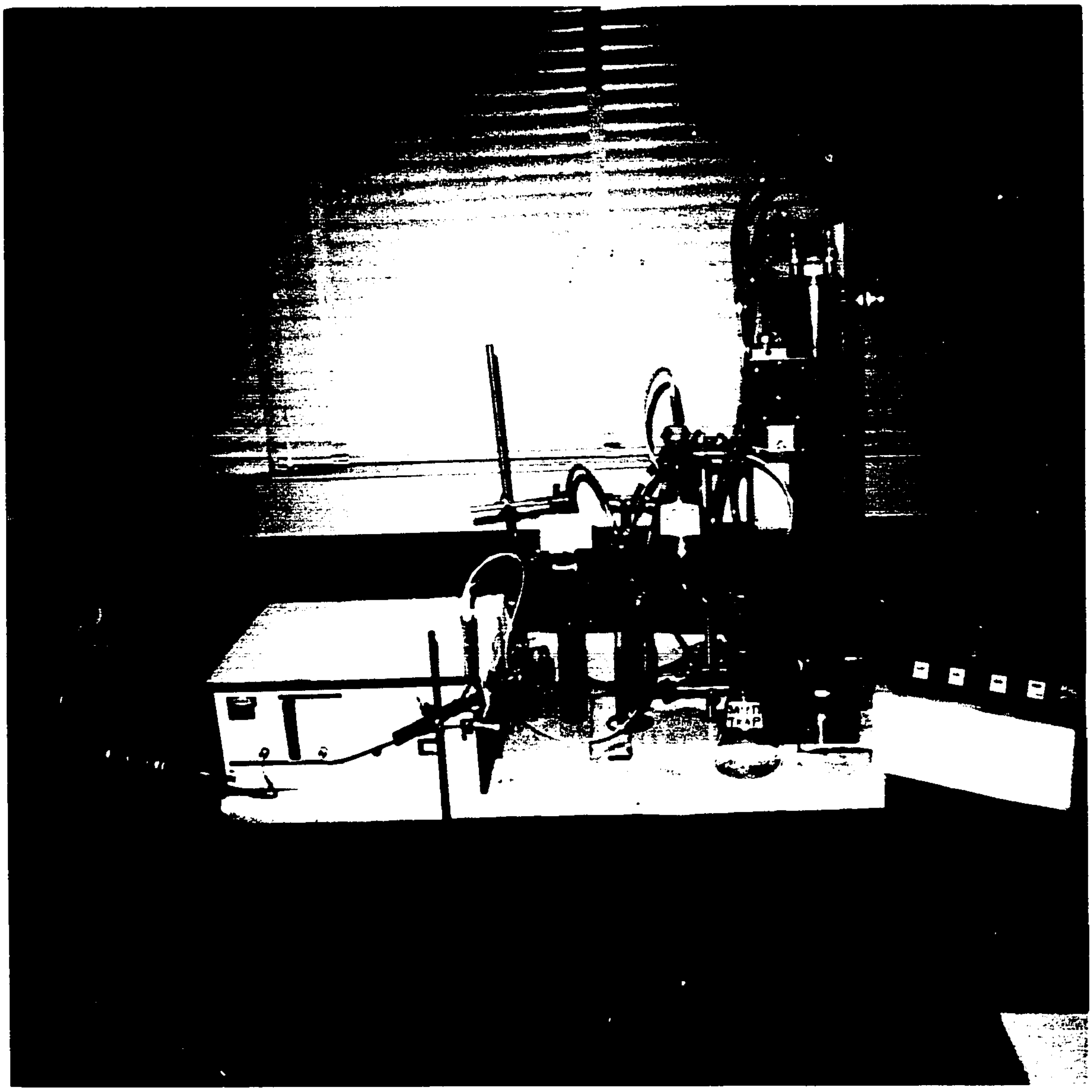


FIGURE 3. OZONATION SYSTEM.

1. OXYGEN
2. OZONE GENERATOR
3. ROTAMETER
4. OZONE CONTACTOR
5. FOAM TRAP
6. O_3 DECOMPOSITION DEVICE
7. O_3 SAMPLING BOTTLE

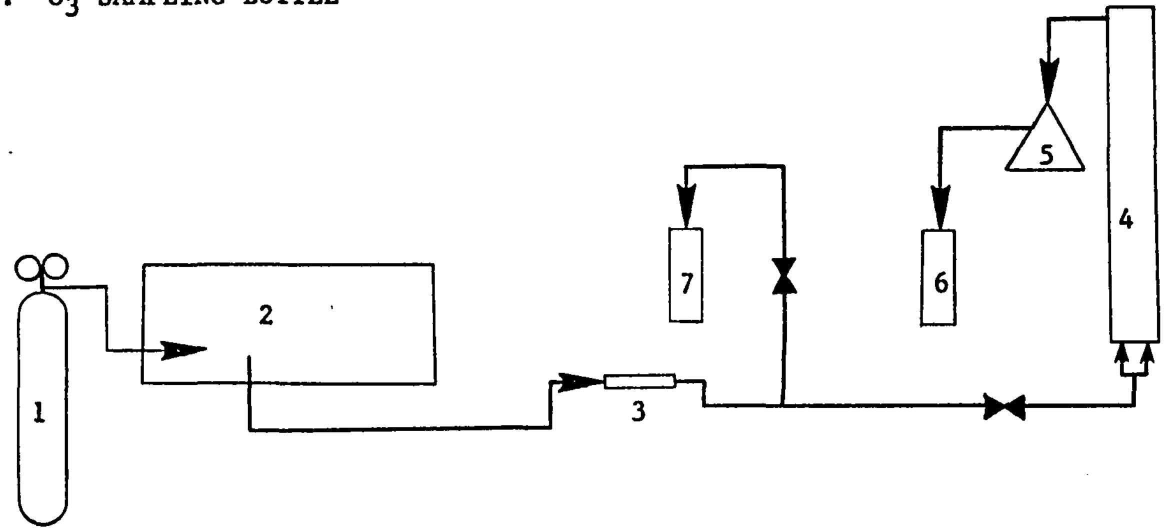


FIGURE 4. OZONATION SYSTEM FLOW DIAGRAM.

1. OXYGEN
2. OZONE GENERATOR
3. ROTAMETER
4. OZONE-UV CONTACTOR
5. FOAM TRAP
6. O_3 DECOMPOSITION CYLINDER
7. O_3 SAMPLING CYLINDER
8. UV LAMP

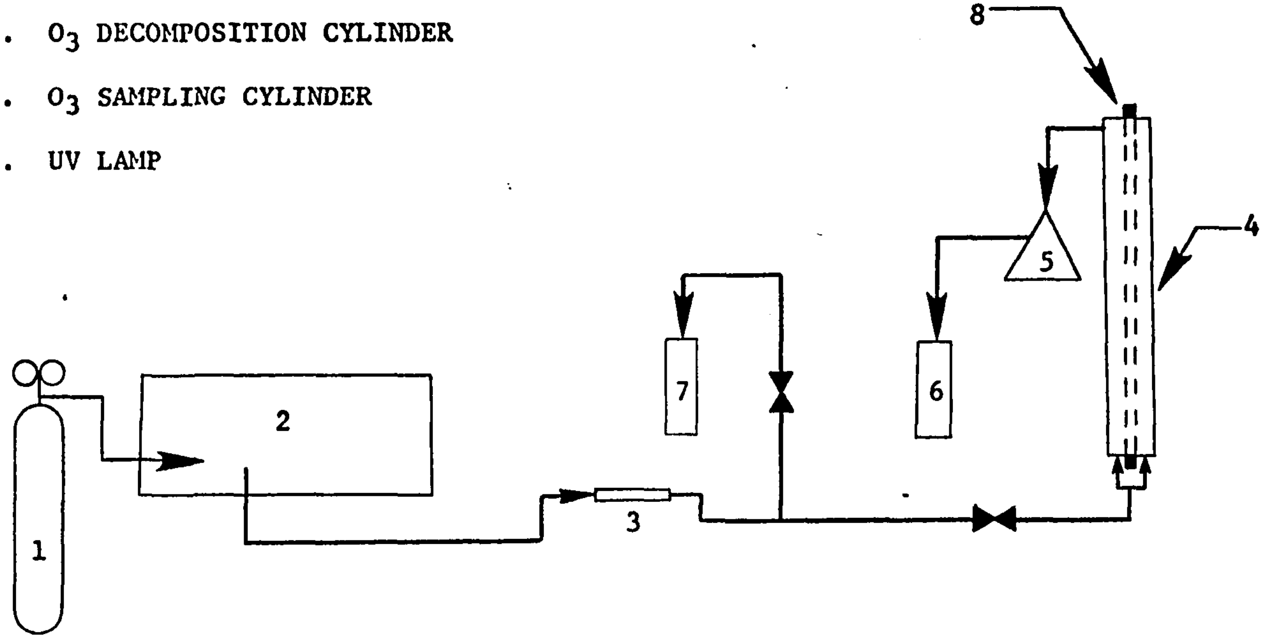


FIGURE 5. OZONE-UV SYSTEM FLOW DIAGRAM.

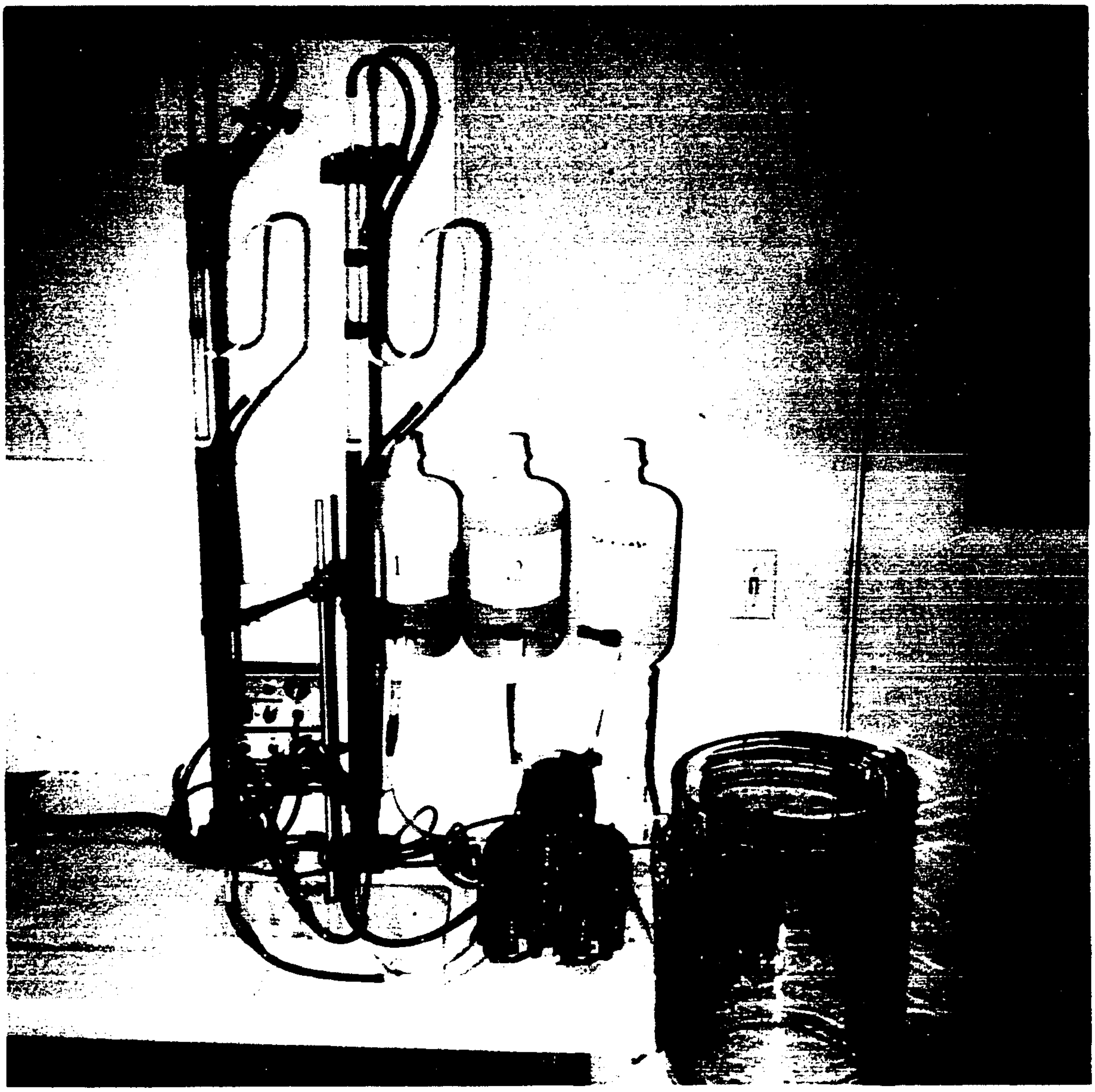


FIGURE 6. ACTIVATED CARBON ADSORPTION COLUMN SYSTEM.

1. FLOW CONTROL BOXES
2. CARBON COLUMNS
3&4. DILUTED URINE TANKS
5. BACKWASH WATER TANK
6&7. DILUTED URINE PUMPS
8. BACKWASH WATER PUMP
9. TREATED WATER COLLECTION TANK

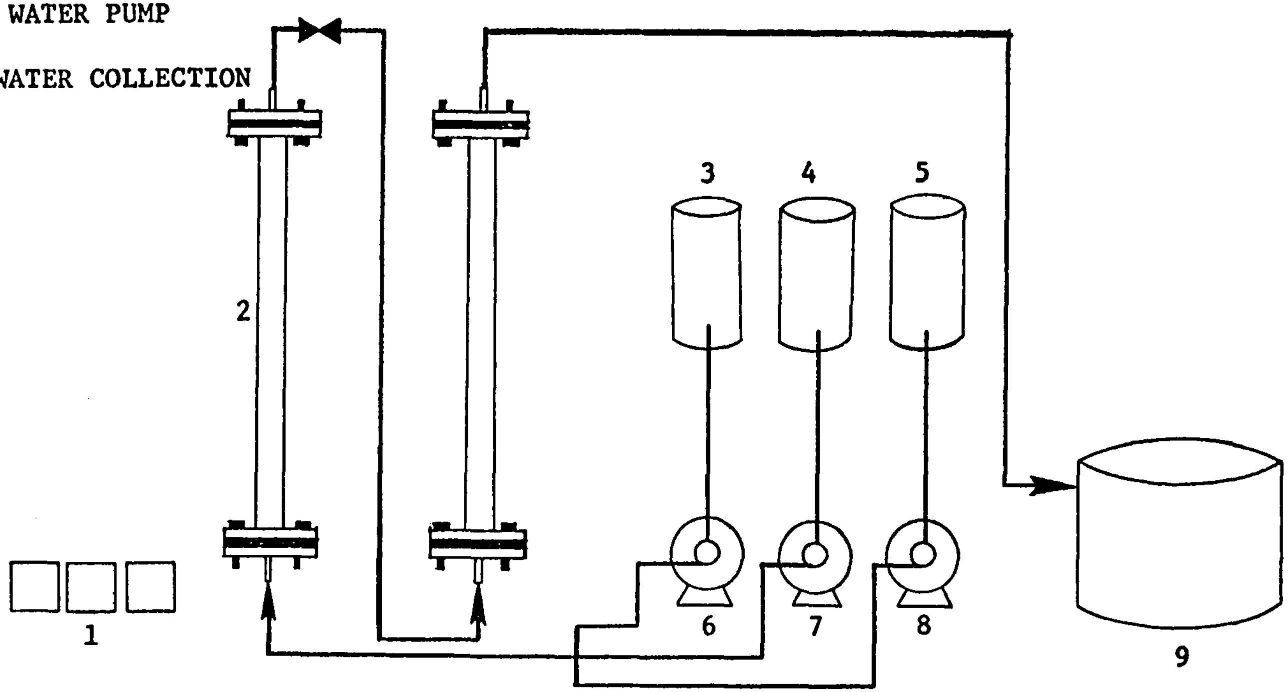


FIGURE 7. FLOW DIAGRAM OF ACTIVATED CARBON ADSORPTION SYSTEM.

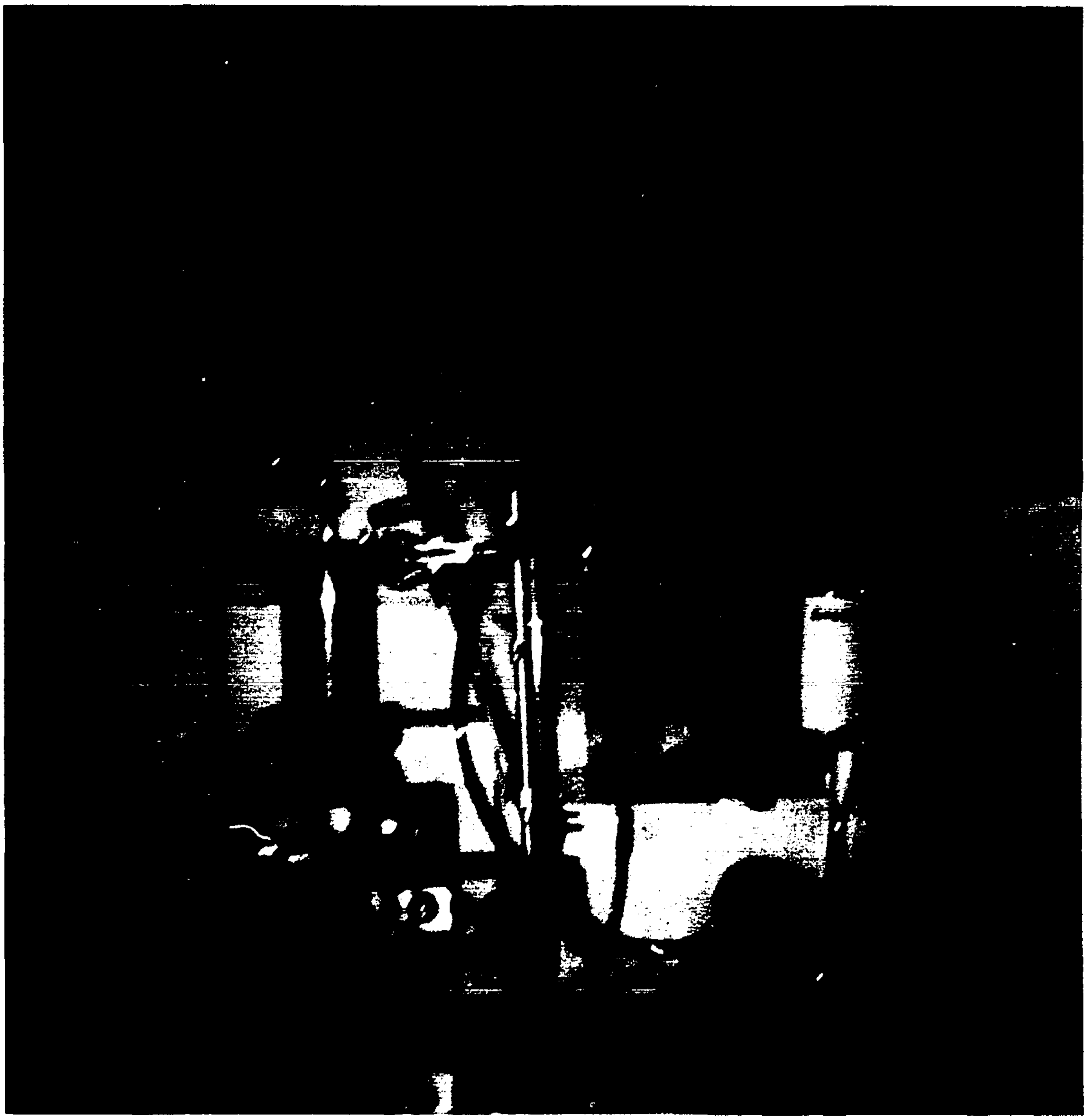


FIGURE 8. CARBON REGENERATION BY OZONATION.

1. CARBON COLUMN
2. DILUTED URINE TANK
3. BACKWASH WATER TANK
4. DILUTED URINE PUMP
5. BACKWASH WATER PUMP
6. TREATED WATER COLLECTION TANK
7. CARBON-OZONE CONTACTOR
8. OZONE DECOMPOSITION CYLINDER
9. FLOW CONTROL BOXES
10. VENT

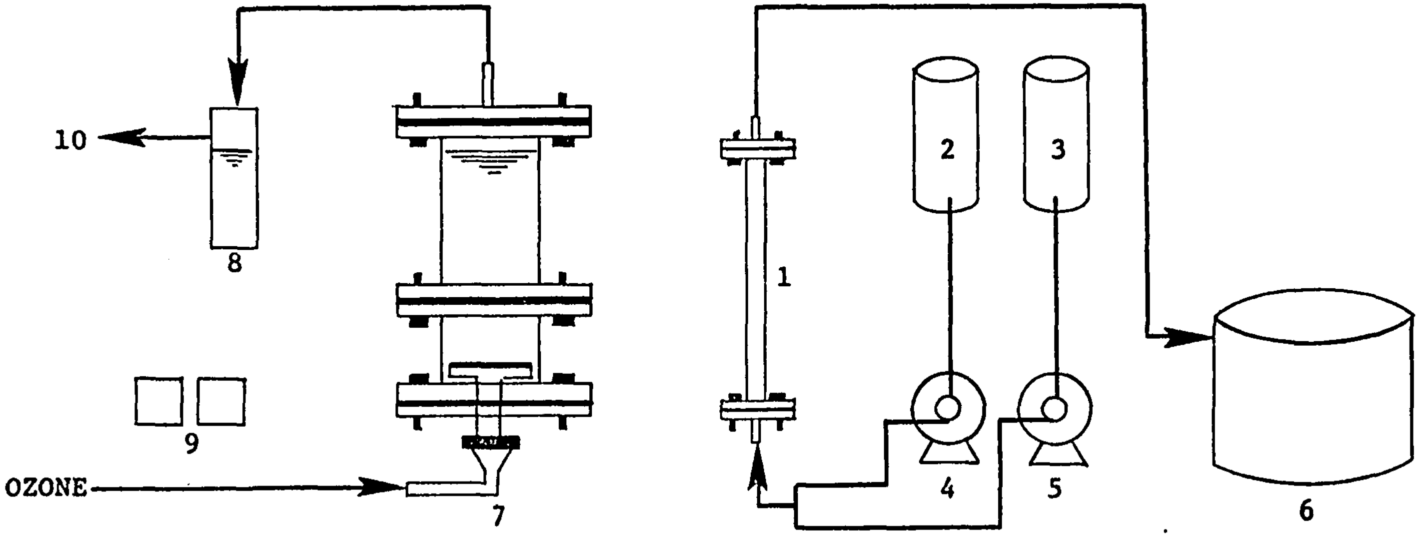


FIGURE 9. CARBON REGENERATION FLOW DIAGRAM.

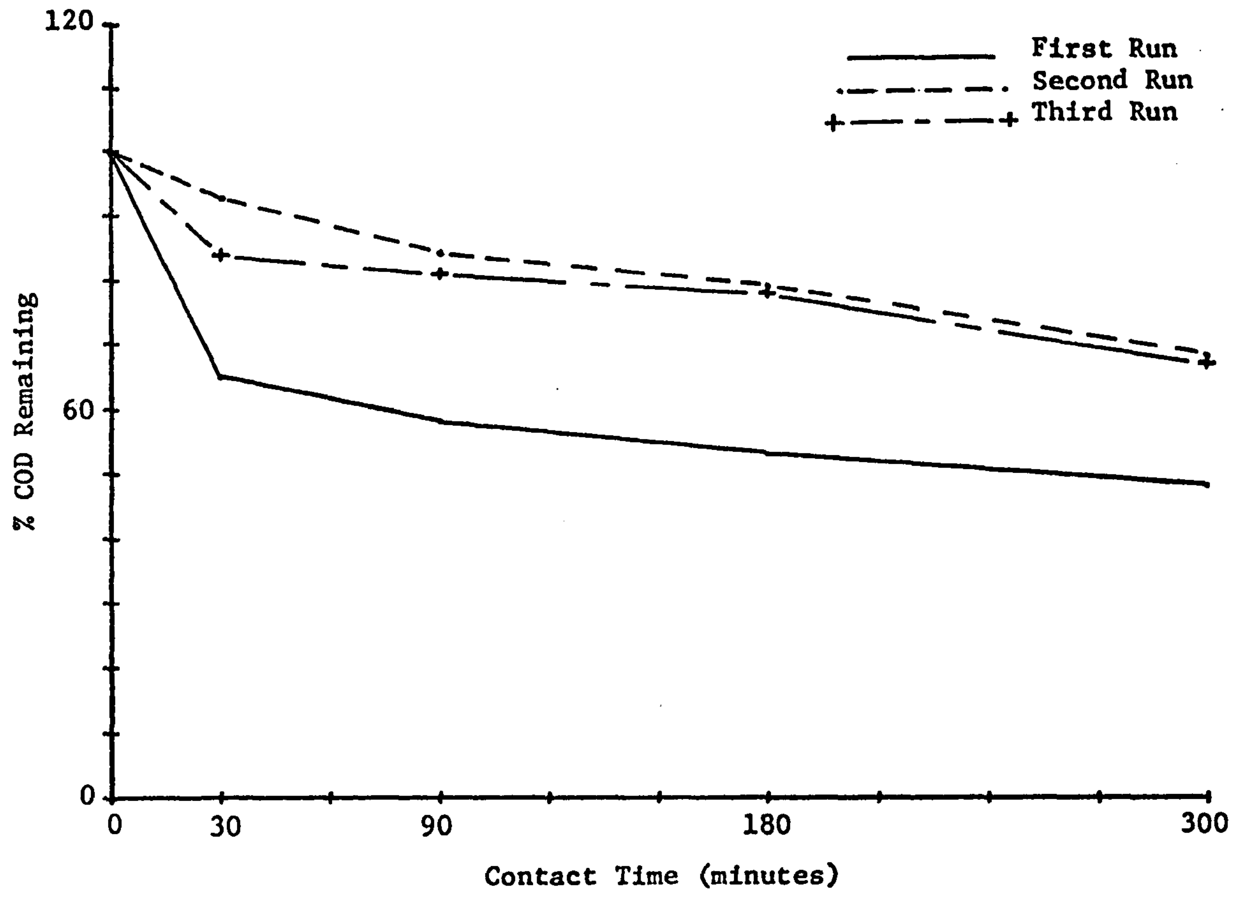


FIGURE 10. COD REDUCTION RATE DURING OZONATION.

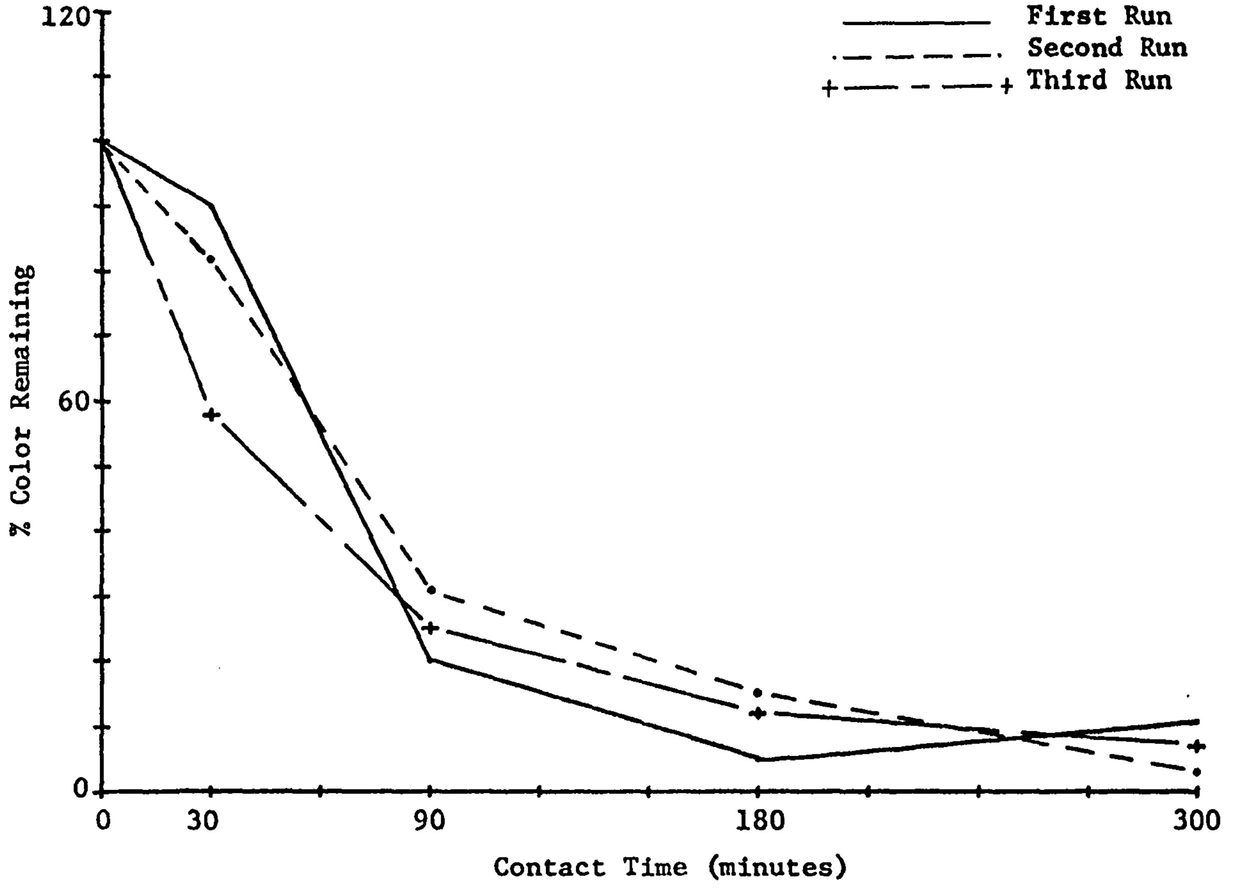


FIGURE 11. COLOR REDUCTION RATE DURING OZONATION.

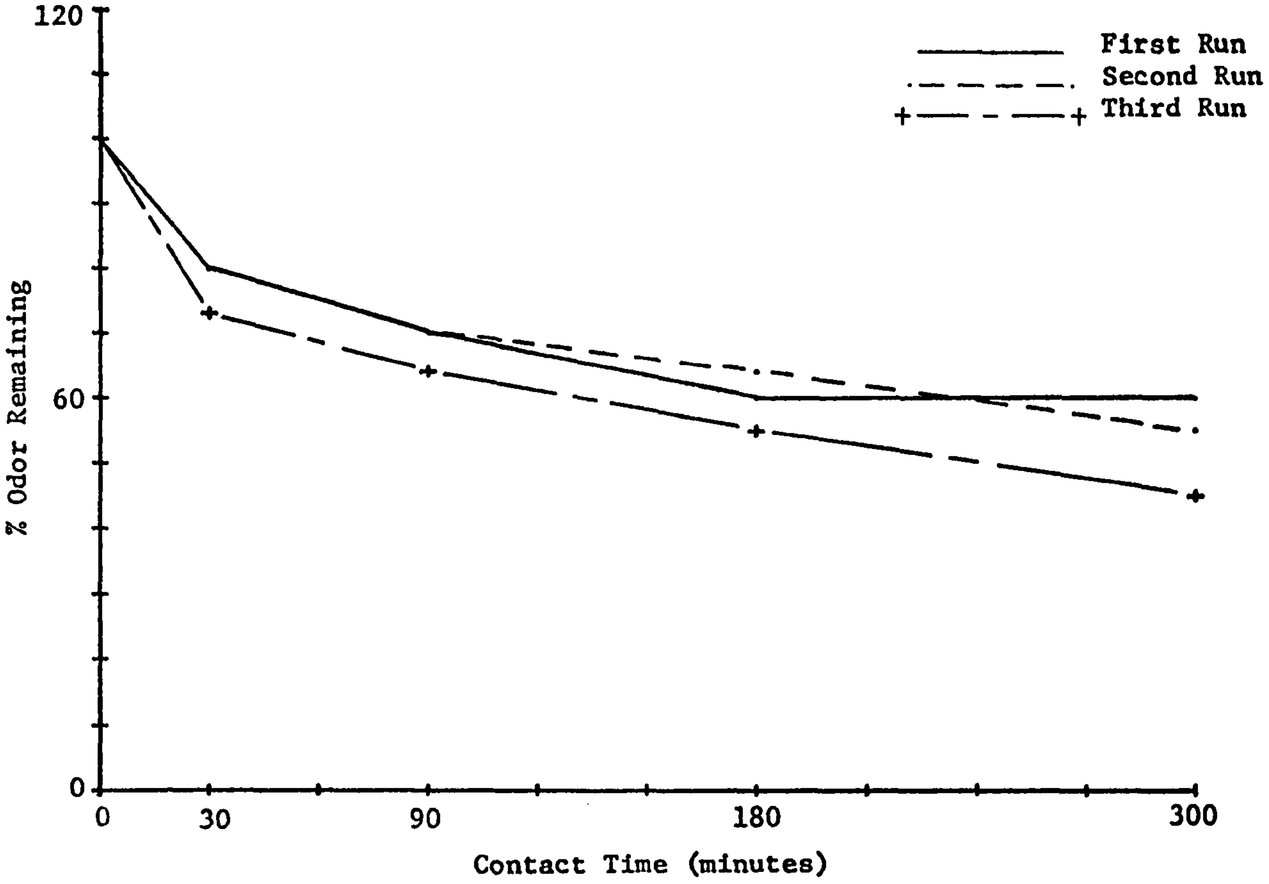


FIGURE 12. ODOR REDUCTION RATE DURING OZONATION.

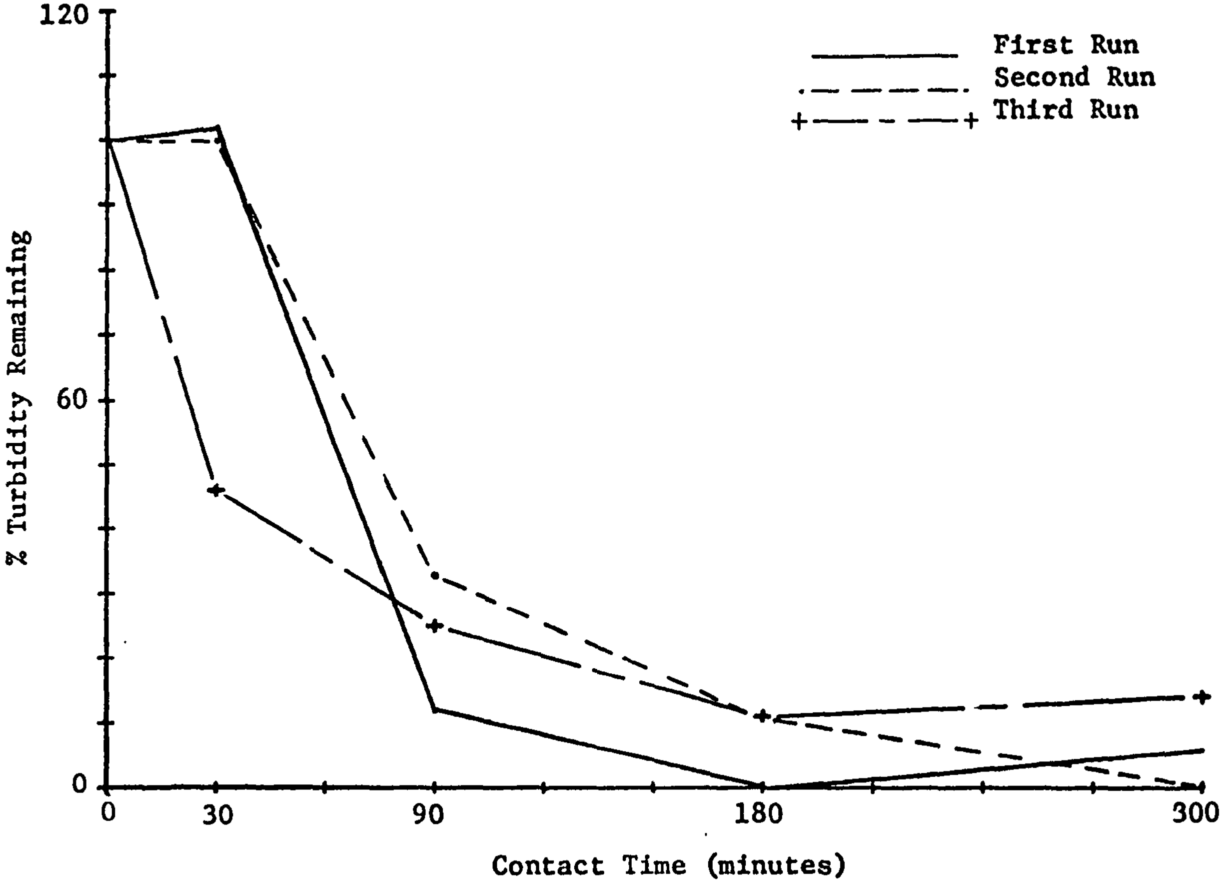


FIGURE 13. TURBIDITY REDUCTION RATE DURING OZONATION.

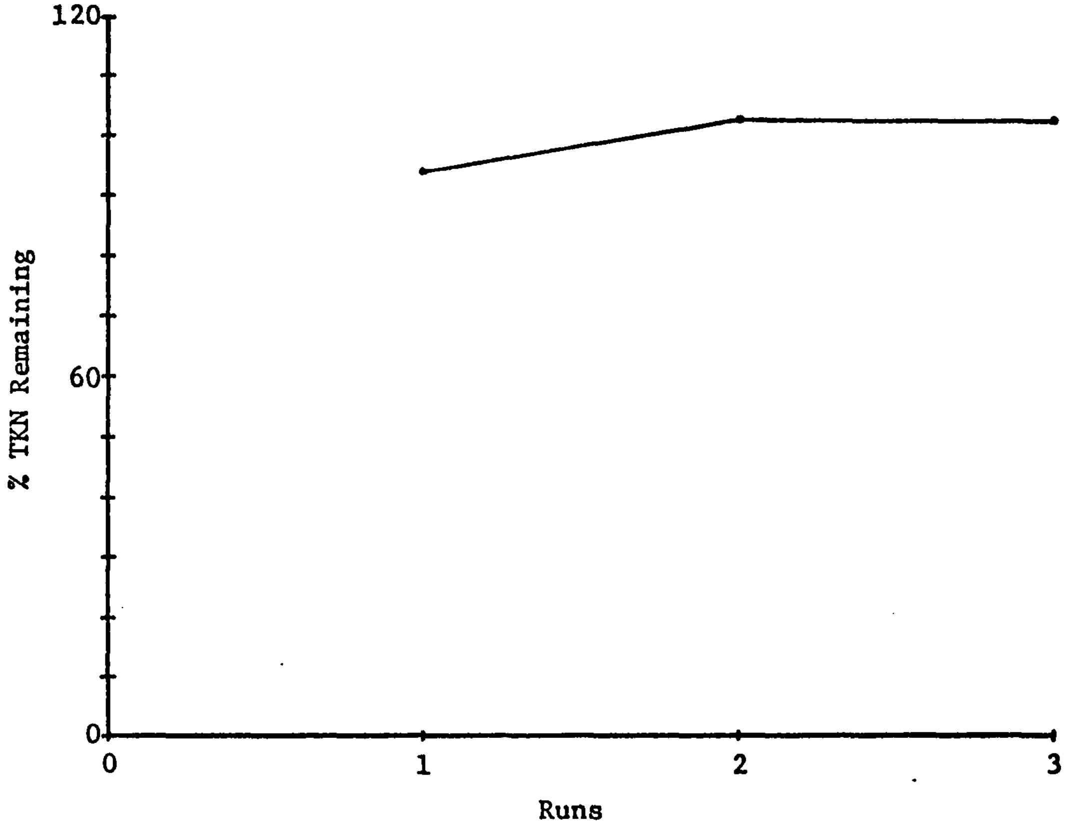


FIGURE 14. TKN REDUCTION RATE DURING OZONATION.

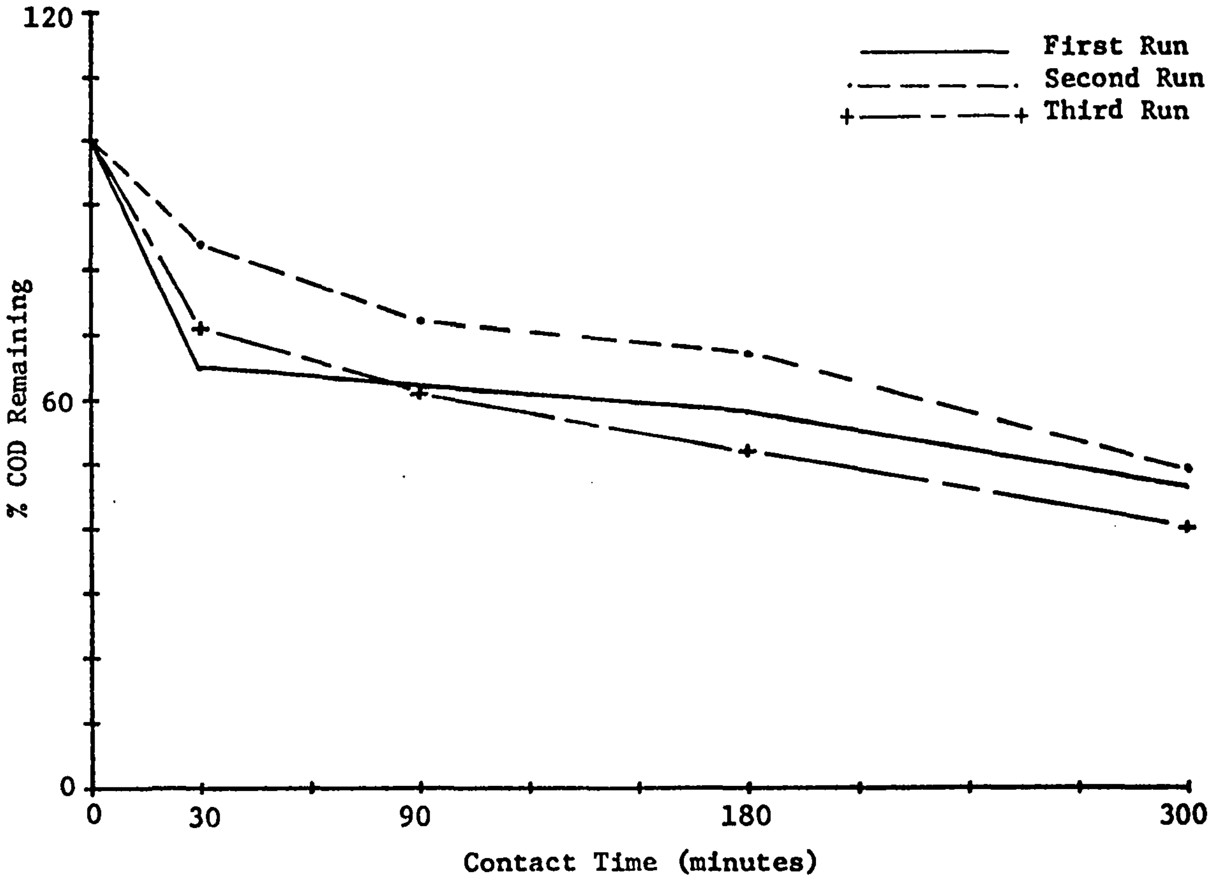


FIGURE 15. COD REDUCTION RATE DURING OZONATION-ULTRAVIOLET RADIATION.

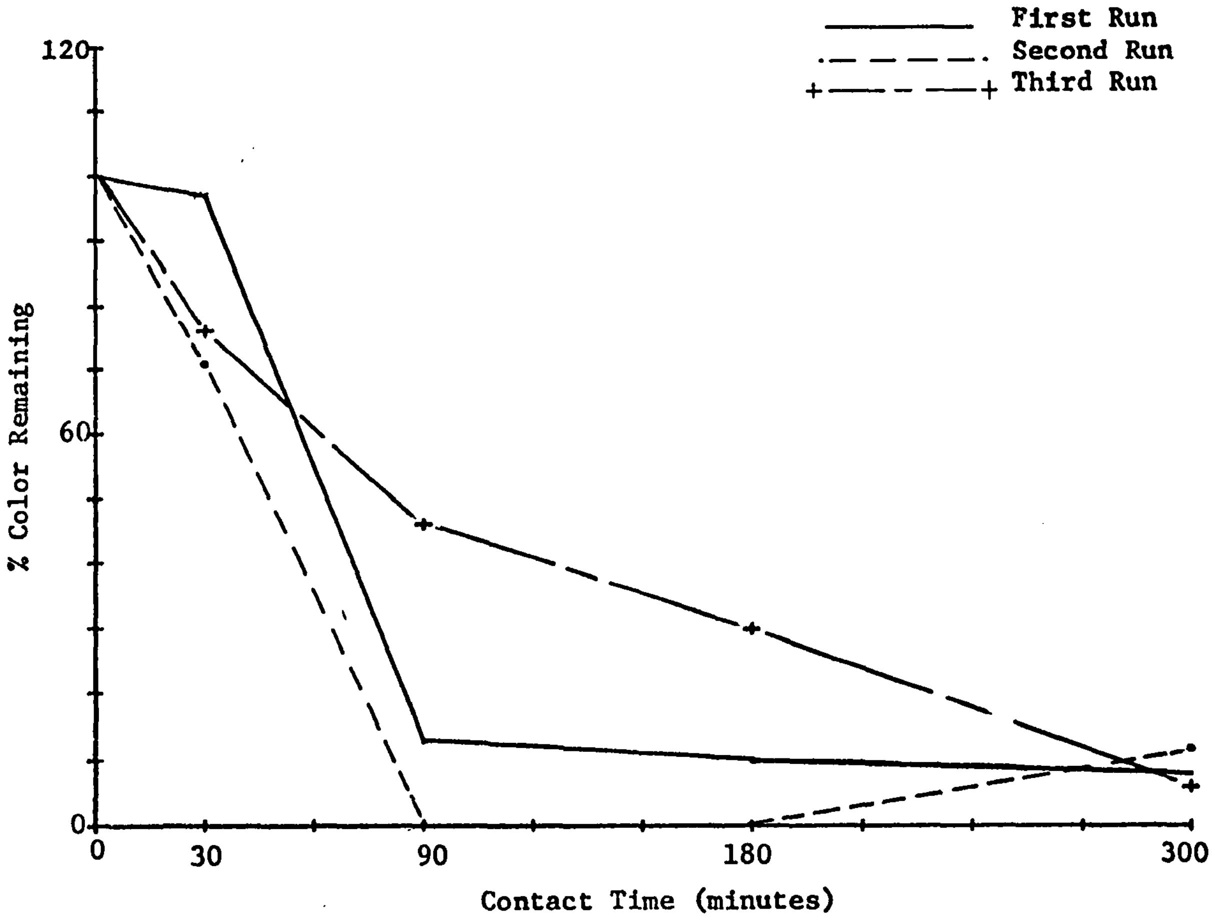


FIGURE 16. COLOR REDUCTION RATE DURING OZONATION-ULTRAVIOLET RADIATION.

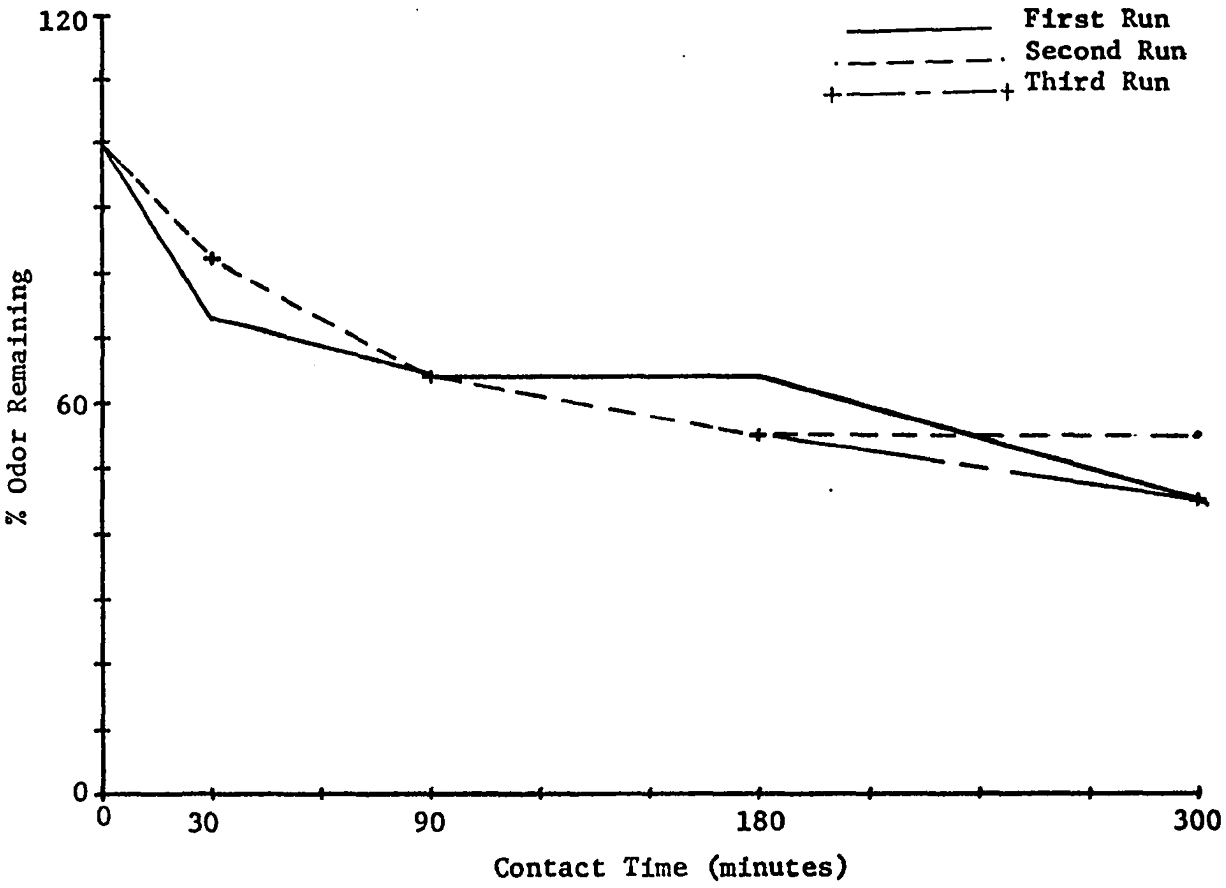


FIGURE 17. ODOR REDUCTION RATE DURING OZONATION-ULTRAVIOLET RADIATION.

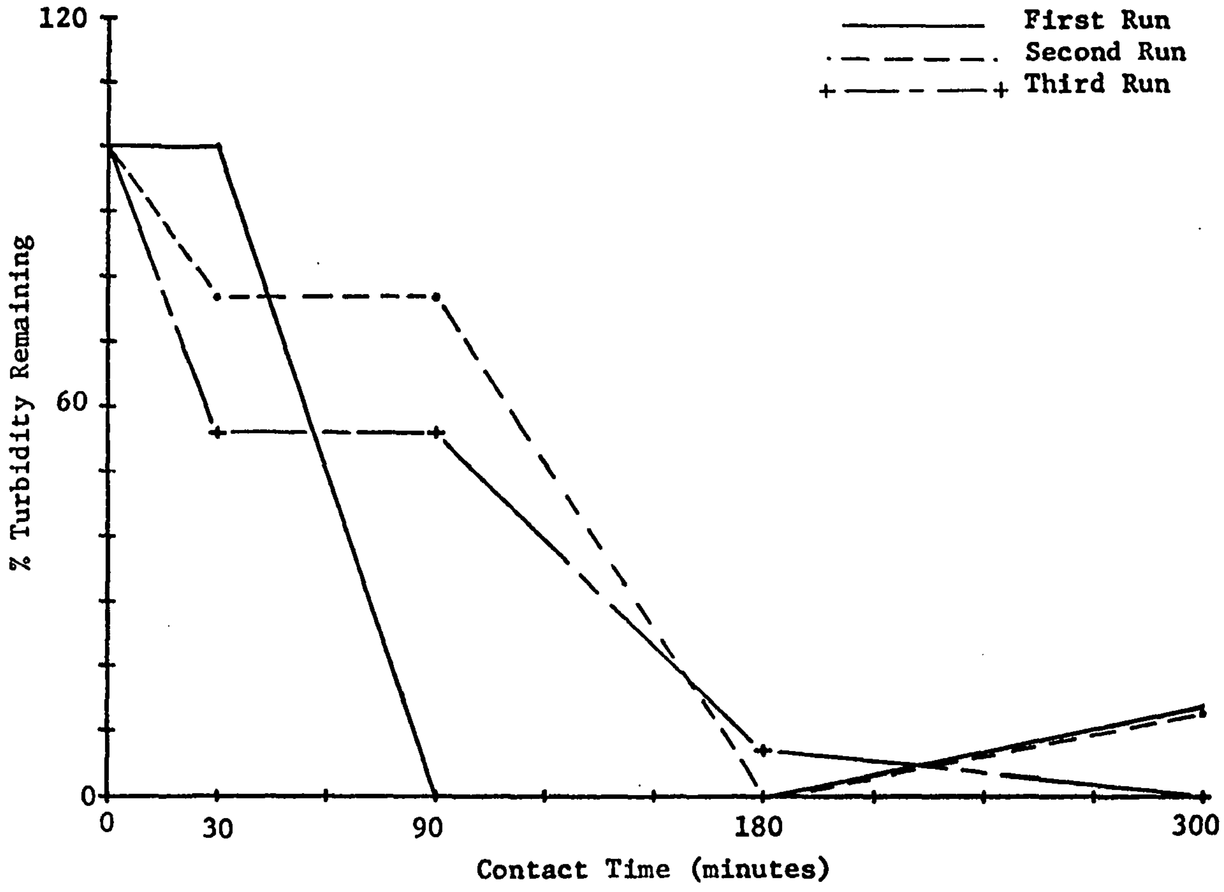


FIGURE 18. TURBIDITY REDUCTION RATE DURING OZONATION-ULTRAVIOLET RADIATION.

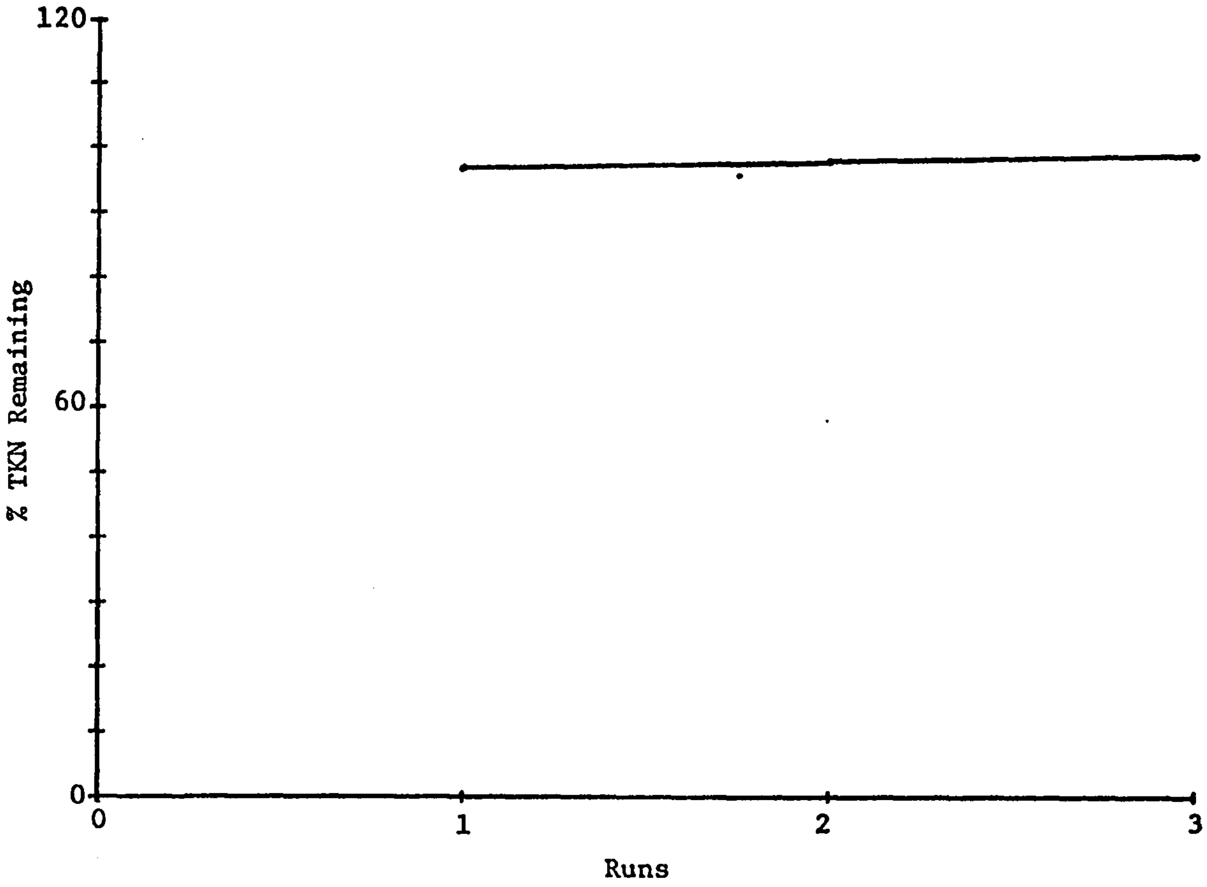


FIGURE 19. TKN REDUCTION RATE DURING OZONATION-ULTRAVIOLET RADIATION.

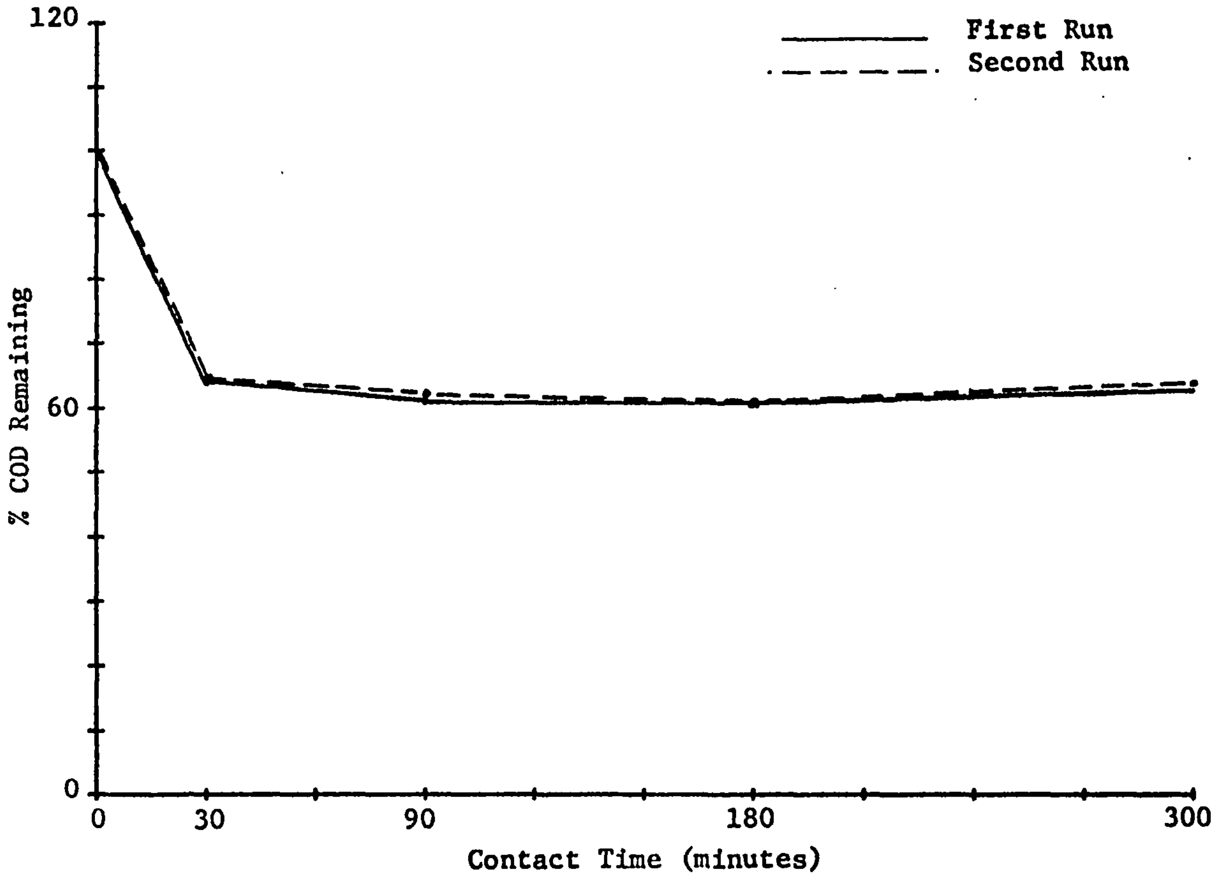


FIGURE 20. COD REDUCTION RATE DURING ULTRAVIOLET RADIATION.

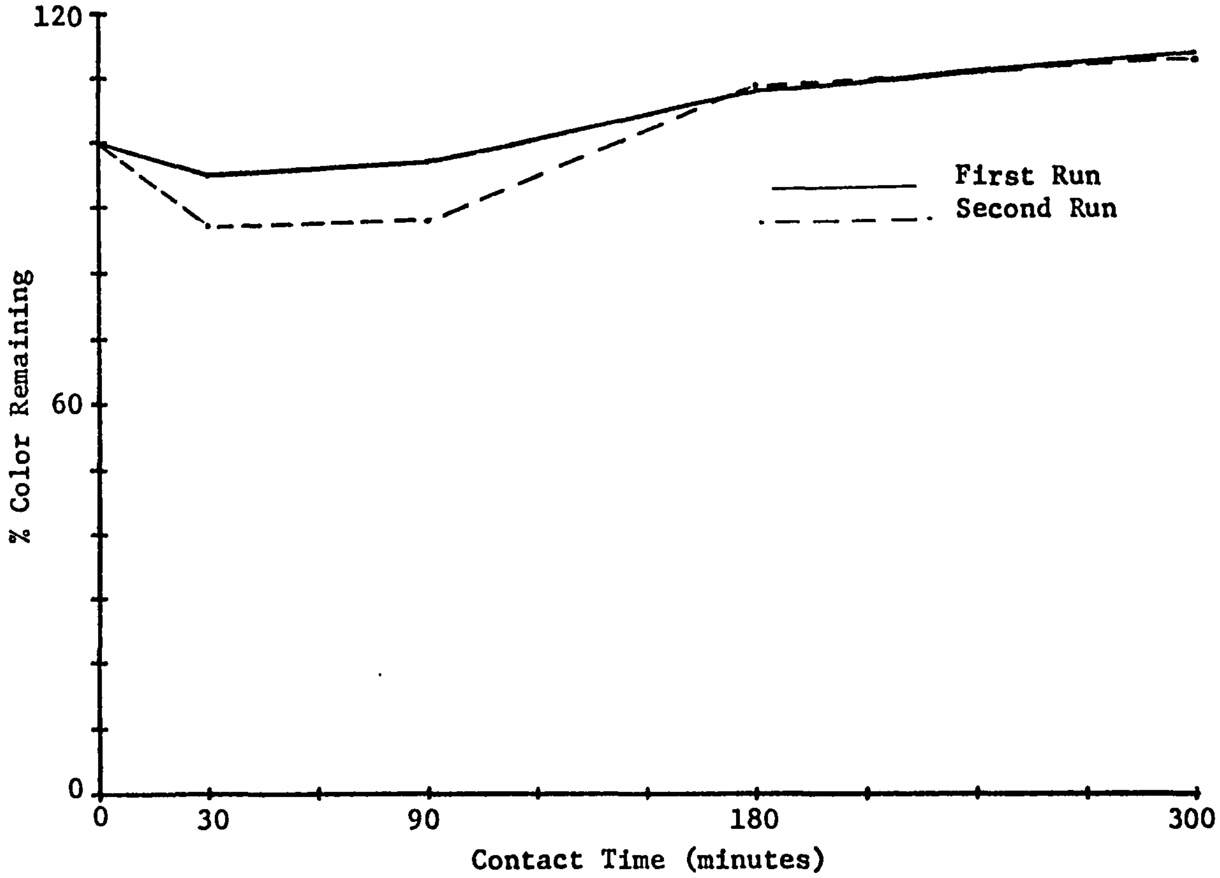


FIGURE 21. COLOR REDUCTION RATE DURING ULTRAVIOLET RADIATION.

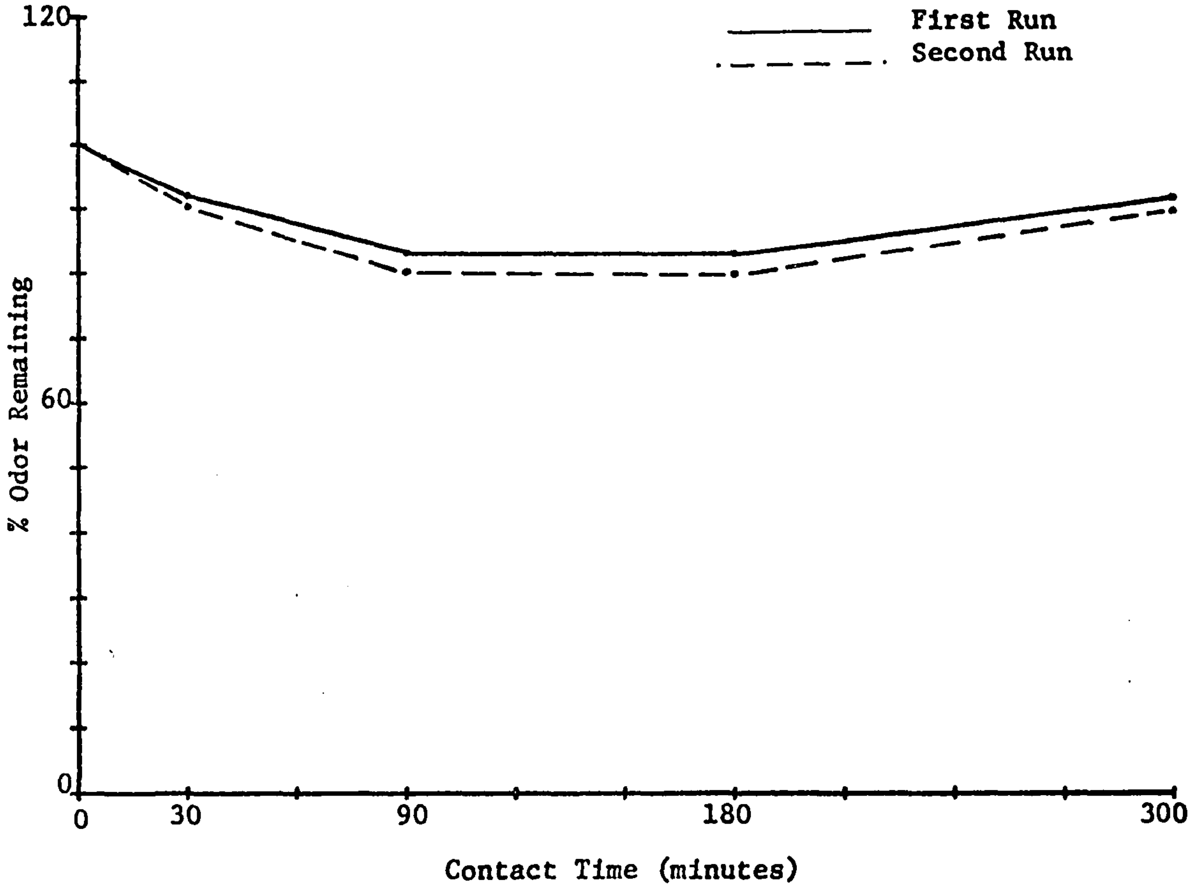


FIGURE 22. ODOR REDUCTION RATE DURING ULTRAVIOLET RADIATION.

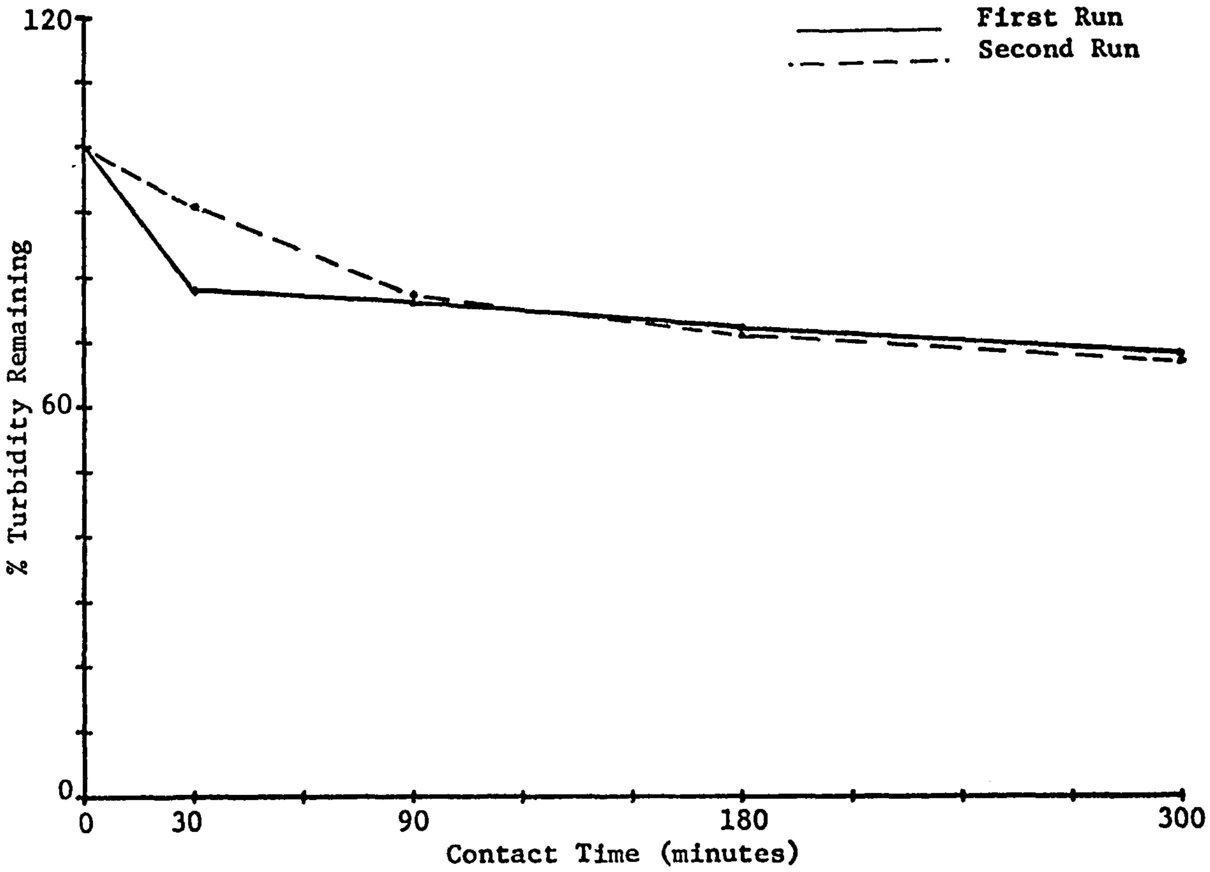


FIGURE 23. TURBIDITY REDUCTION RATE DURING ULTRAVIOLET RADIATION.

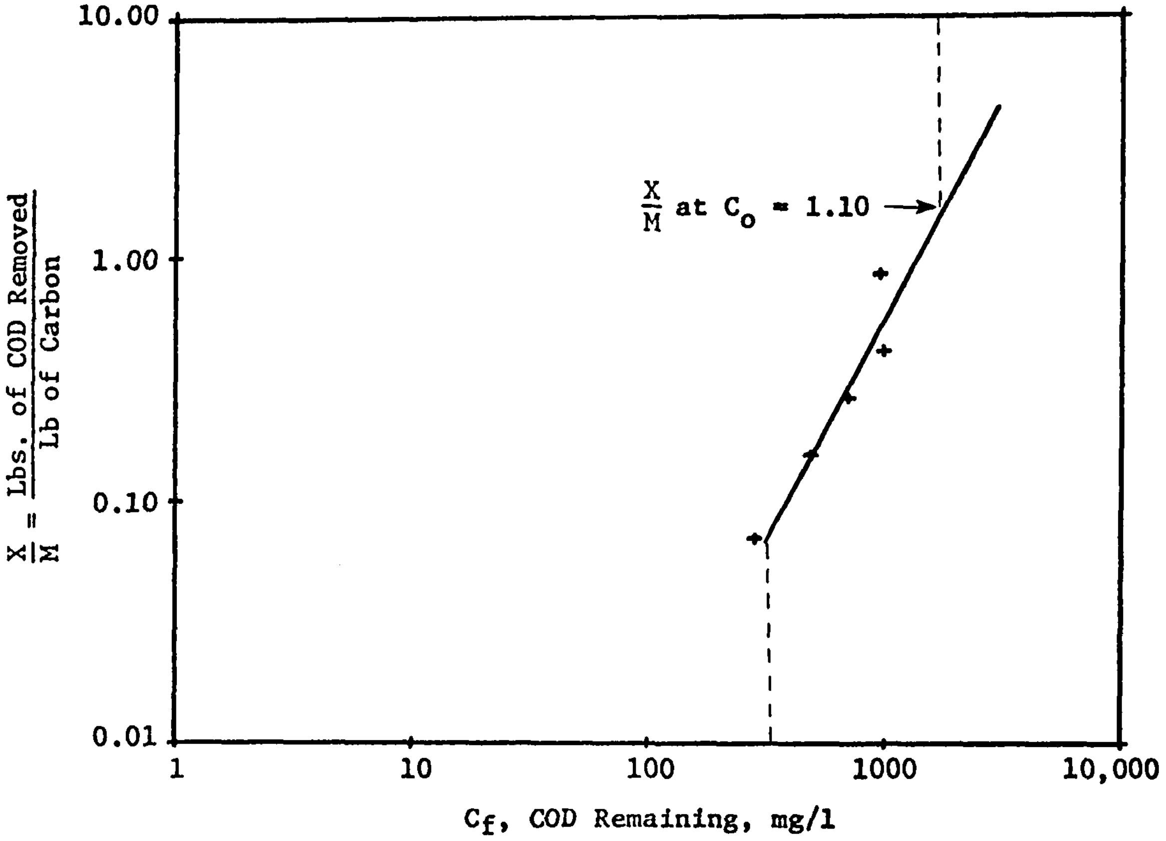


FIGURE 24. NUCHAR WV-L ADSORPTION ISOTHERM.

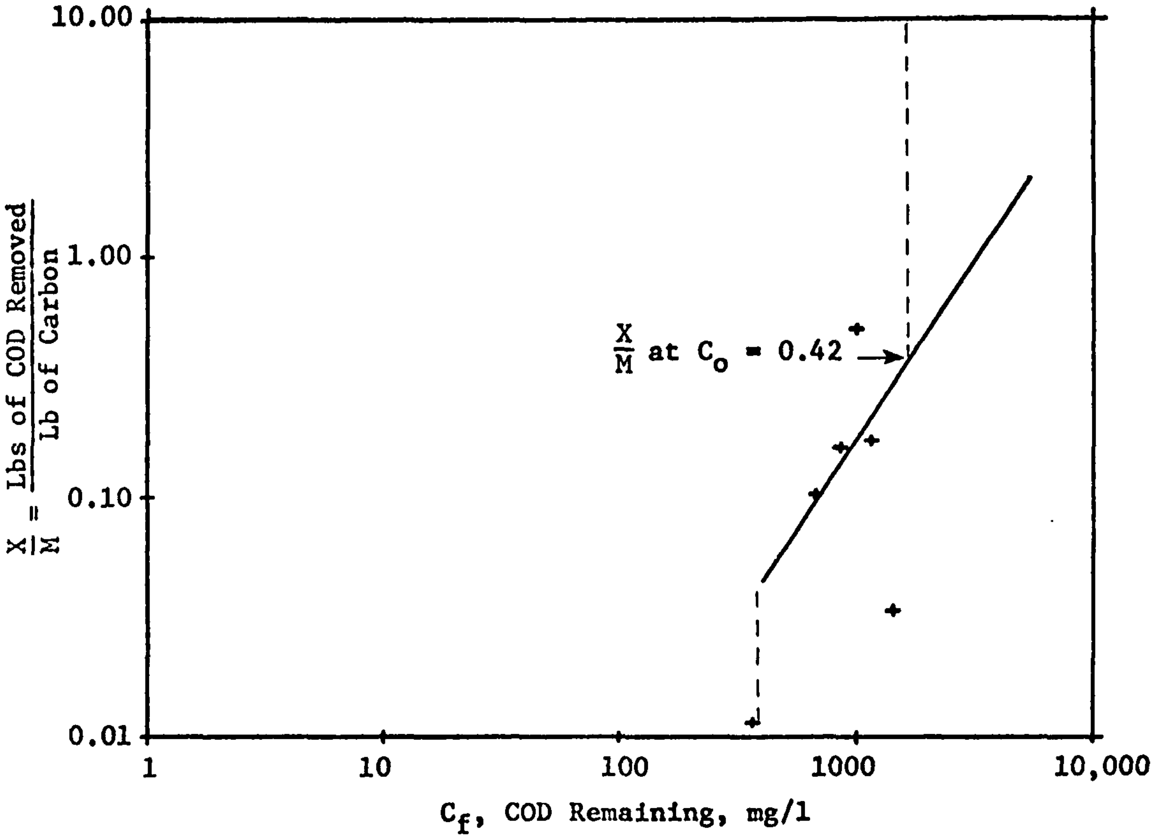


FIGURE 25. NUCHAR WV-G ADSORPTION ISOTHERM.

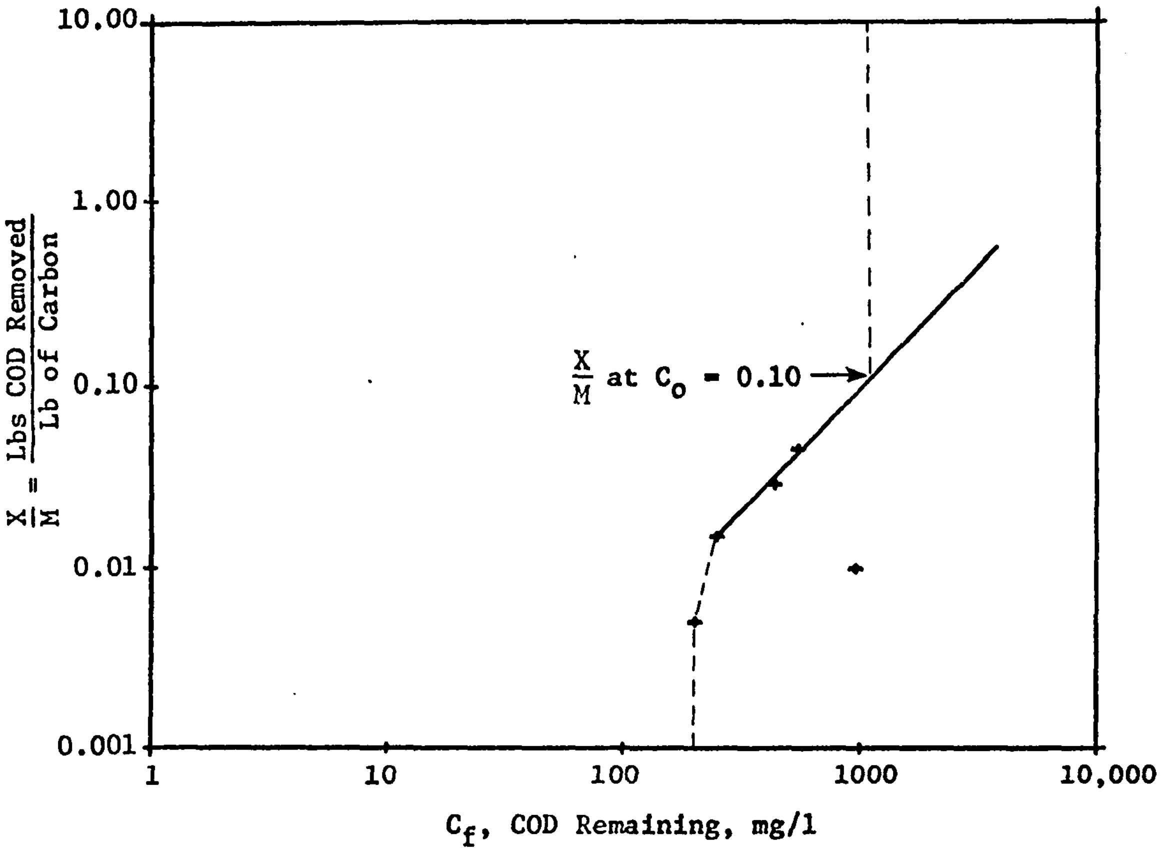


FIGURE 26. DARCO HD-3000 ADSORPTION ISOTHERM.

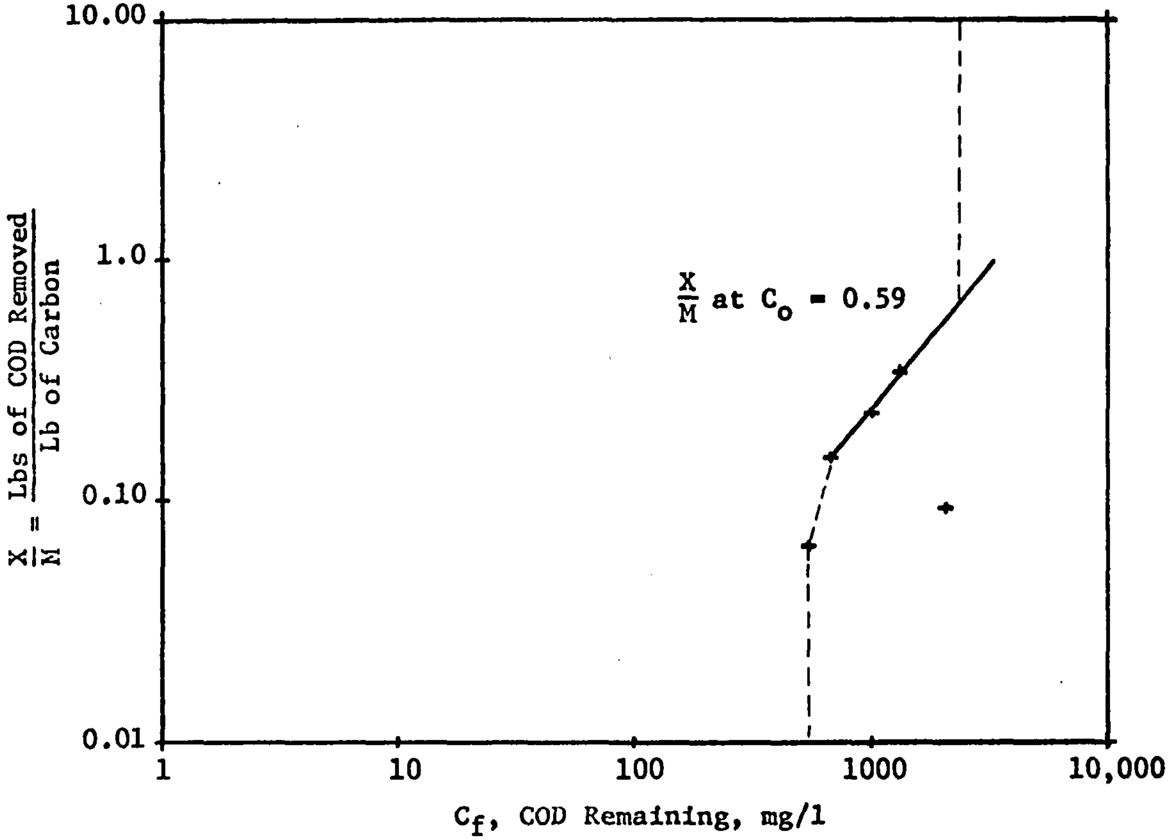


FIGURE 27. FILTRASORB 300 ADSORPTION ISOTHERM.

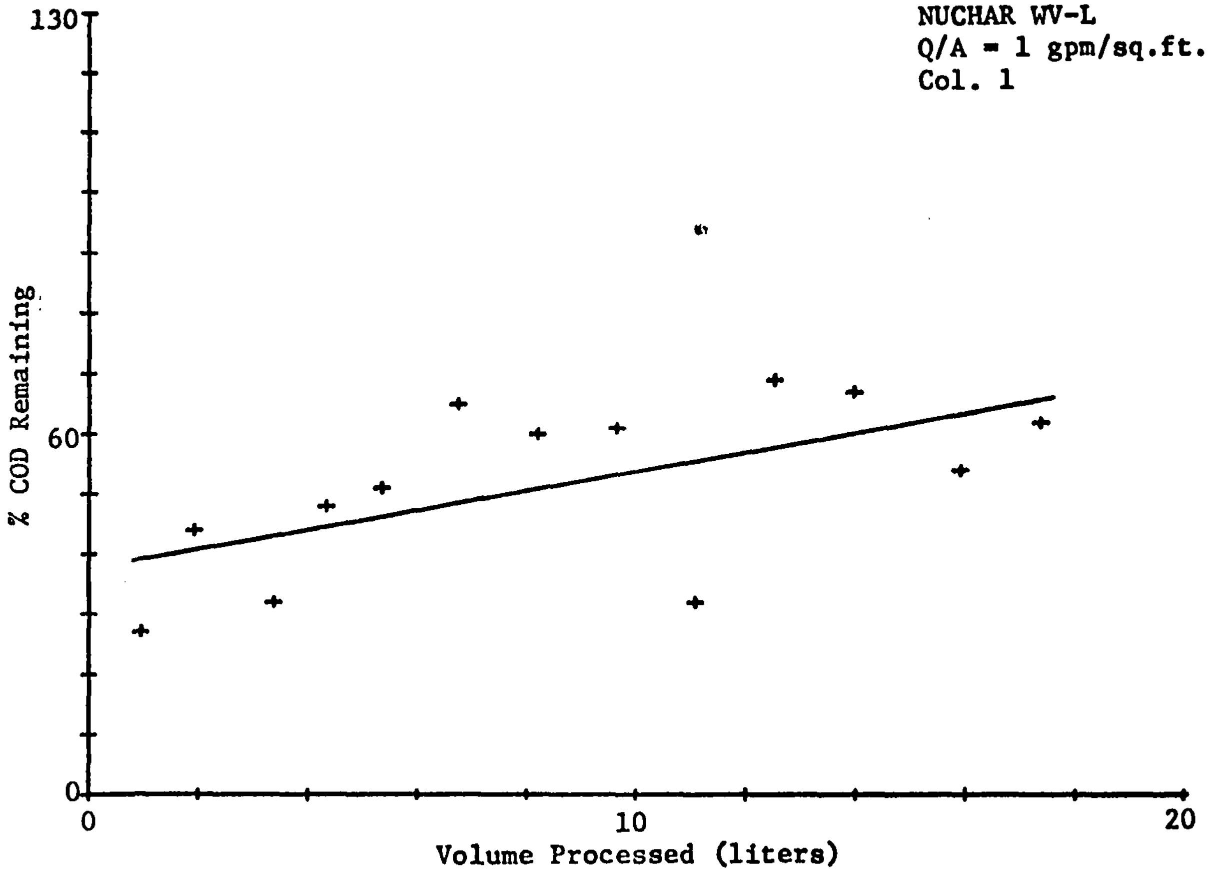
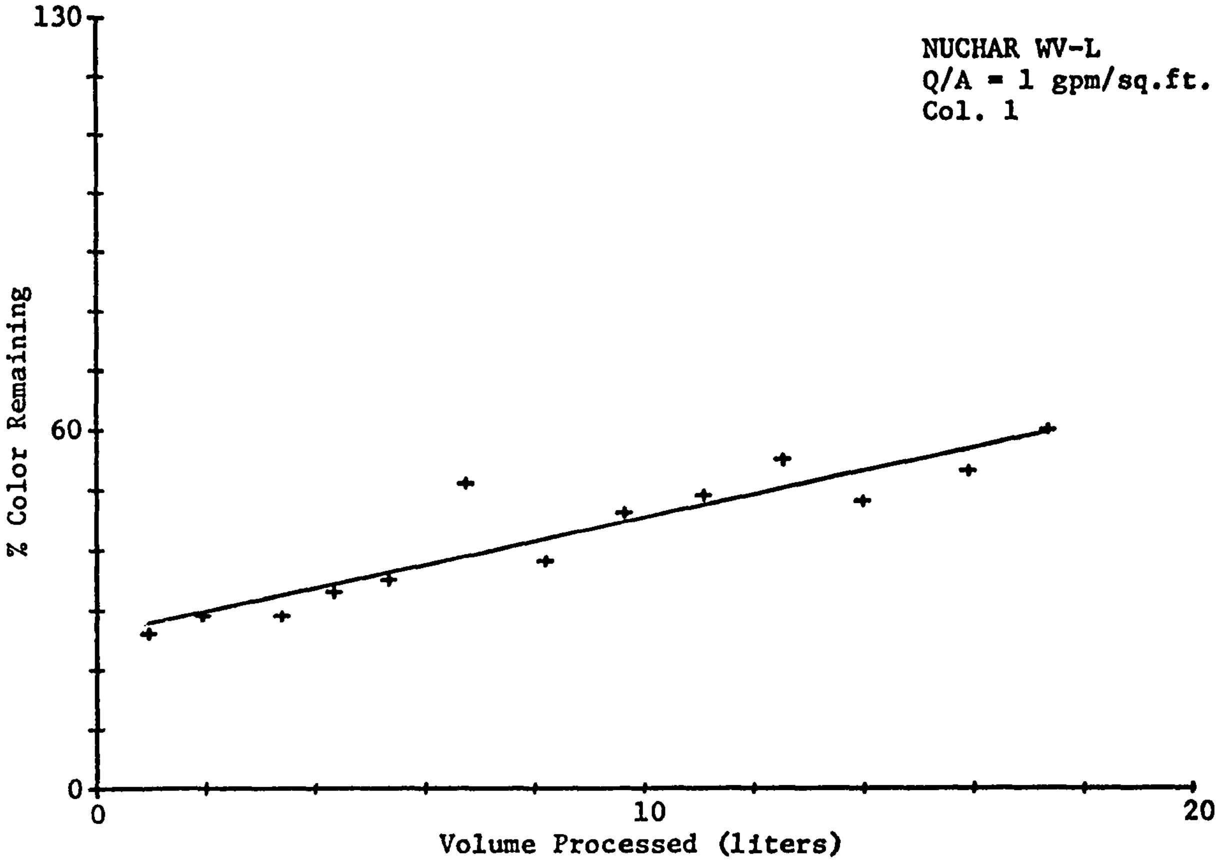


FIGURE 28. BREAKTHROUGH CURVE.



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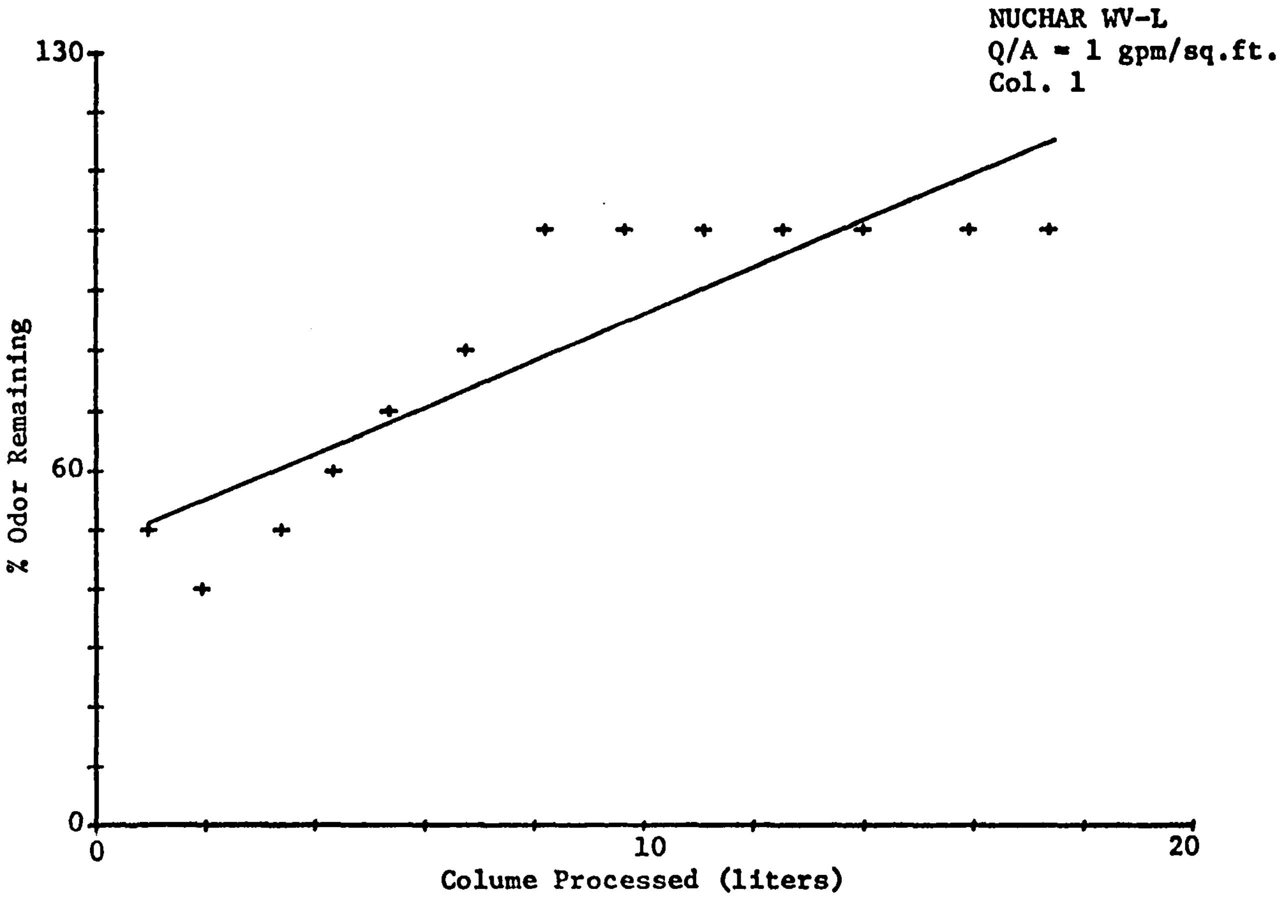

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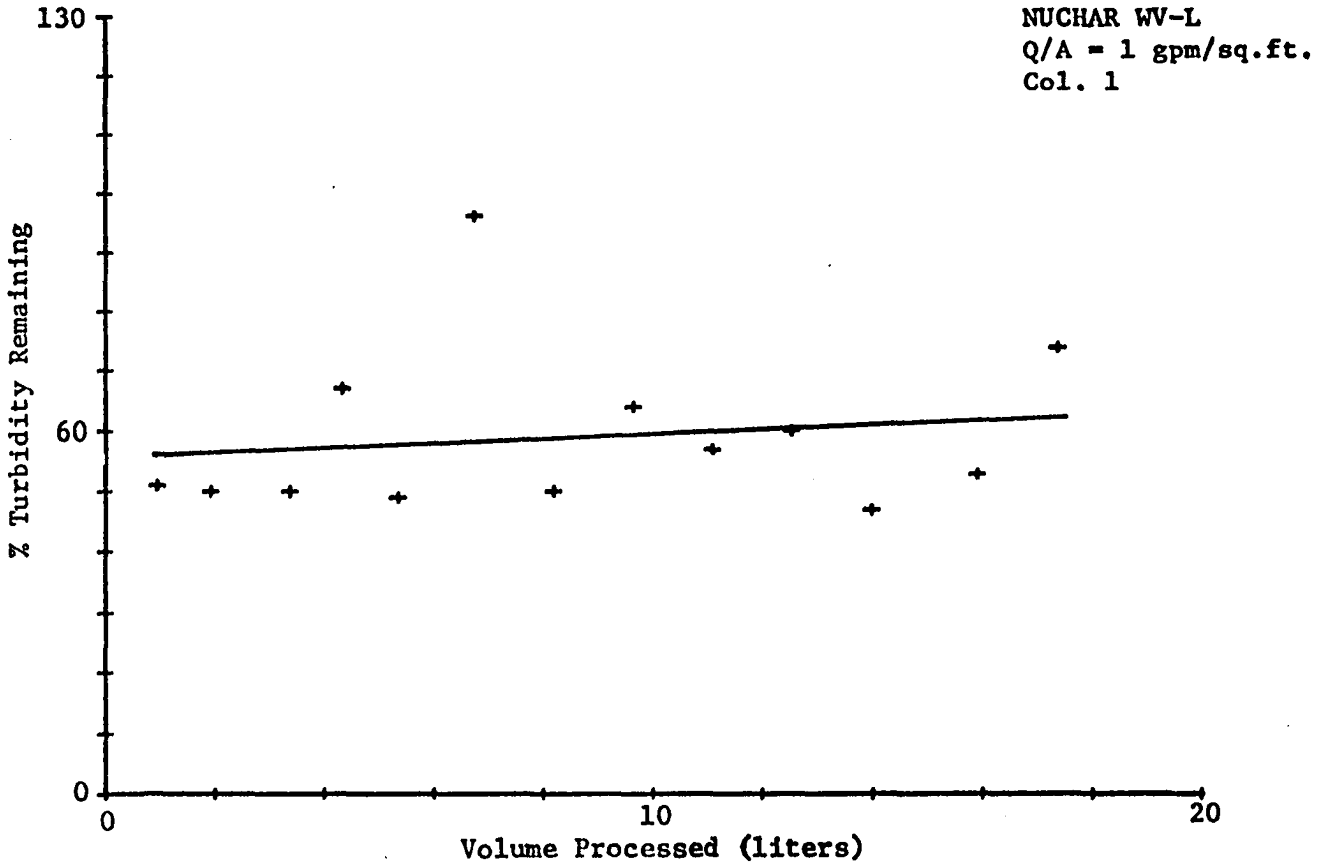

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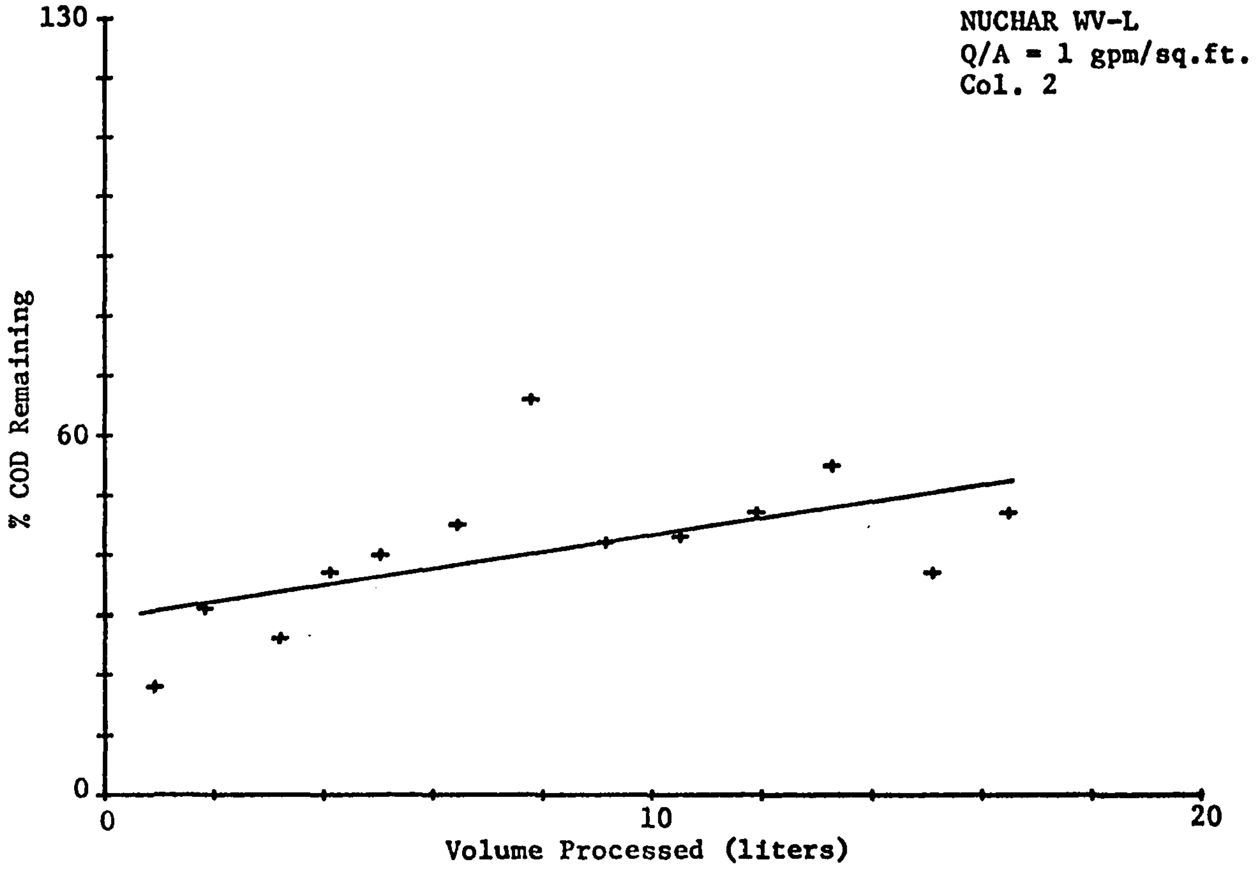

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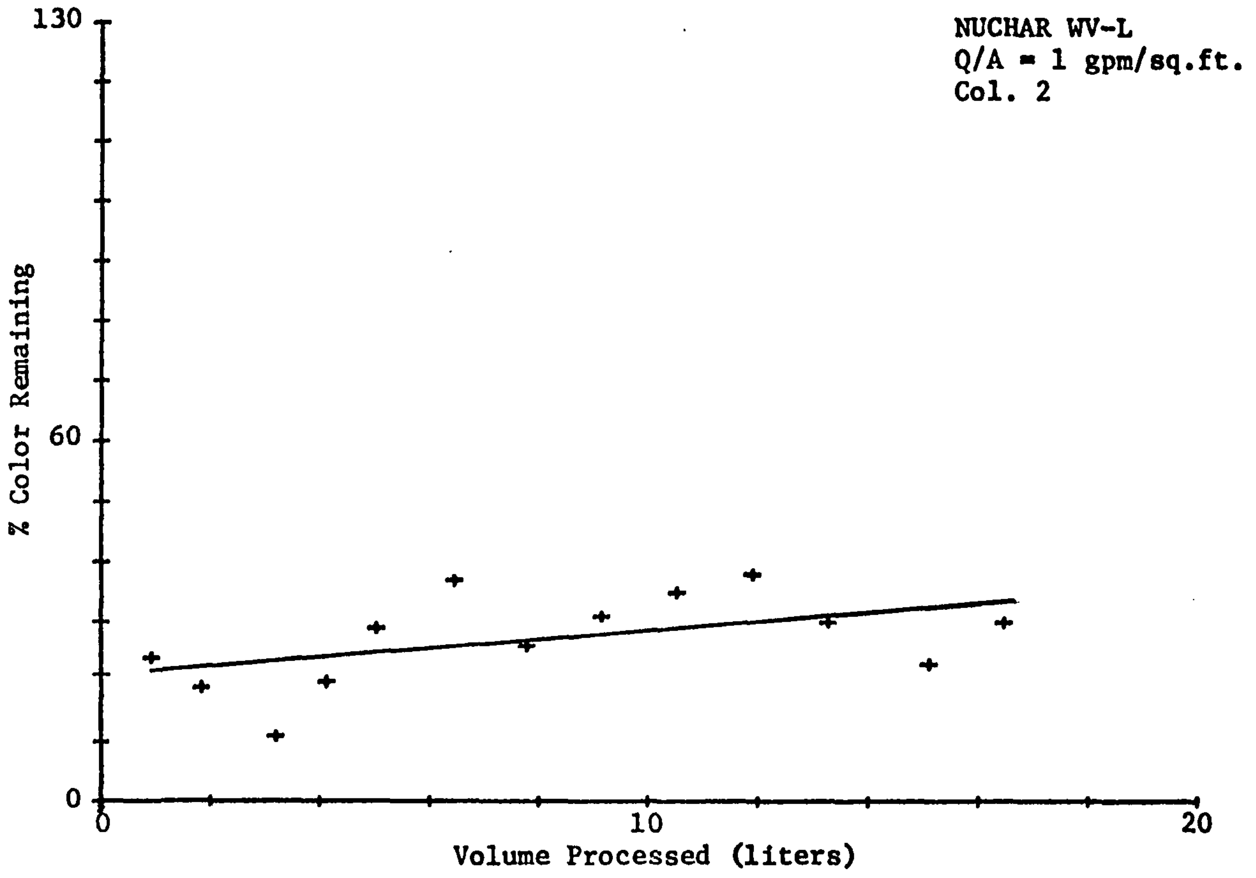

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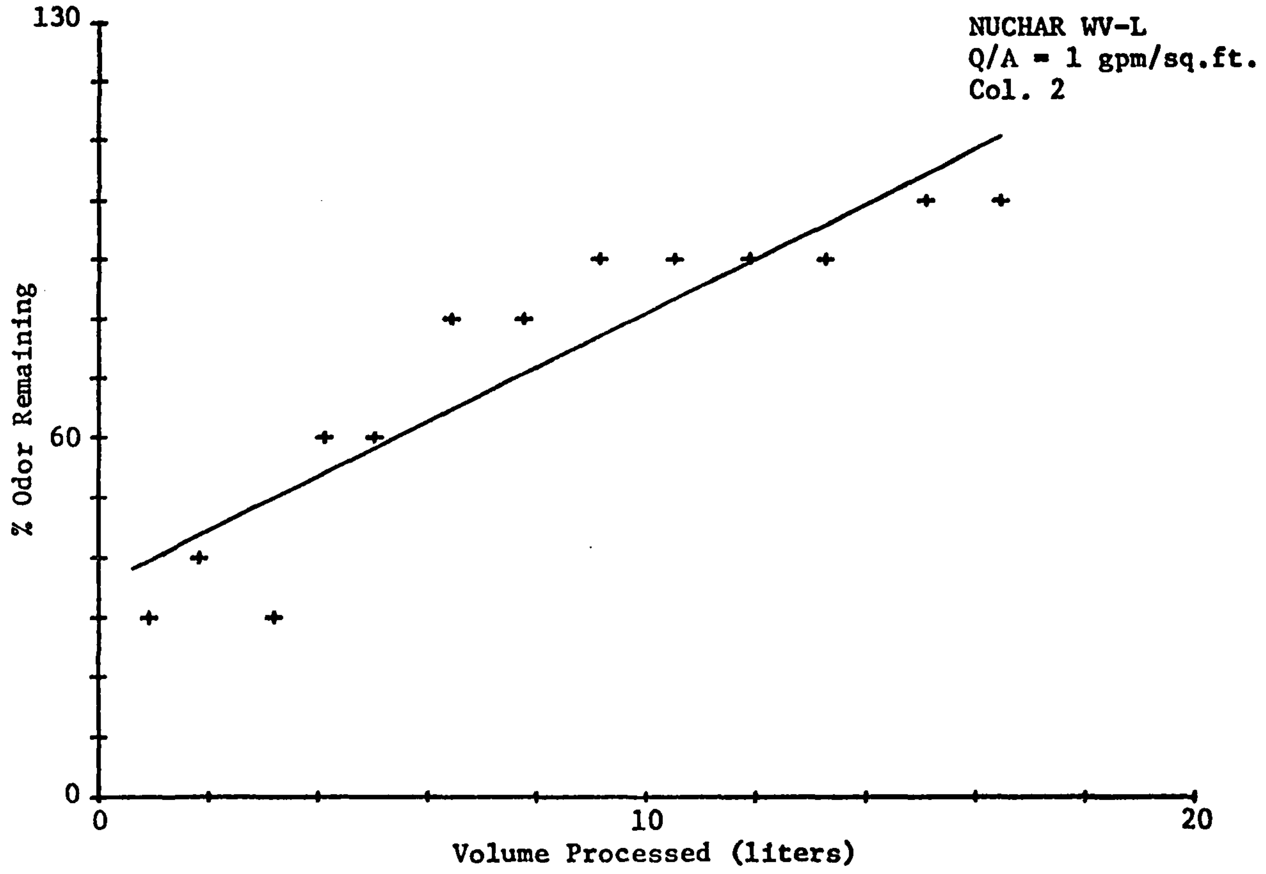

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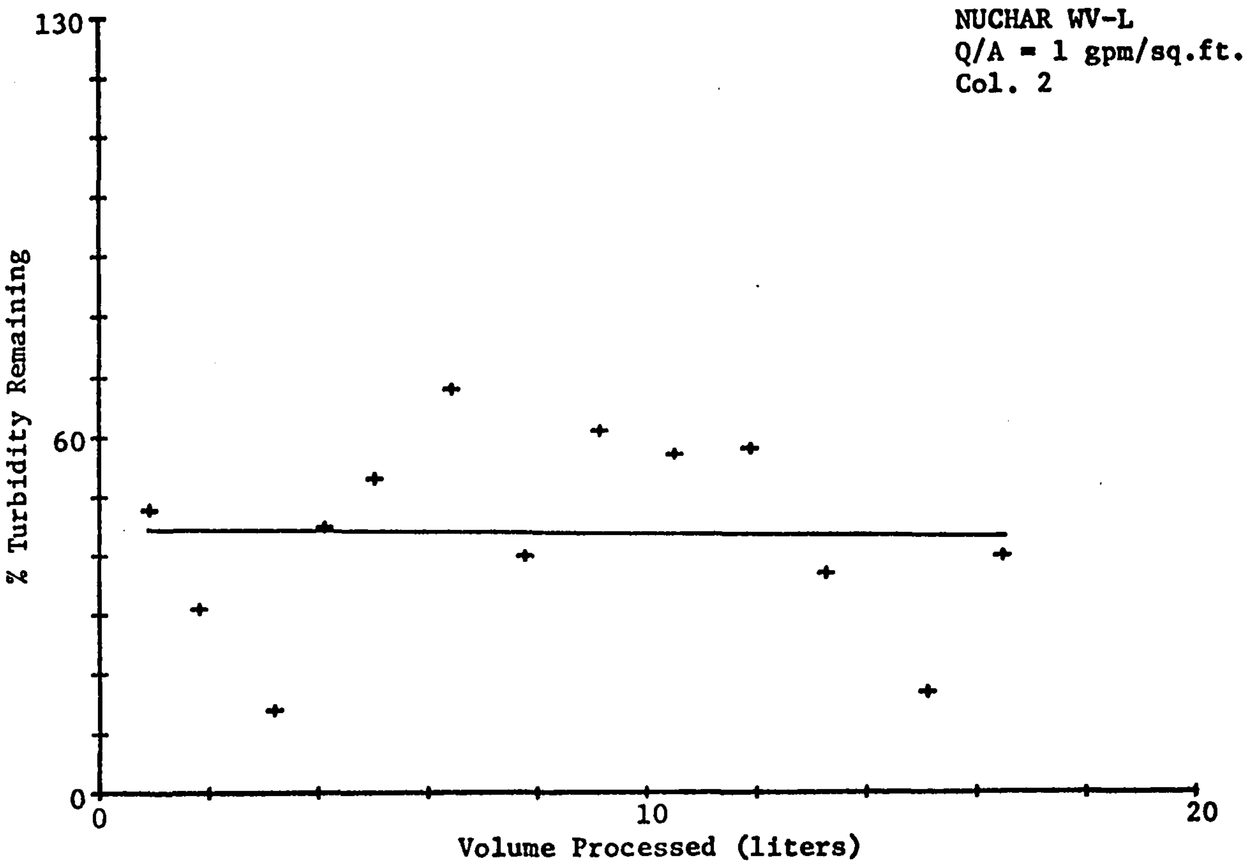

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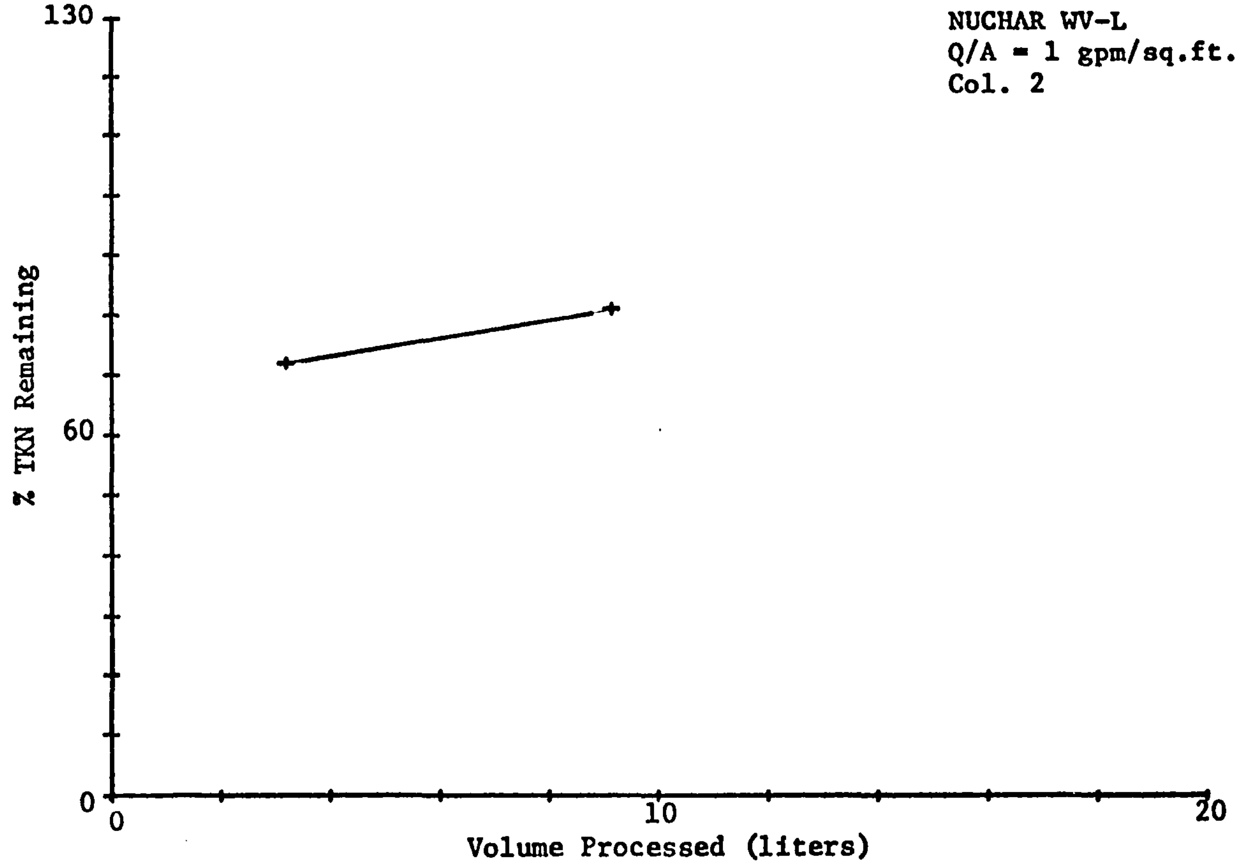

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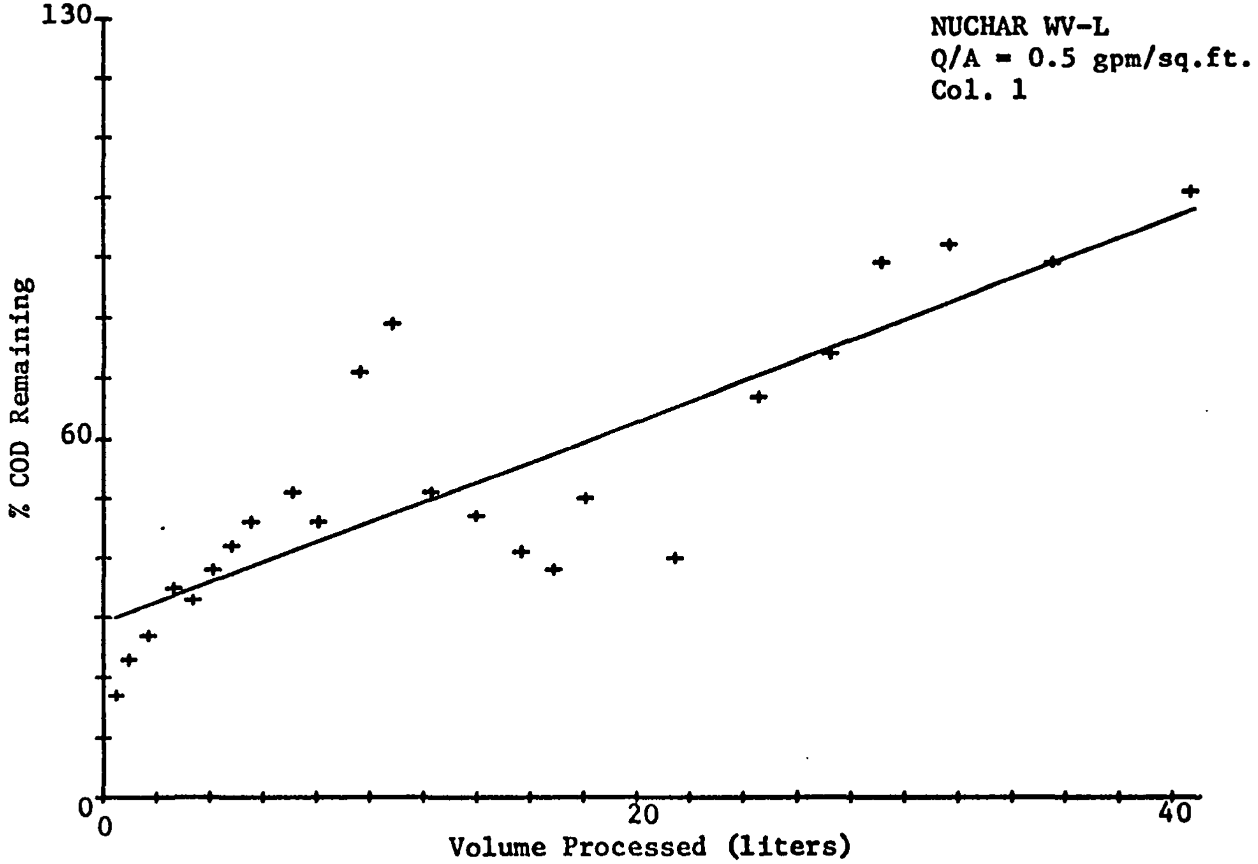

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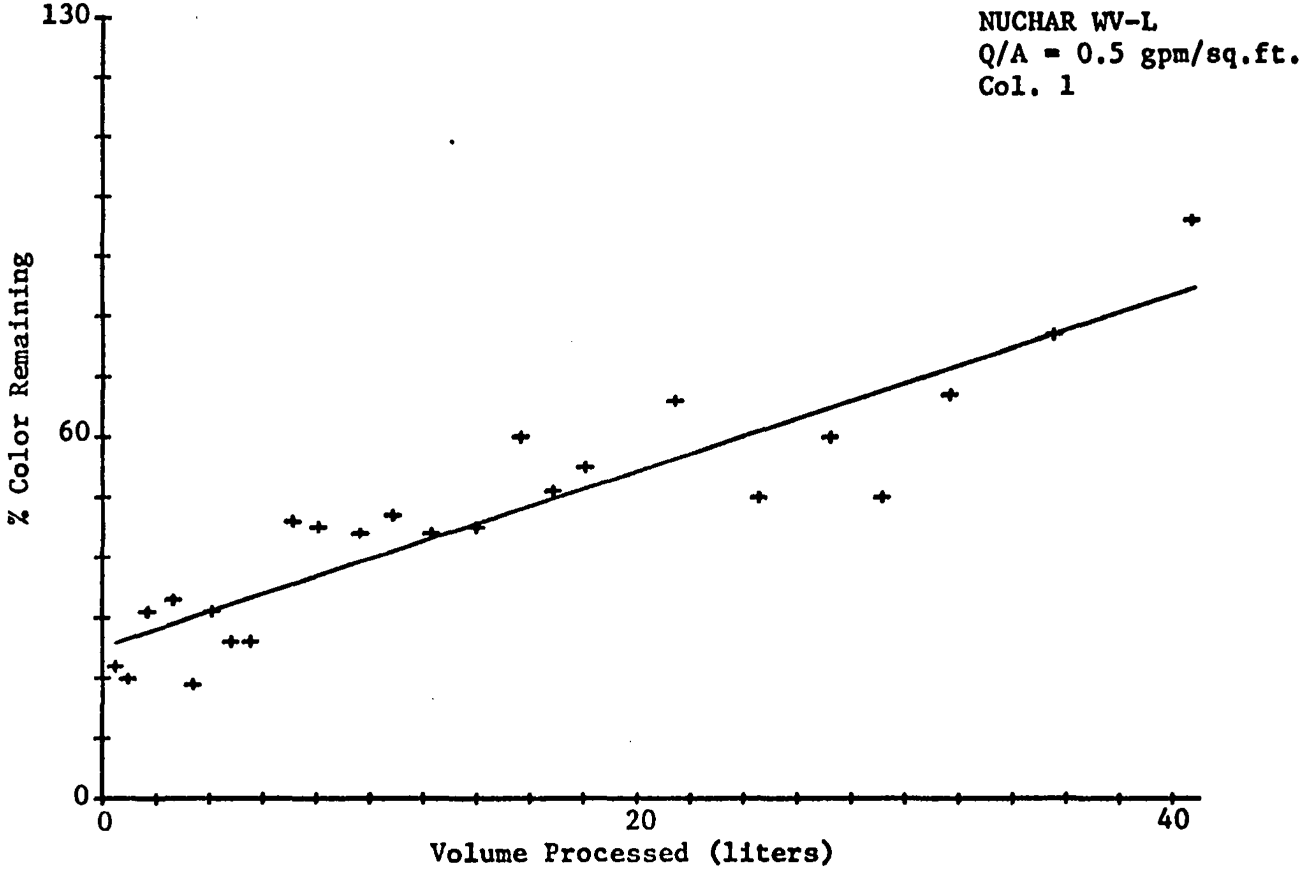

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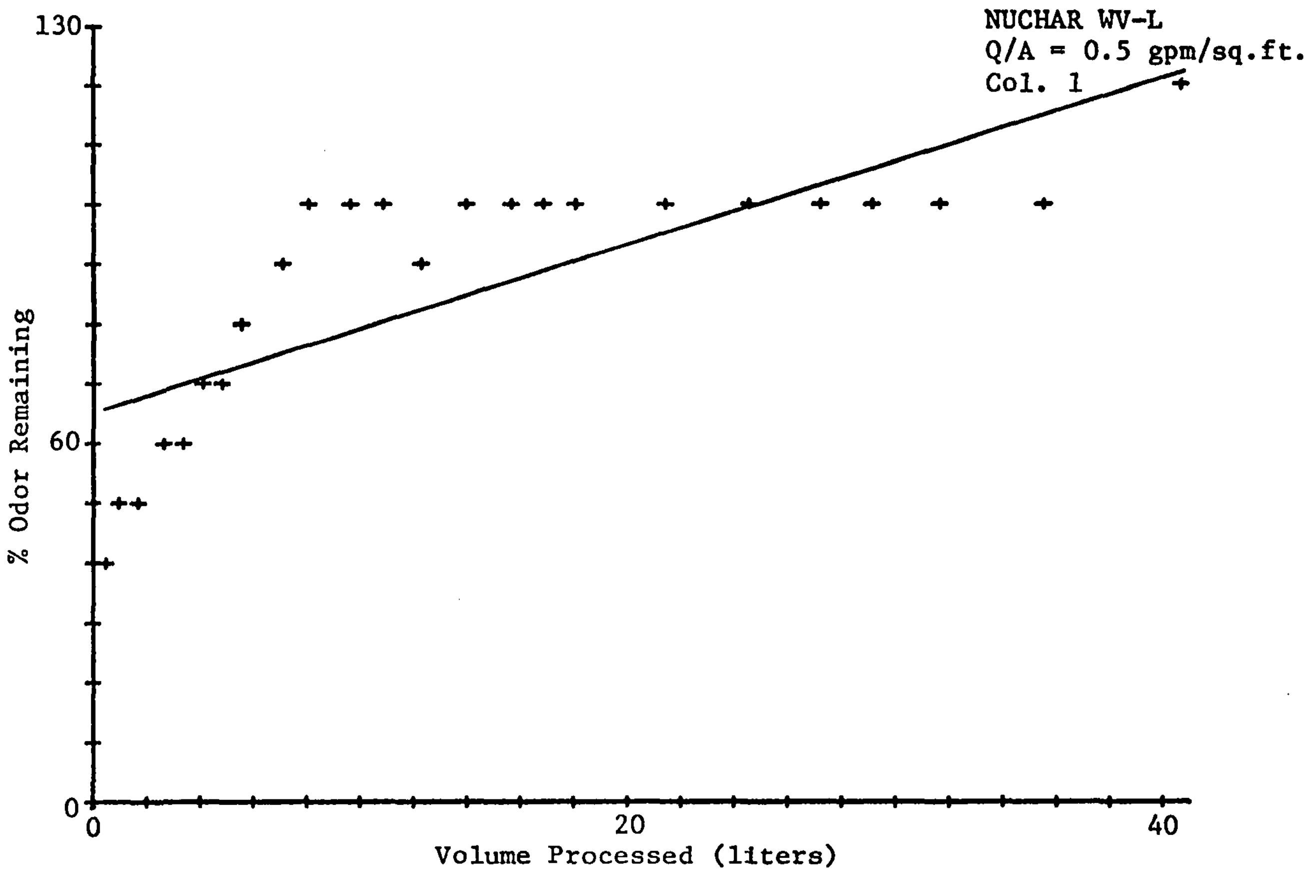

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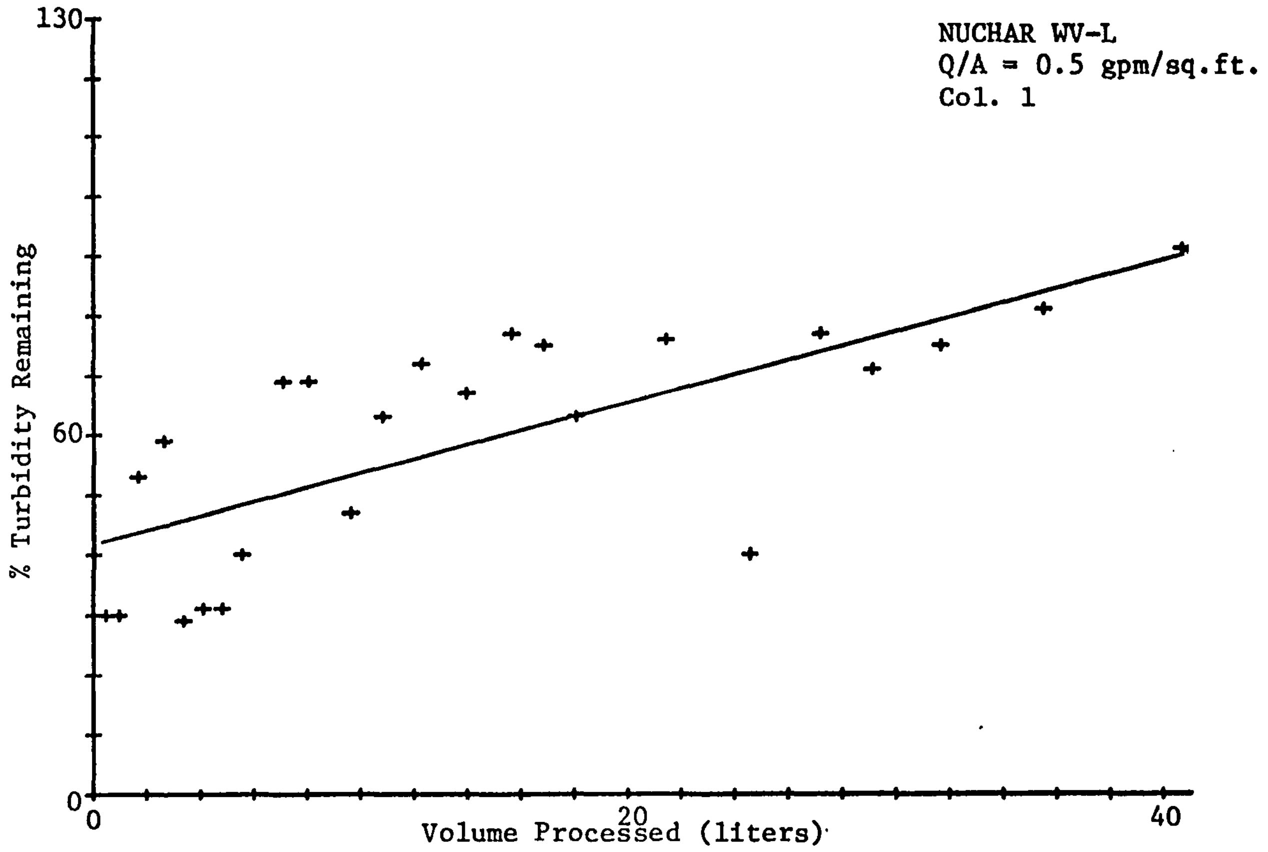

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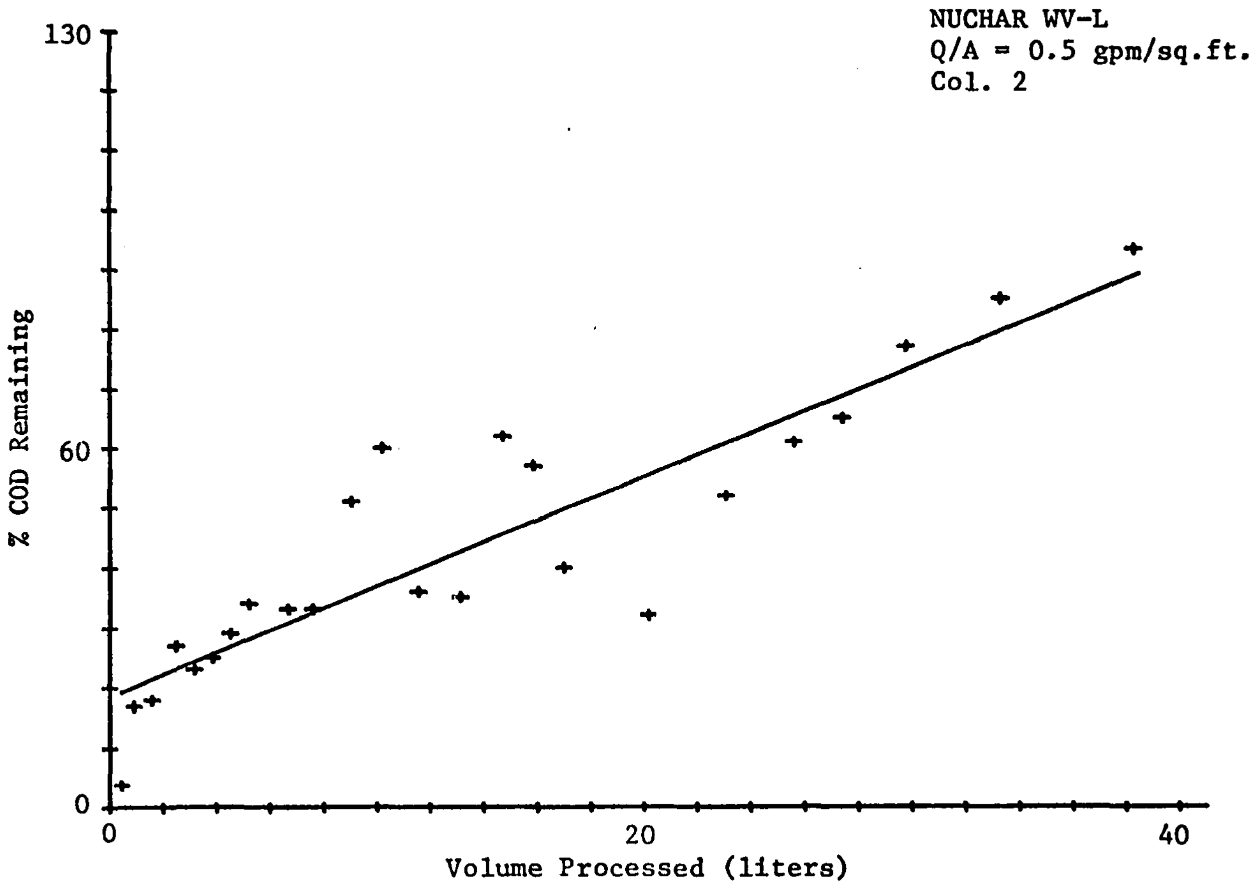

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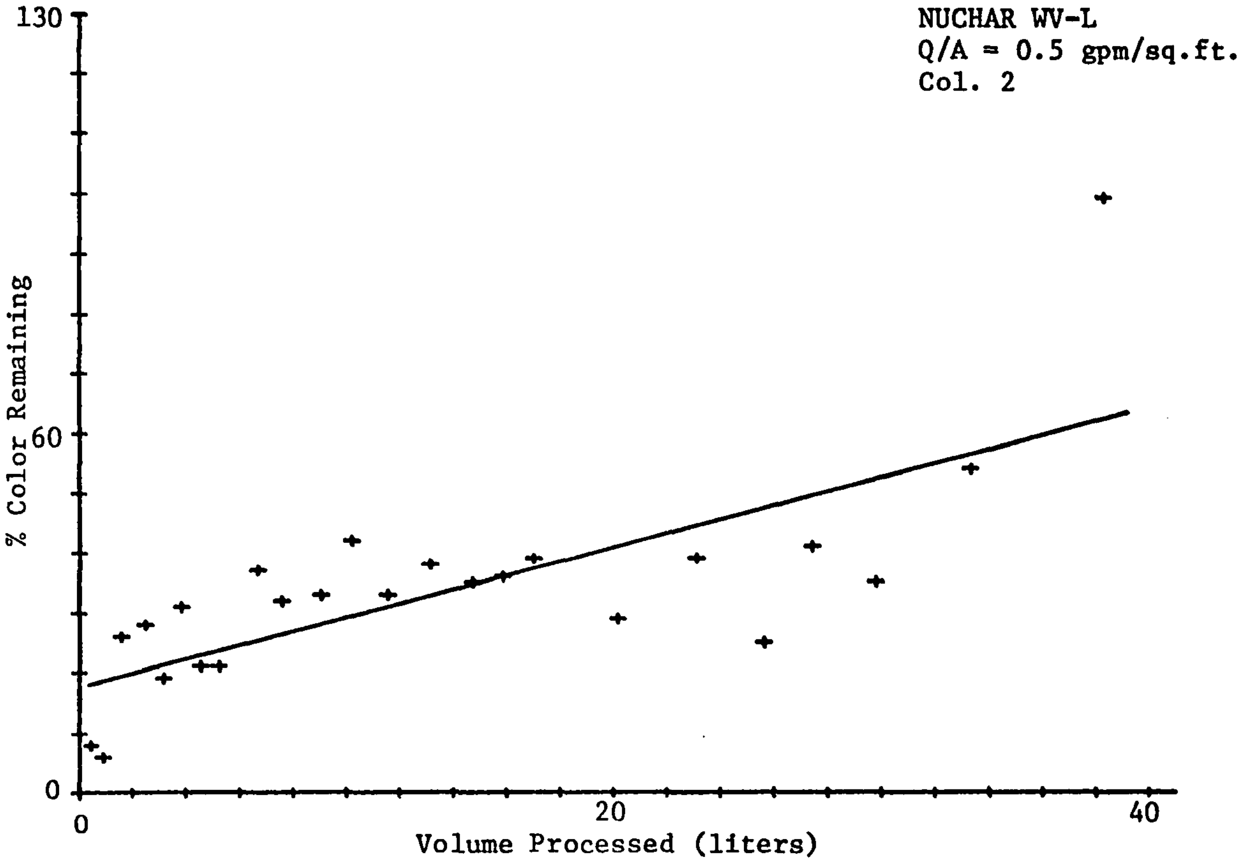

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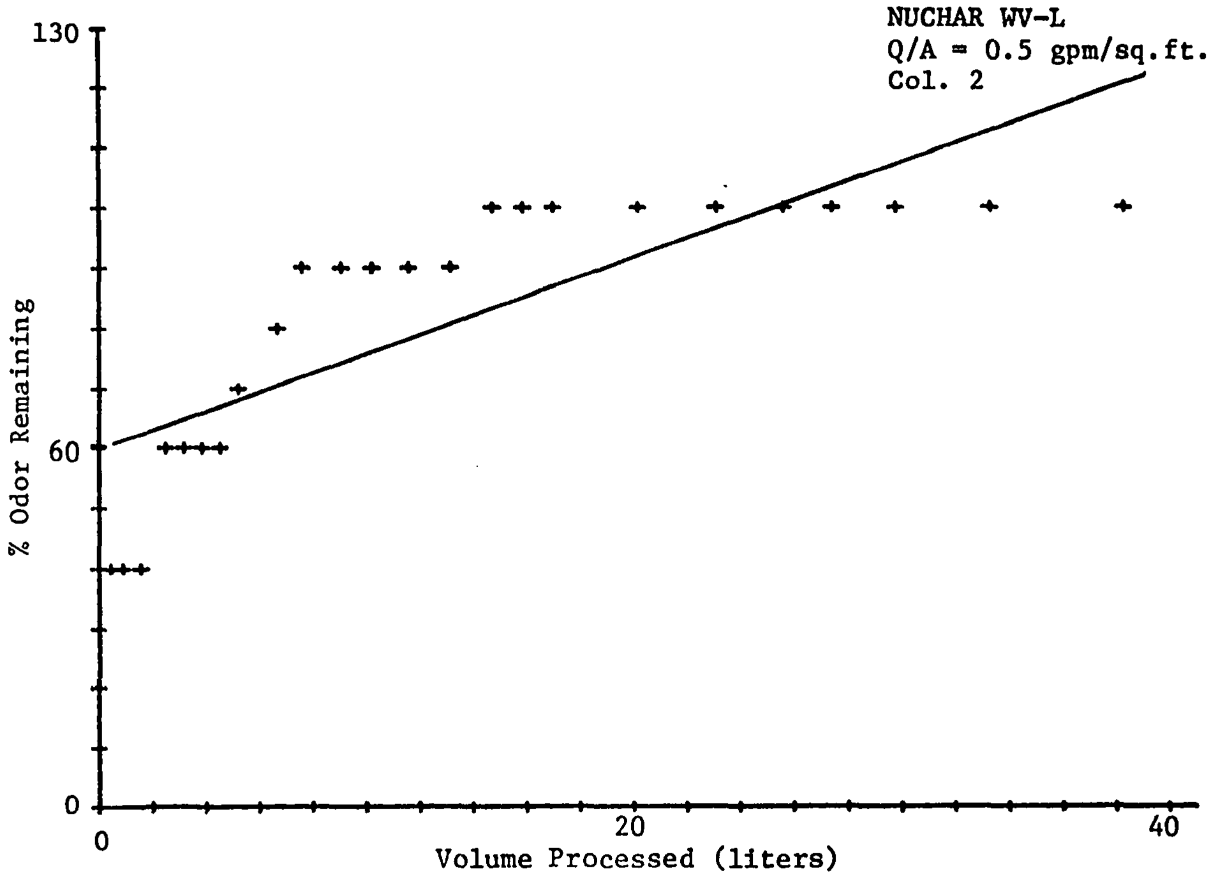

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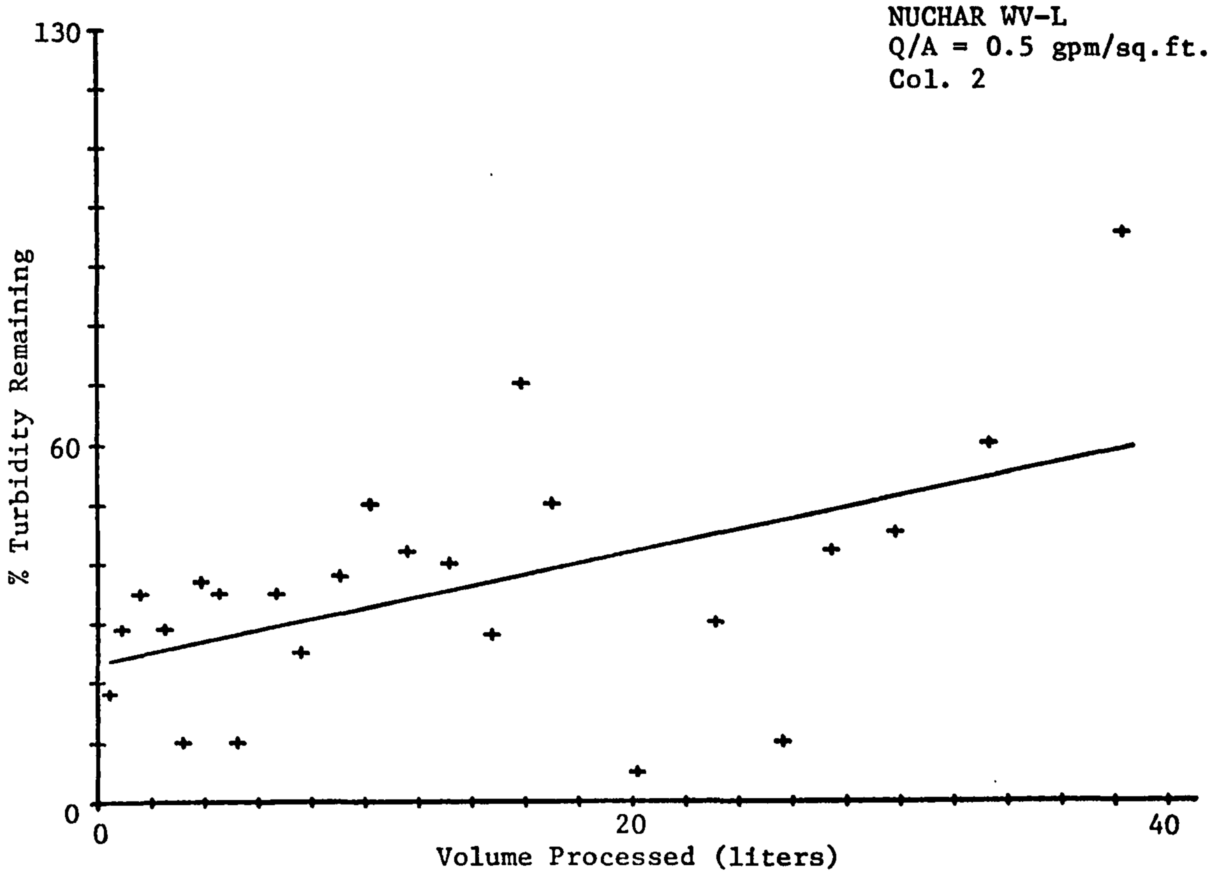

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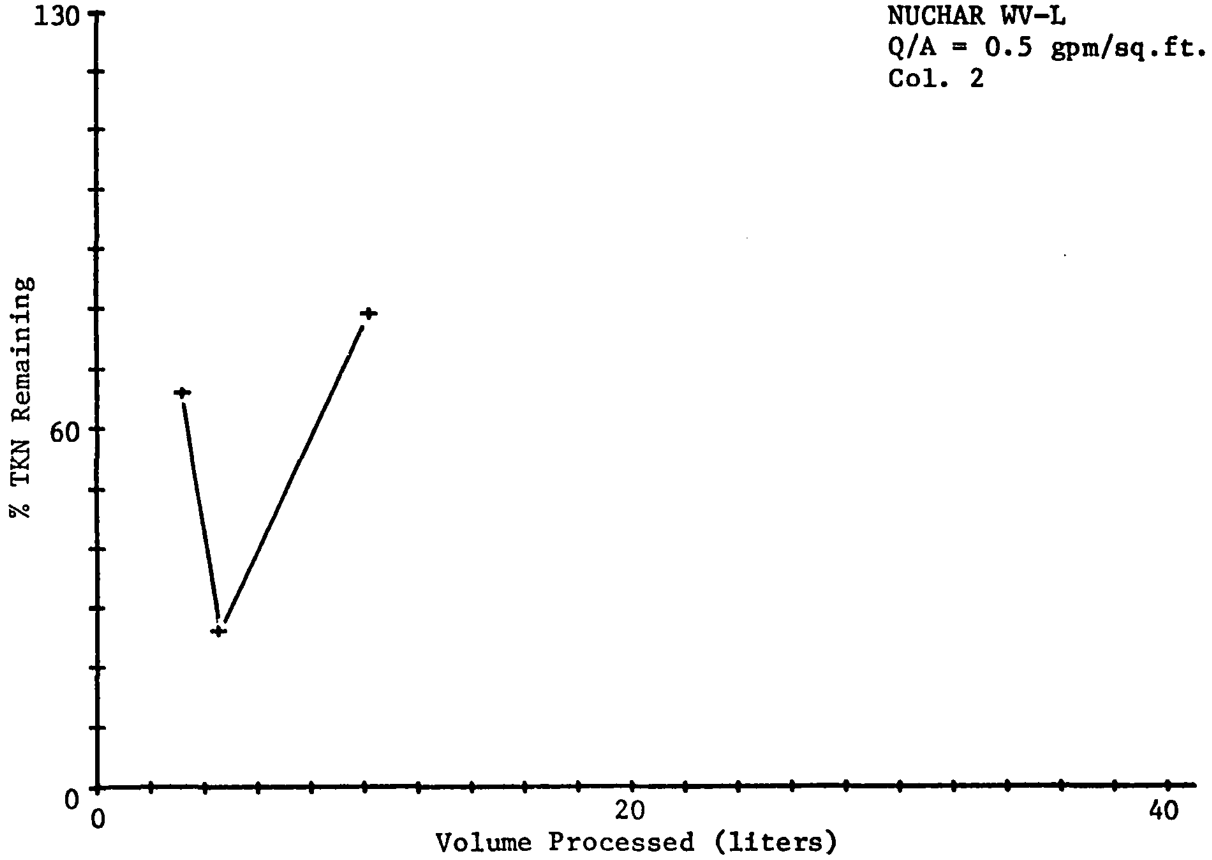

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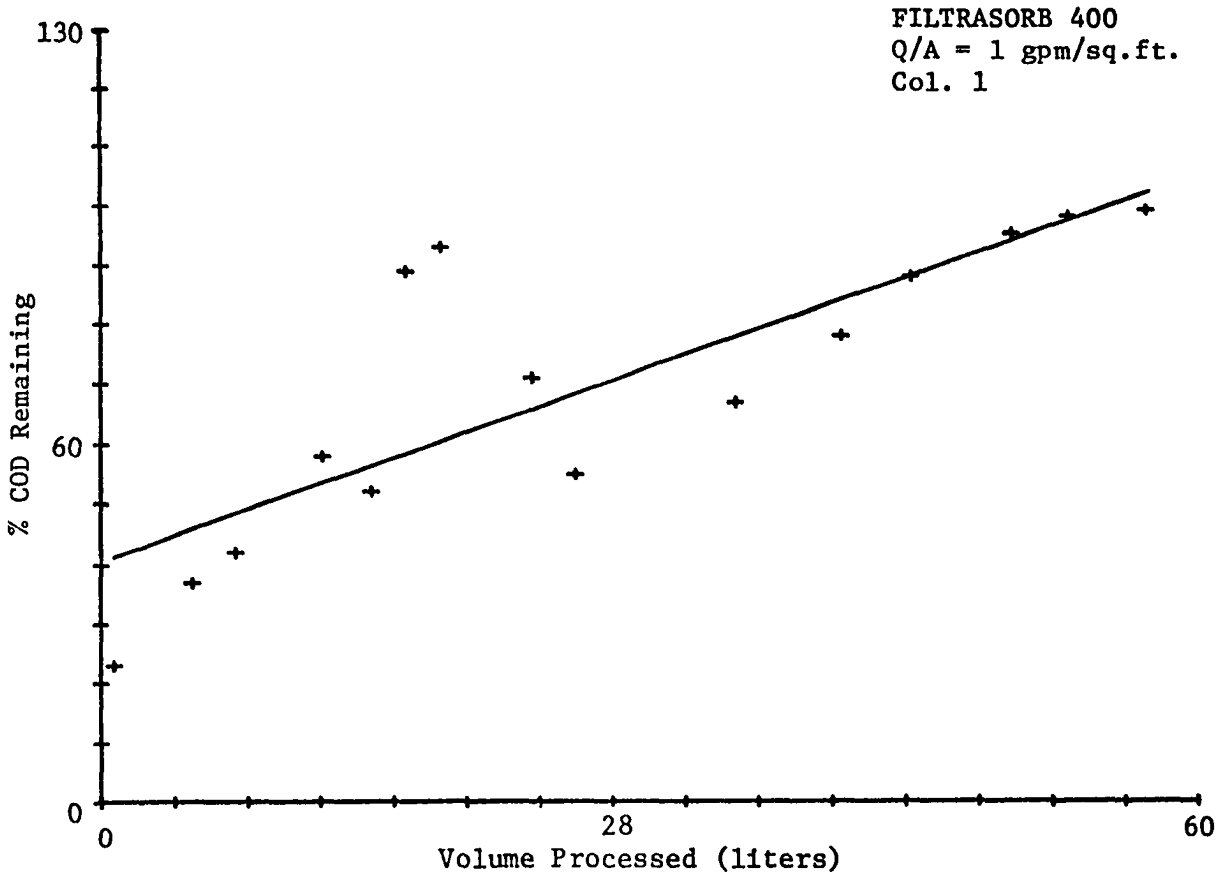

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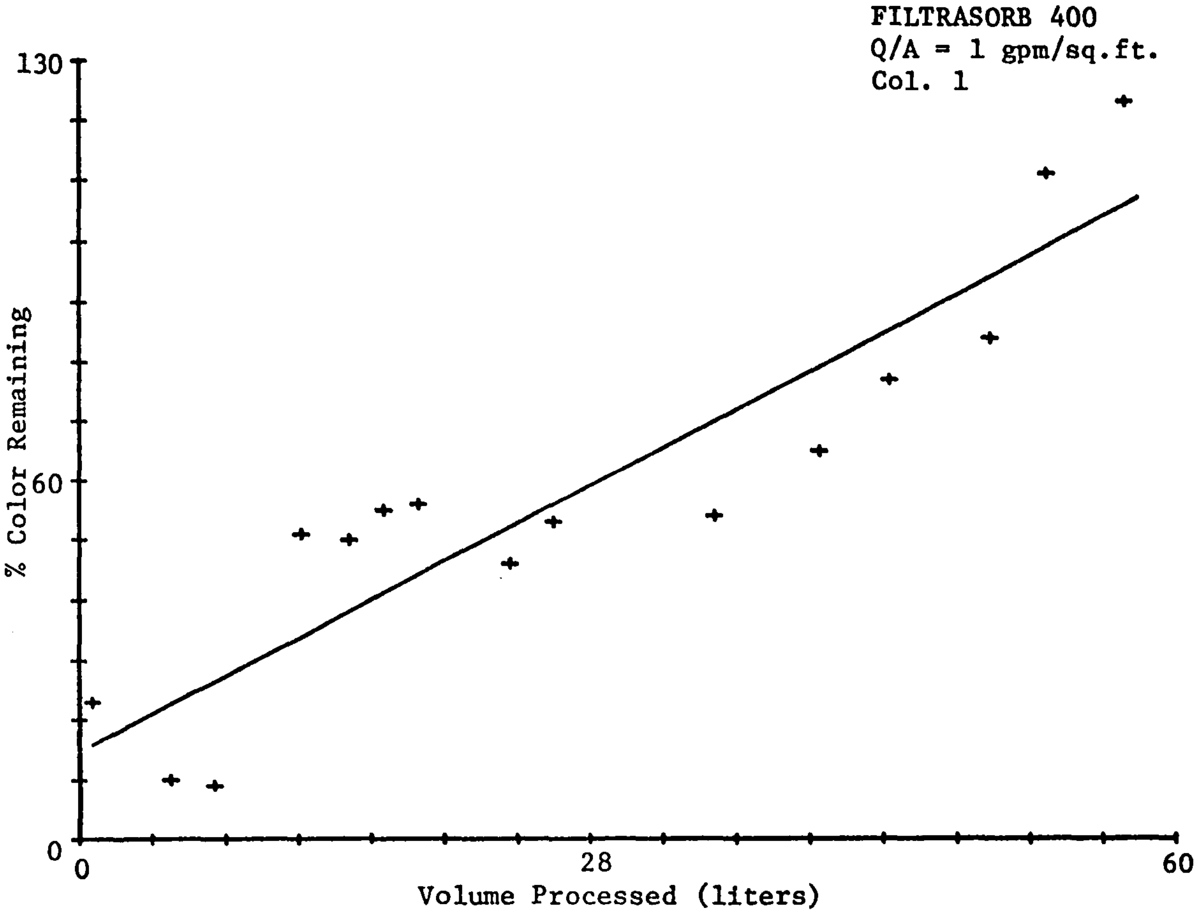

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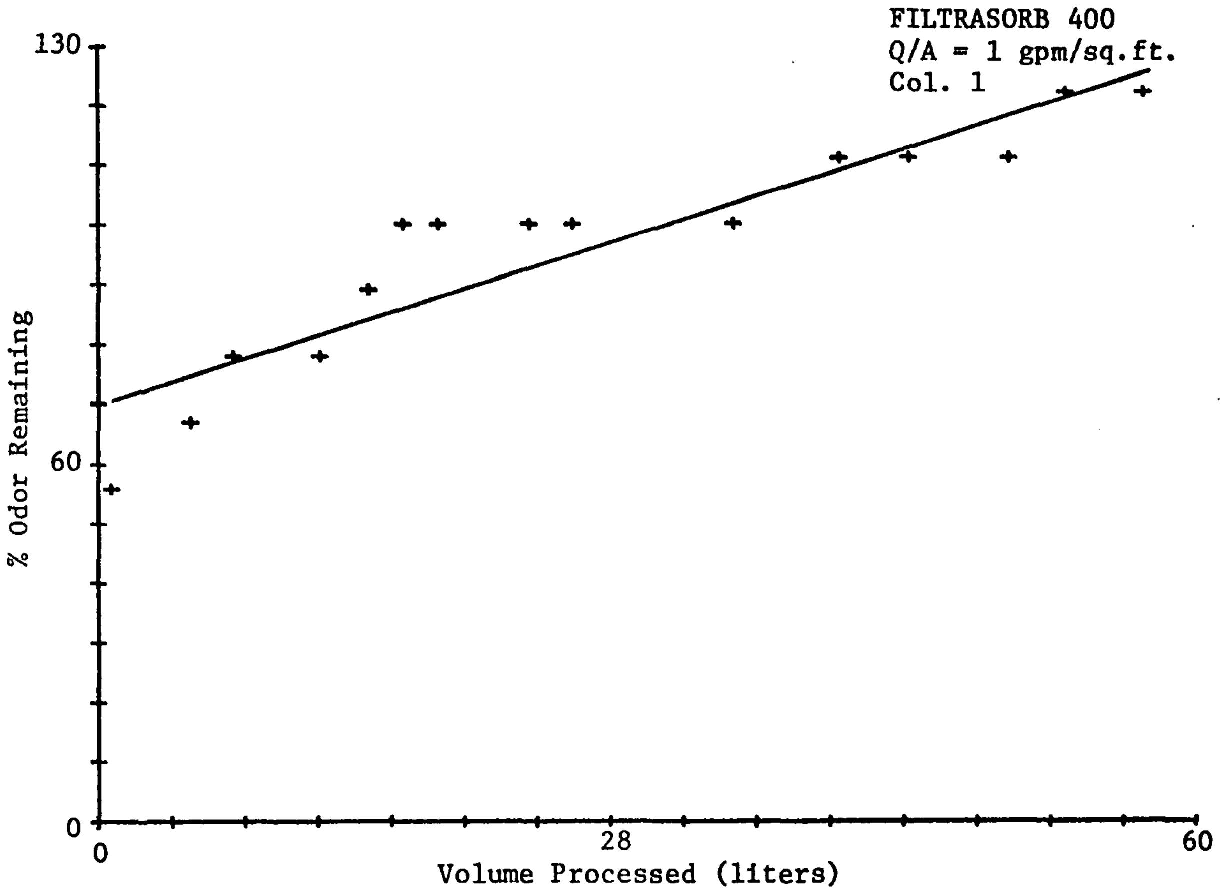

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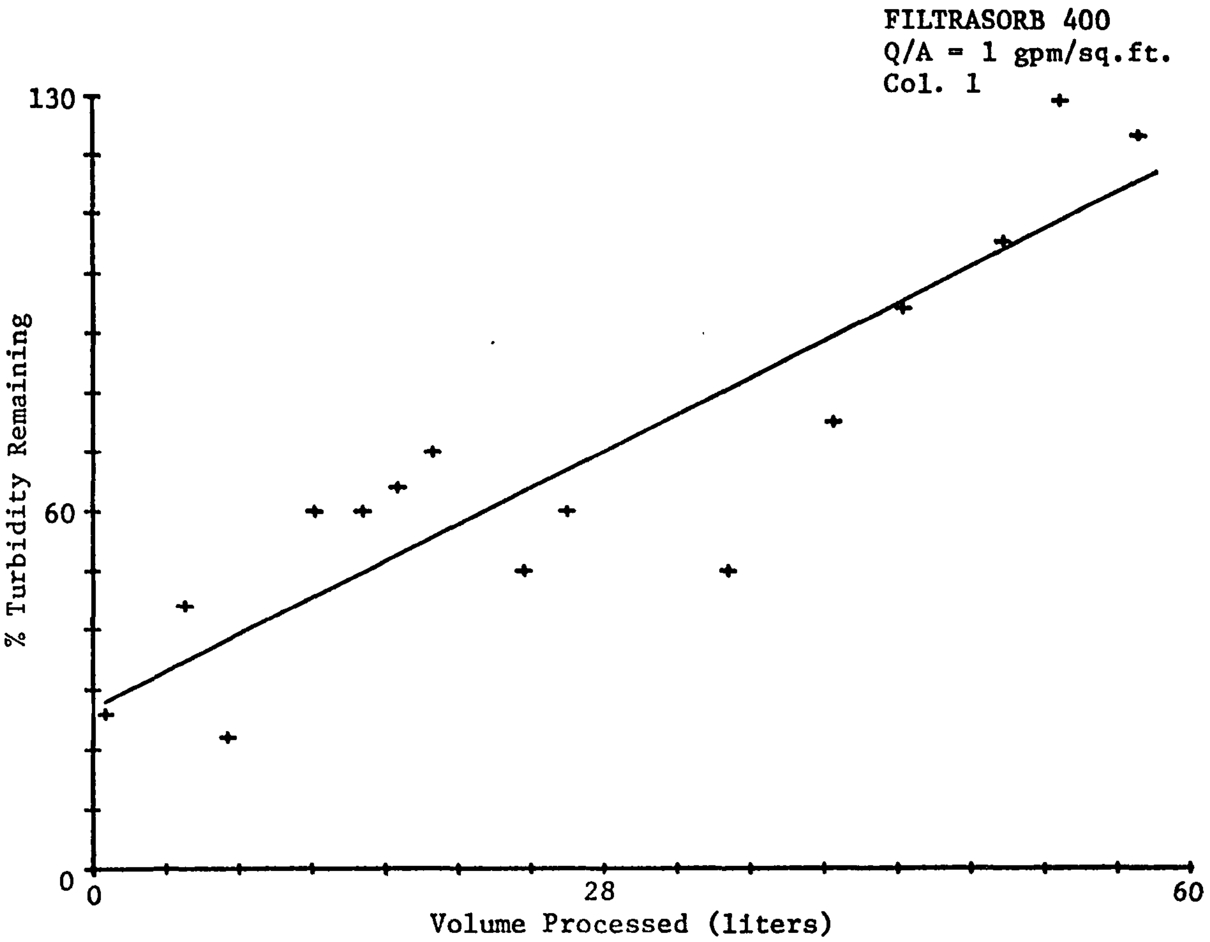


FIGURE 49. BREAKTHROUGH CURVE.

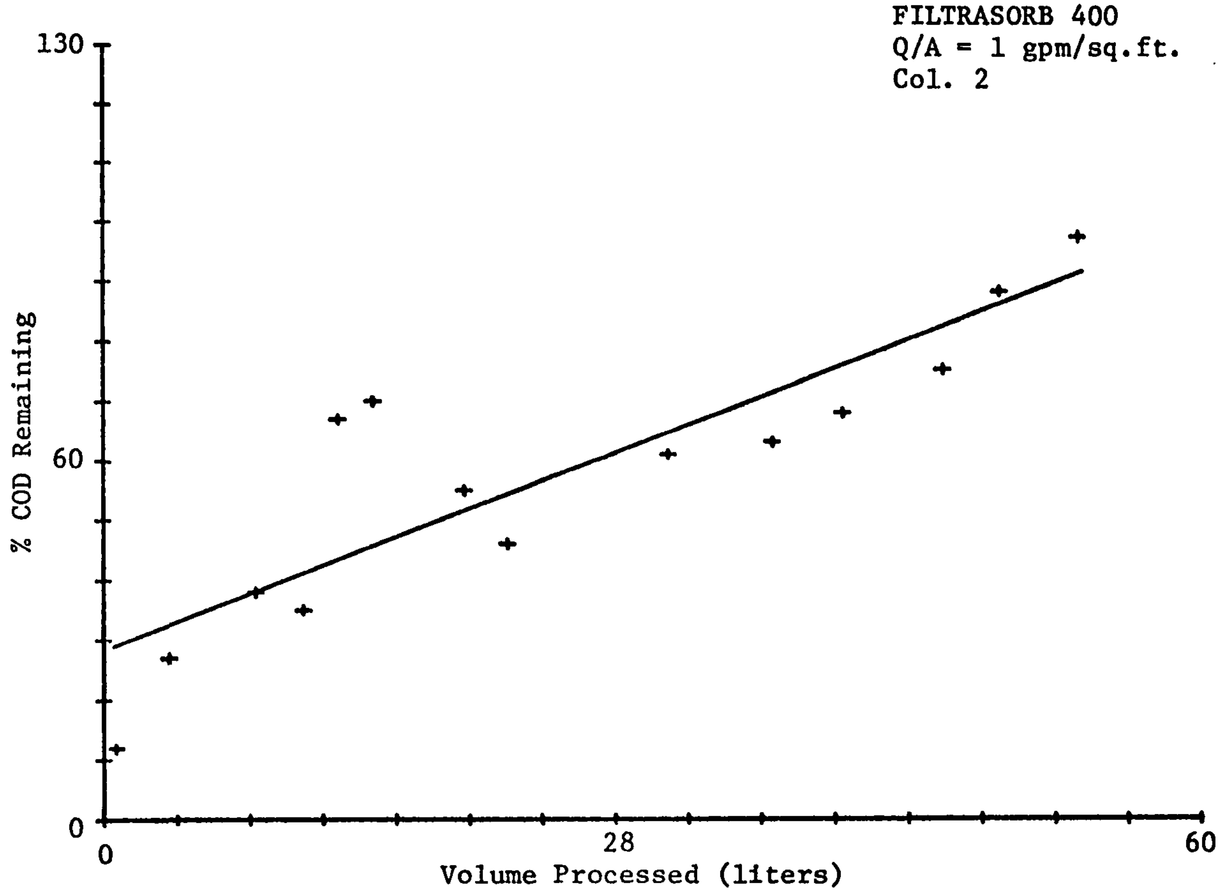


FIGURE 50. BREAKTHROUGH CURVE.

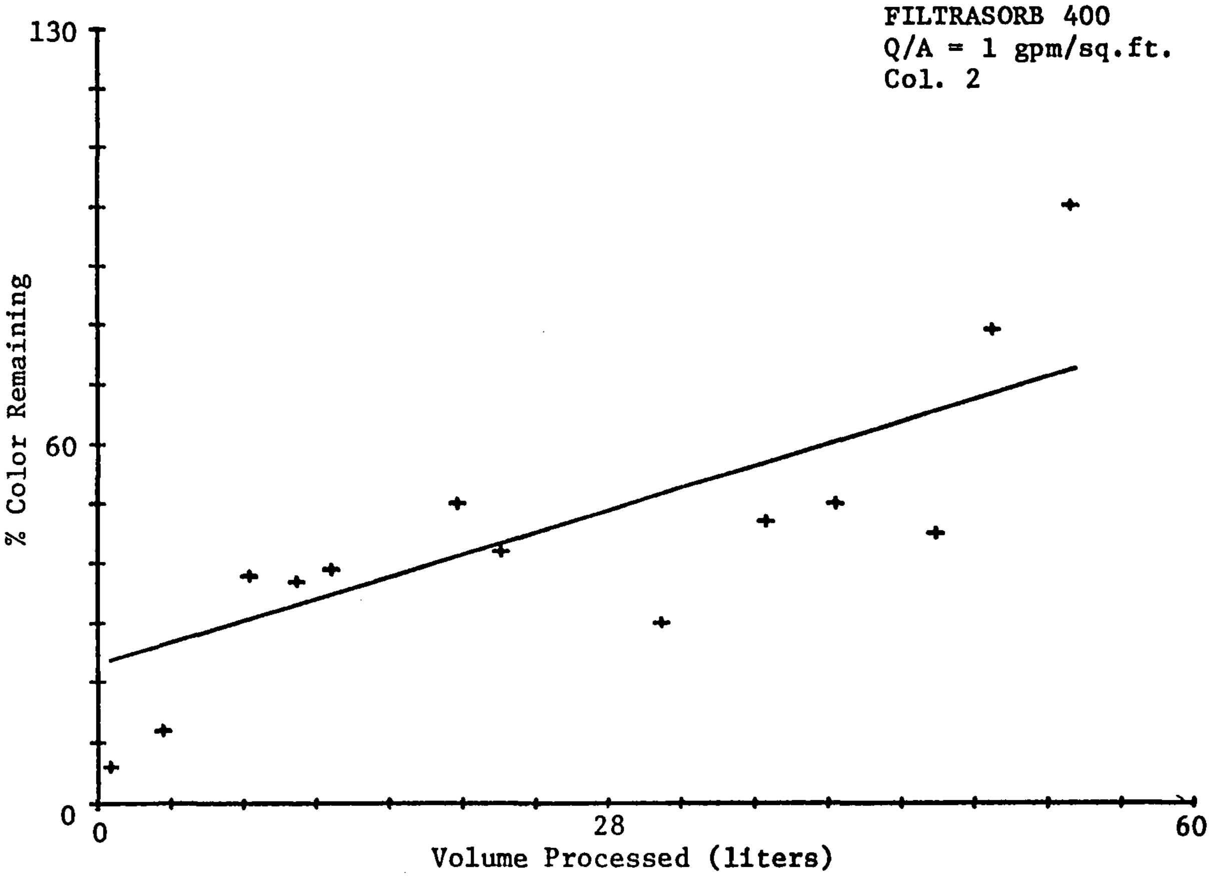


FIGURE 51. BREAKTHROUGH CURVE.

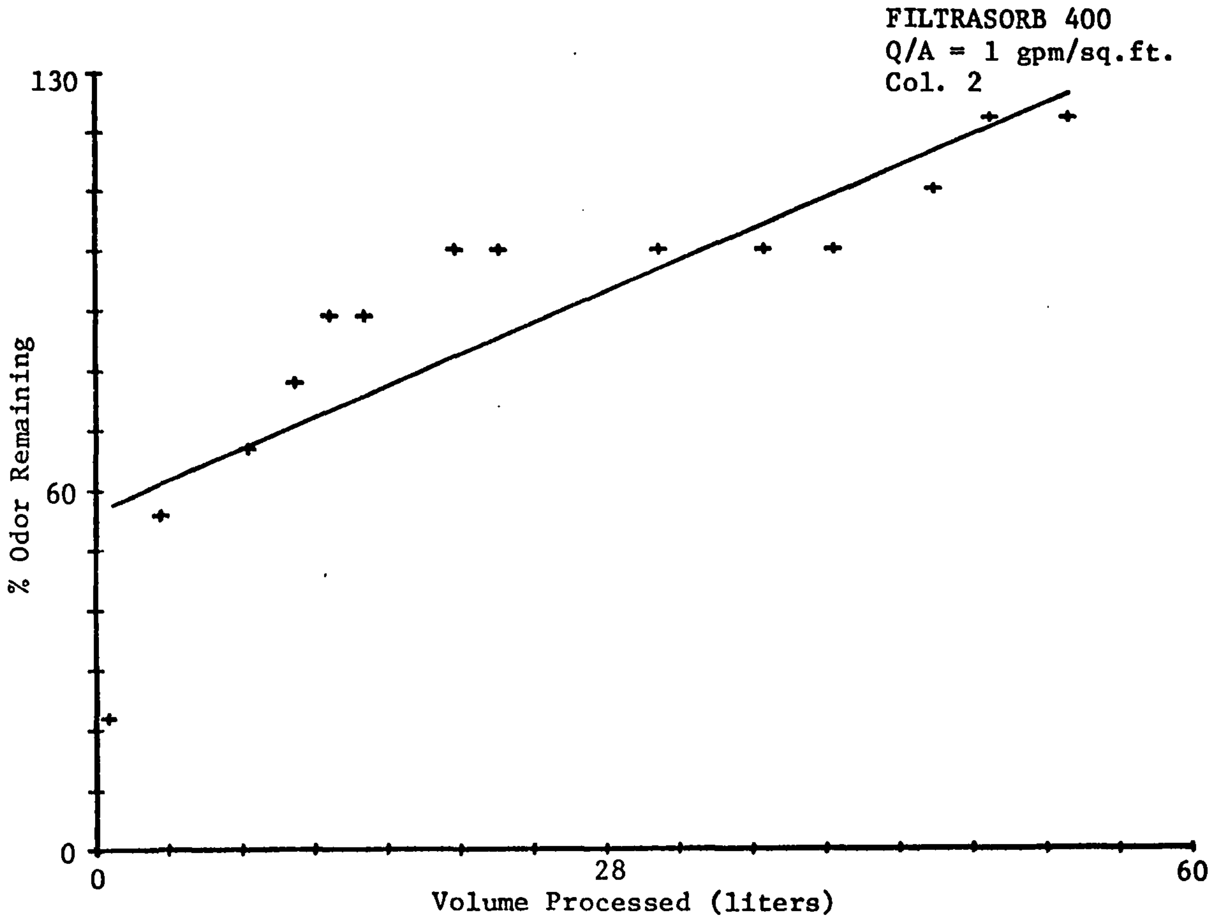


FIGURE 52. BREAKTHROUGH CURVE.

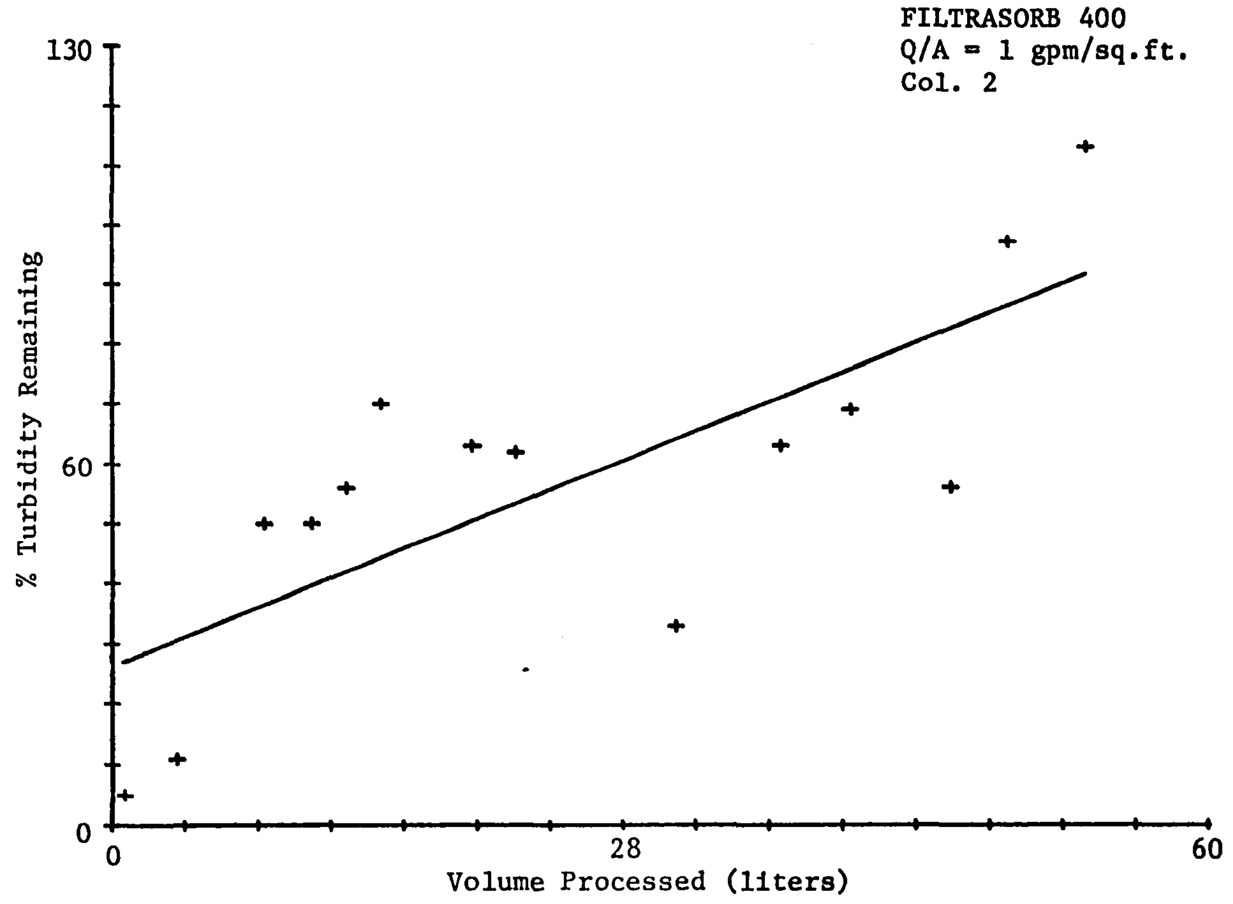


FIGURE 53. BREAKTHROUGH CURVE.

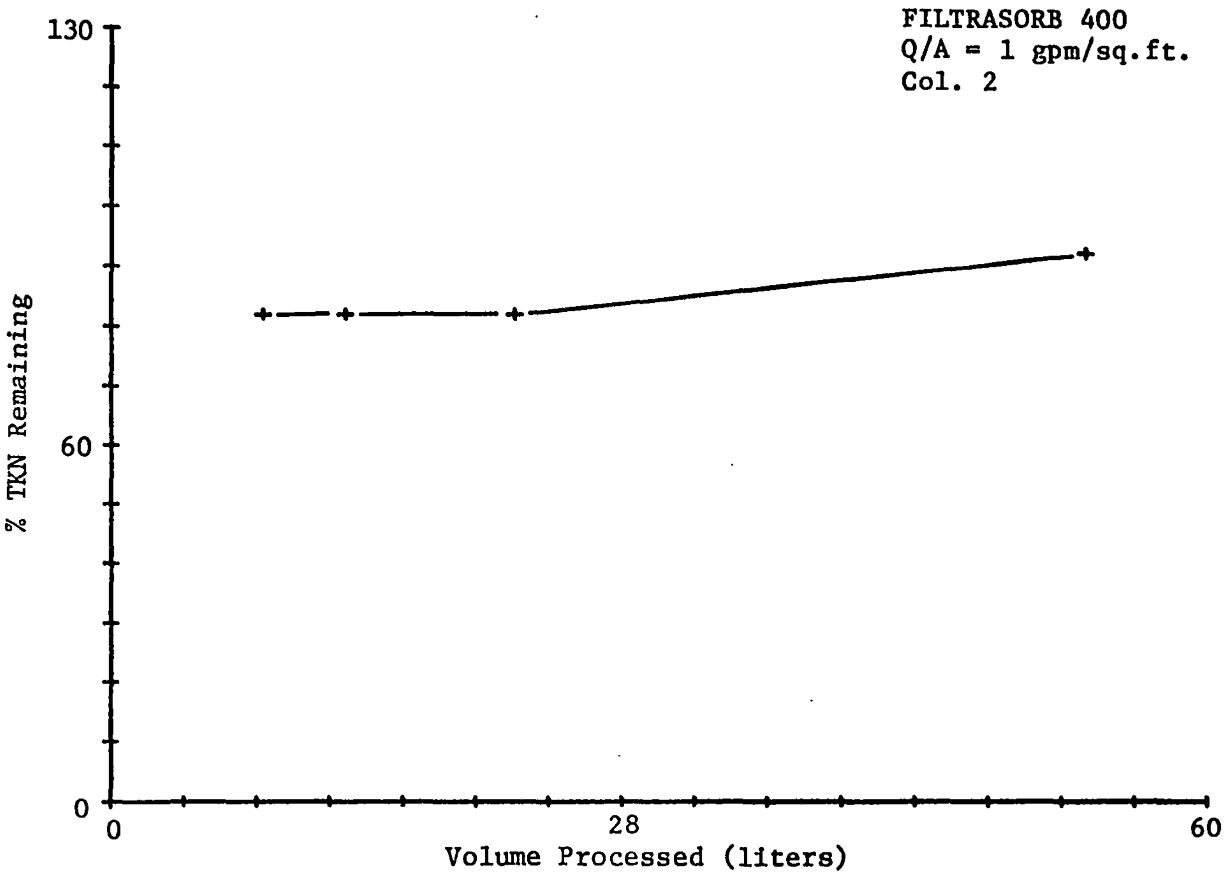


FIGURE 54. BREAKTHROUGH CURVE.

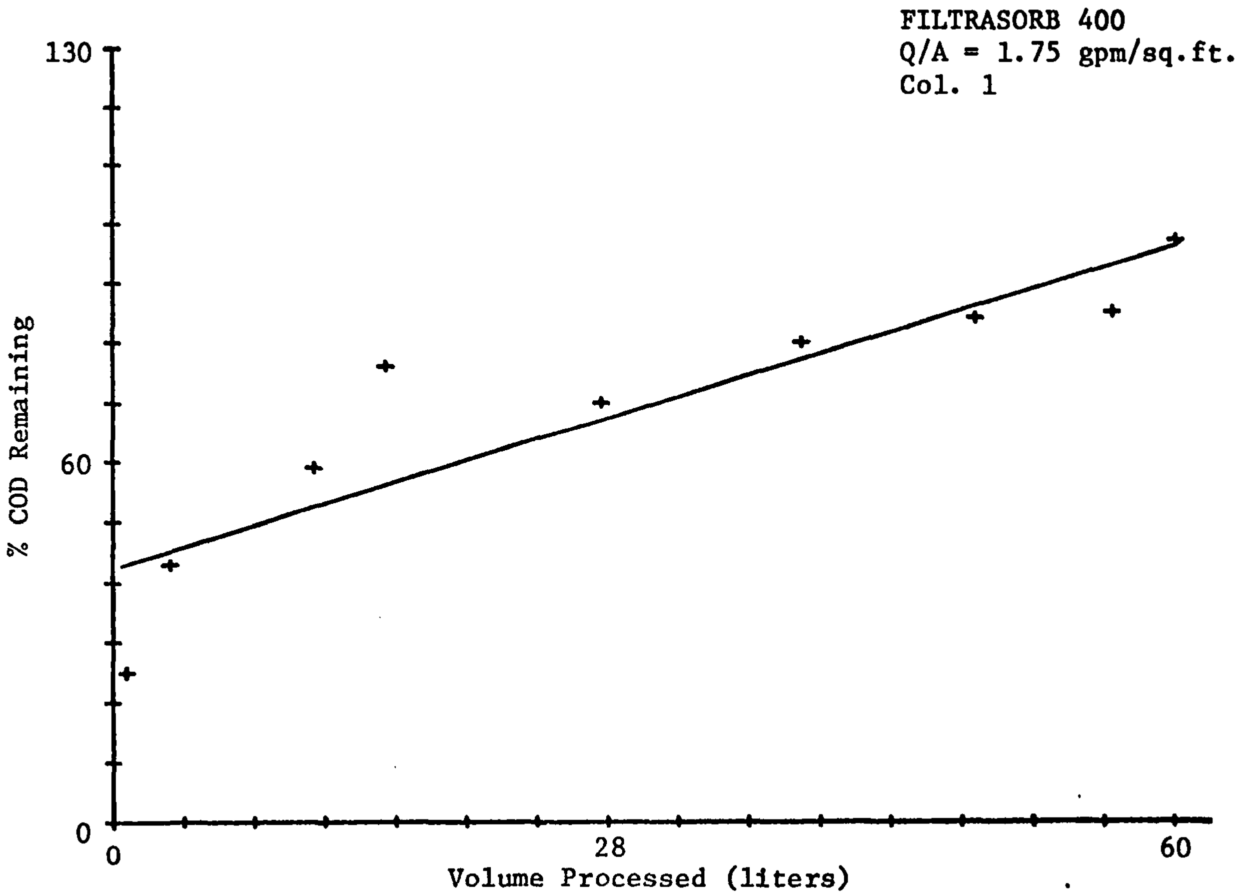


FIGURE 55. BREAKTHROUGH CURVE.

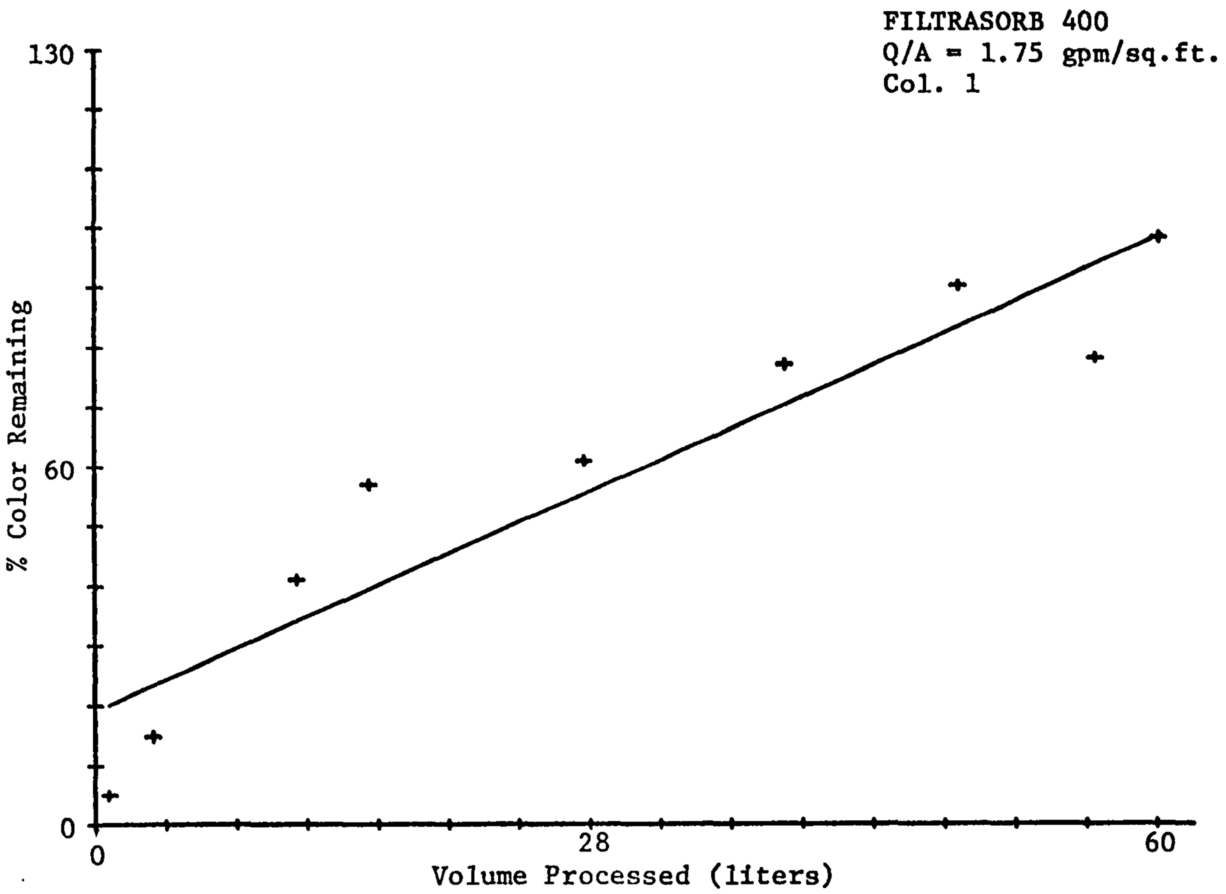


FIGURE 56. BREAKTHROUGH CURVE.

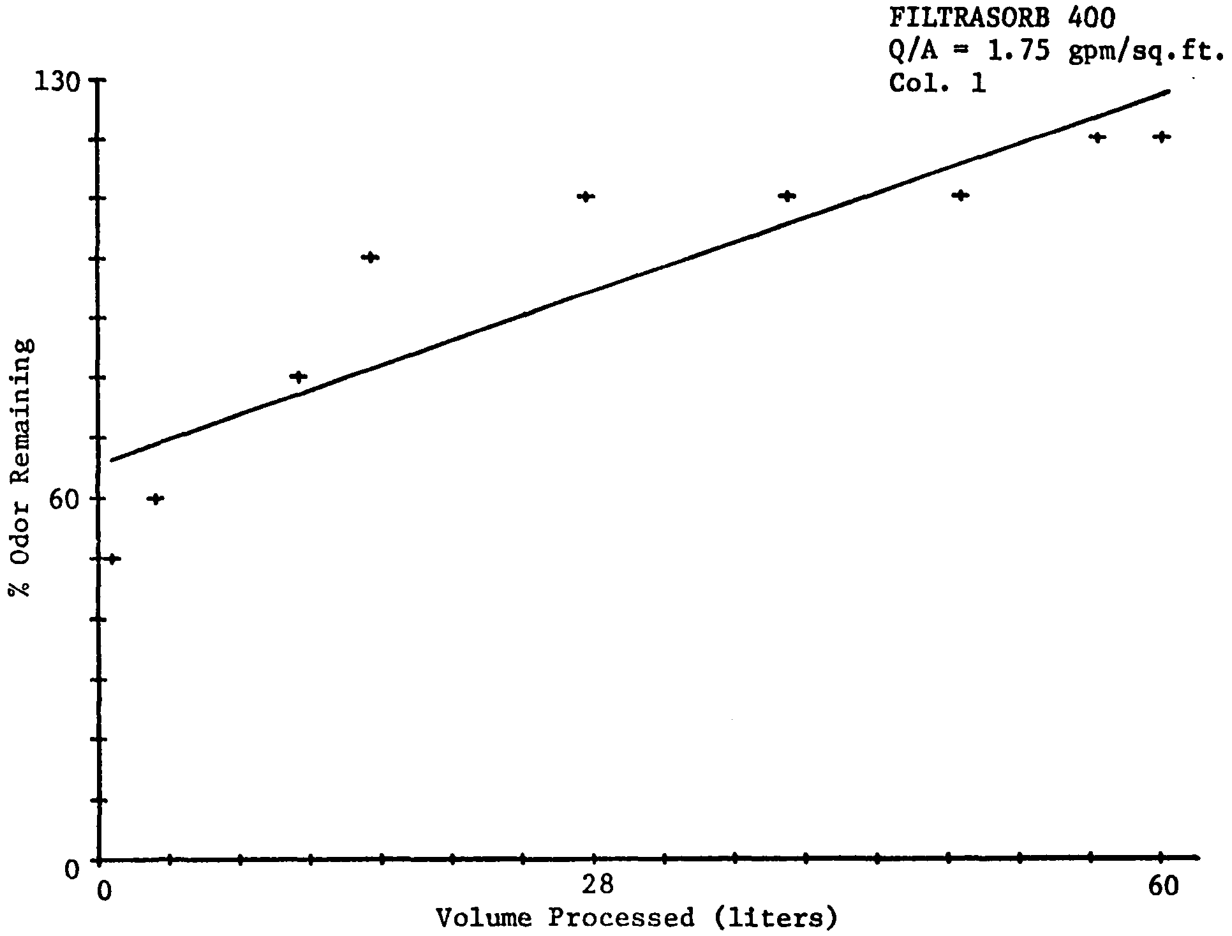


FIGURE 57. BREAKTHROUGH CURVE.

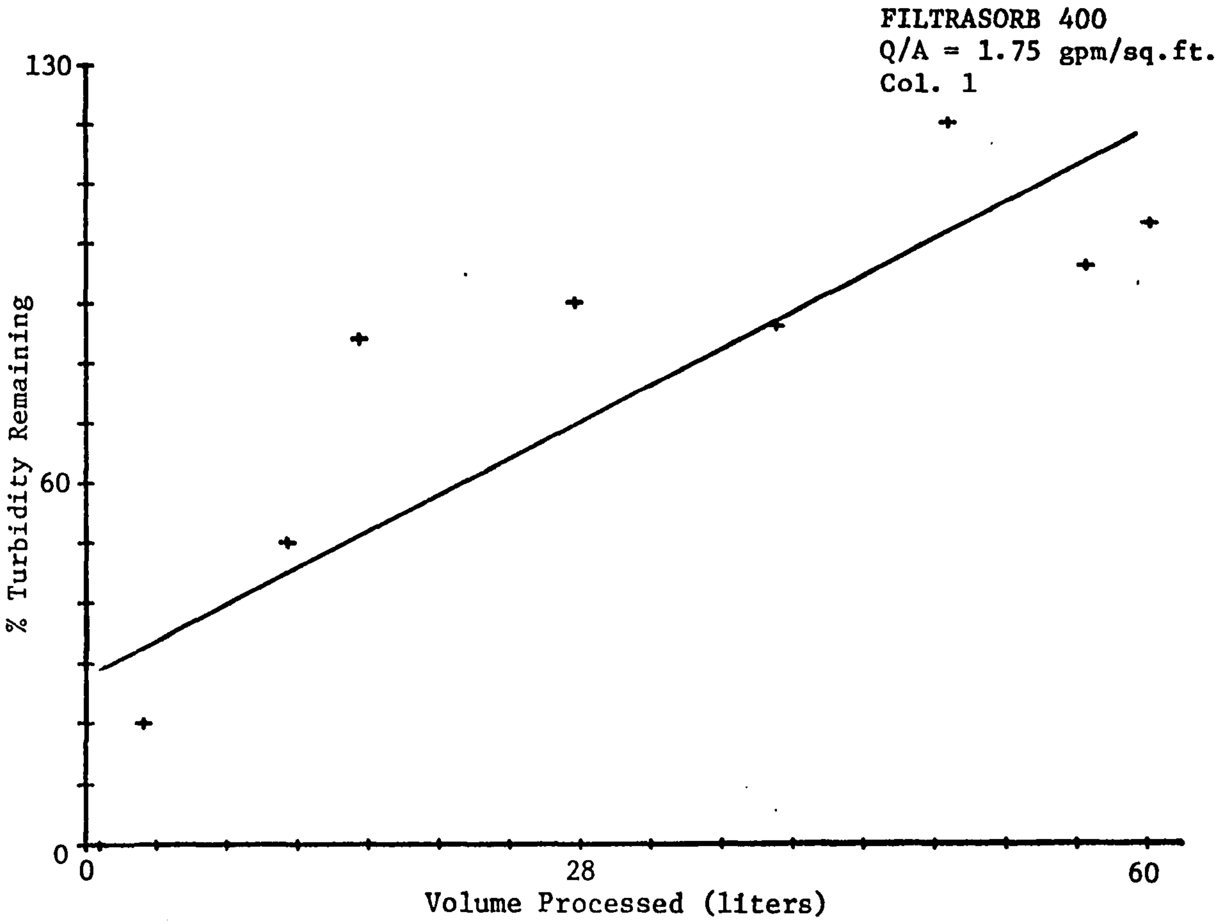


FIGURE 58. BREAKTHROUGH CURVE.

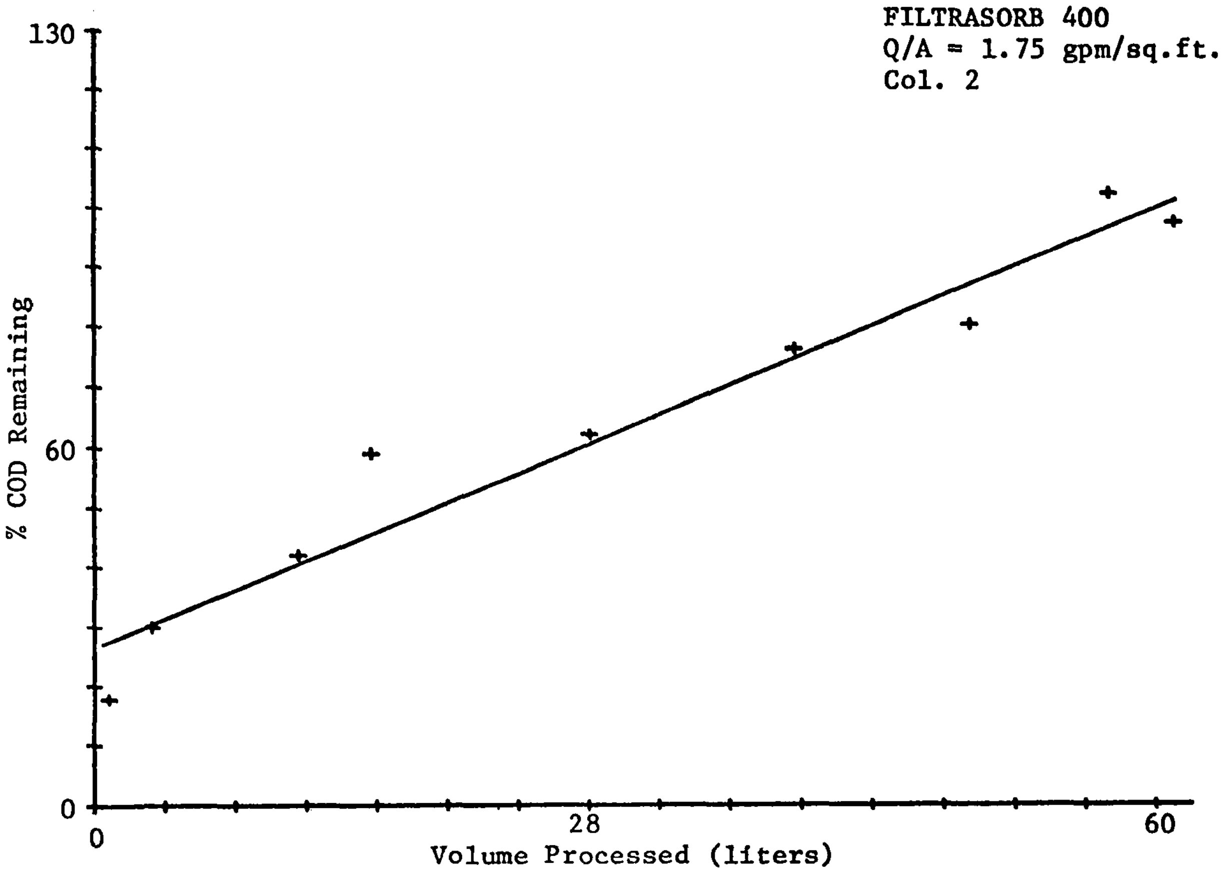


FIGURE 59. BREAKTHROUGH CURVE.

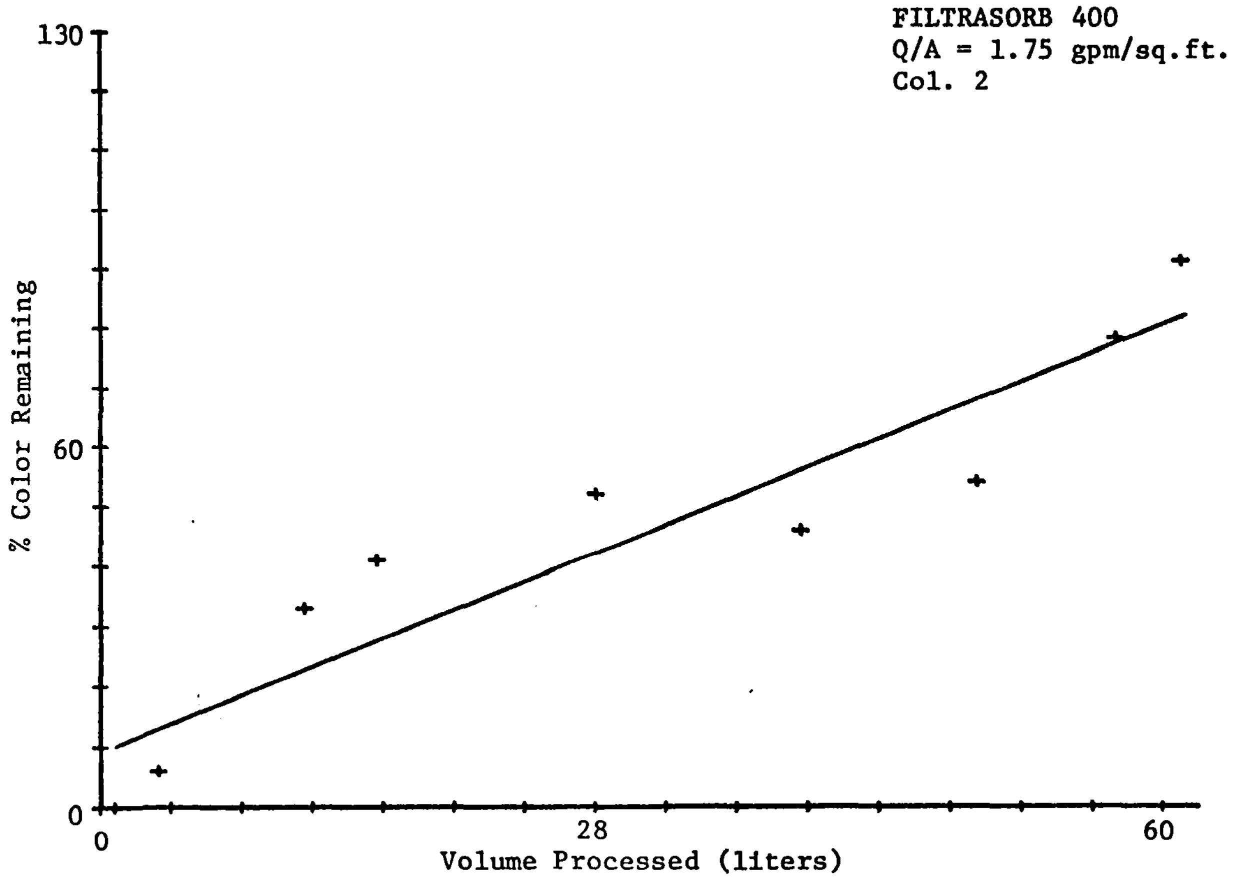


FIGURE 60. BREAKTHROUGH CURVE.

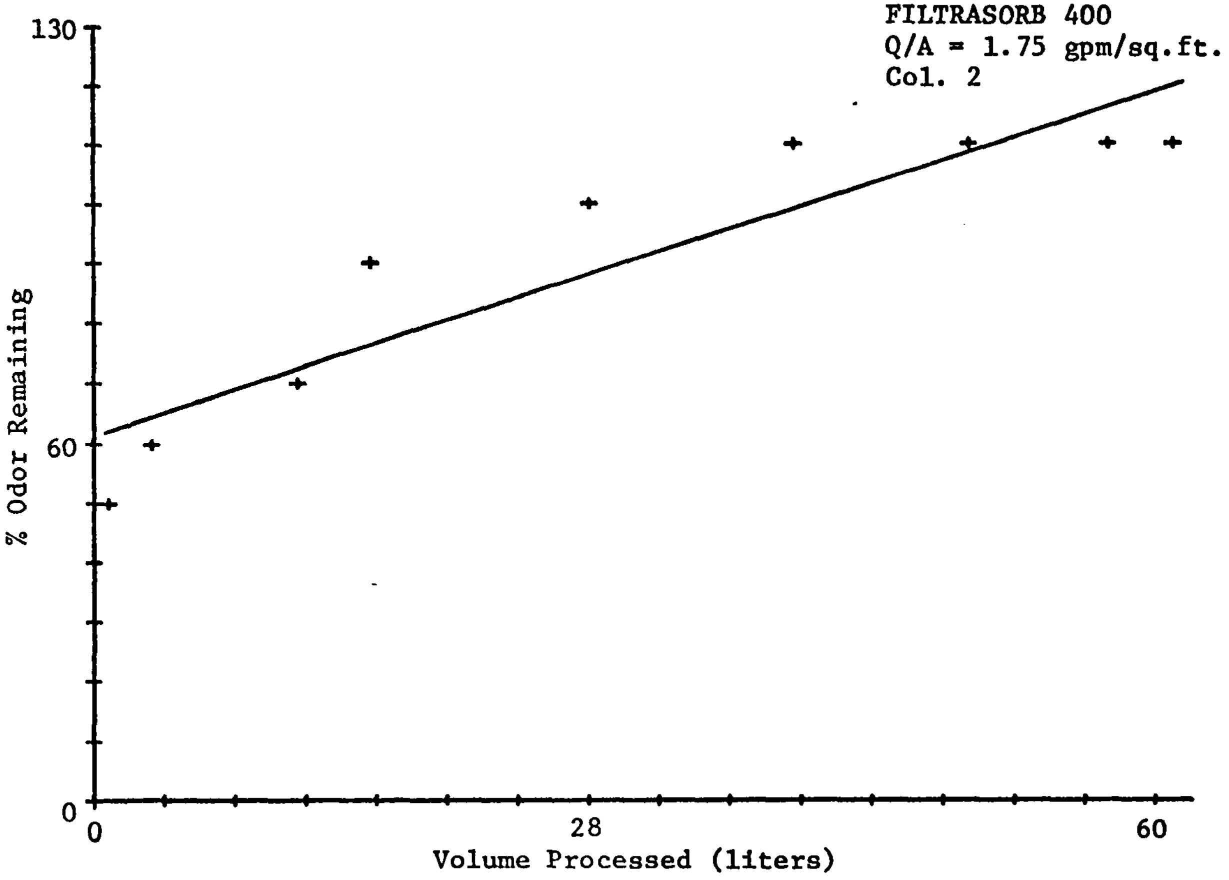


FIGURE 61. BREAKTHROUGH CURVE.

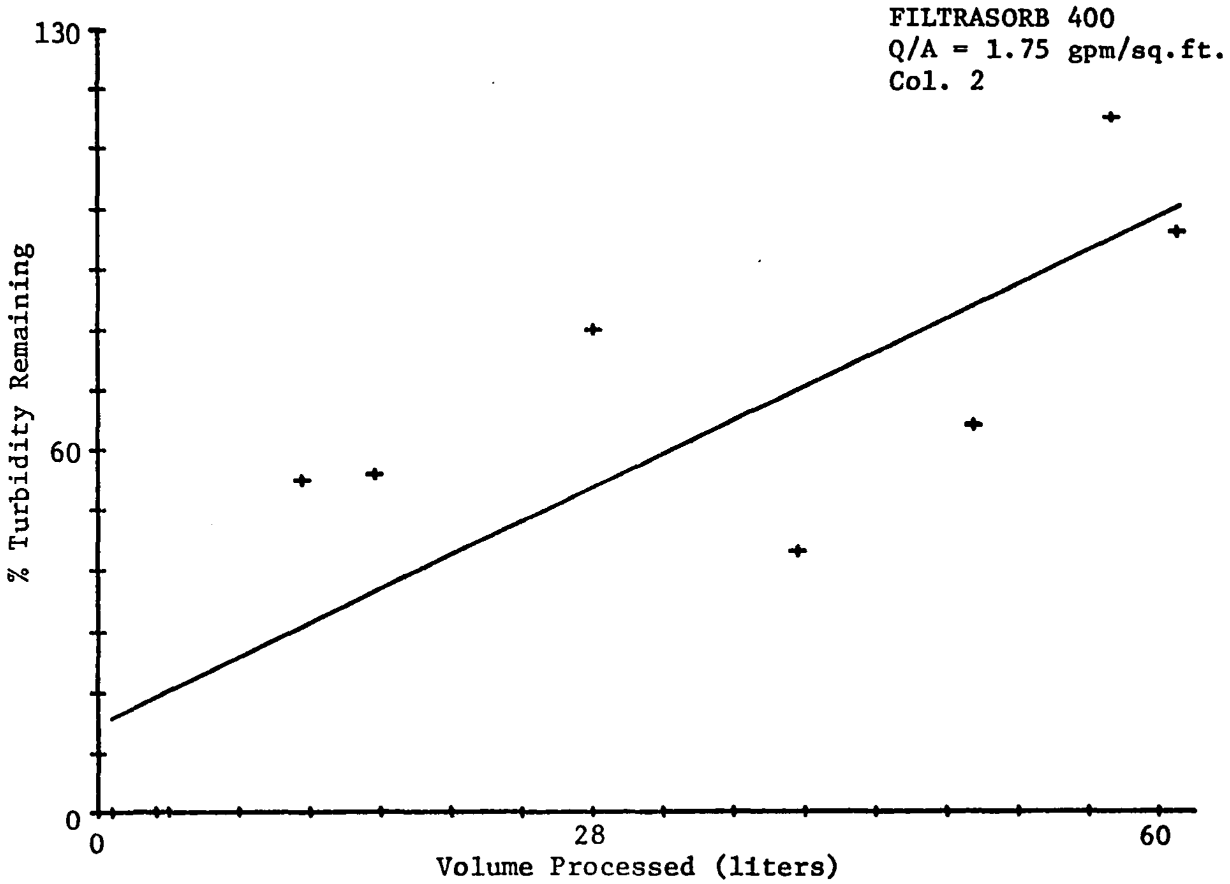


FIGURE 62. BREAKTHROUGH CURVE.

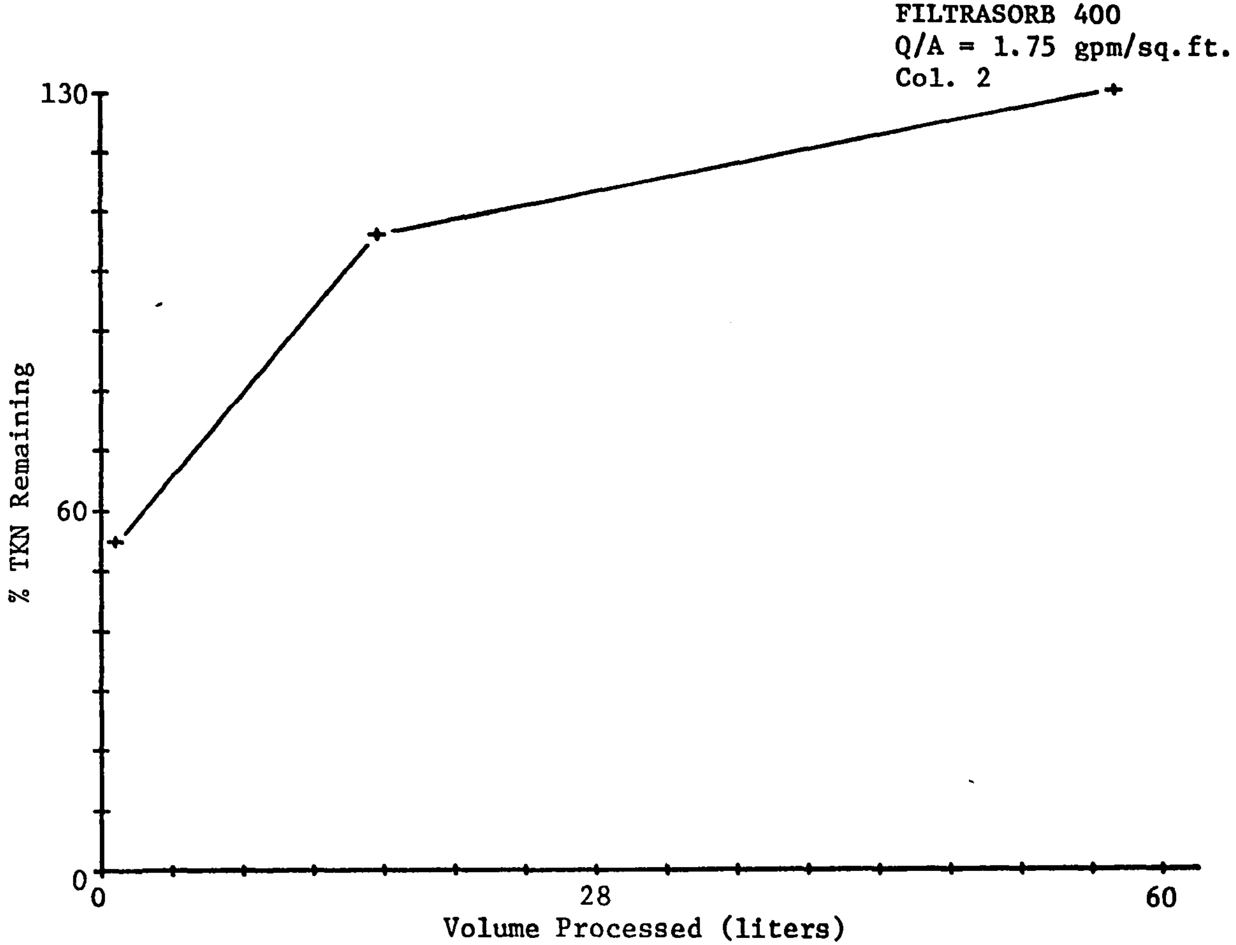


FIGURE 63. BREAKTHROUGH CURVE.

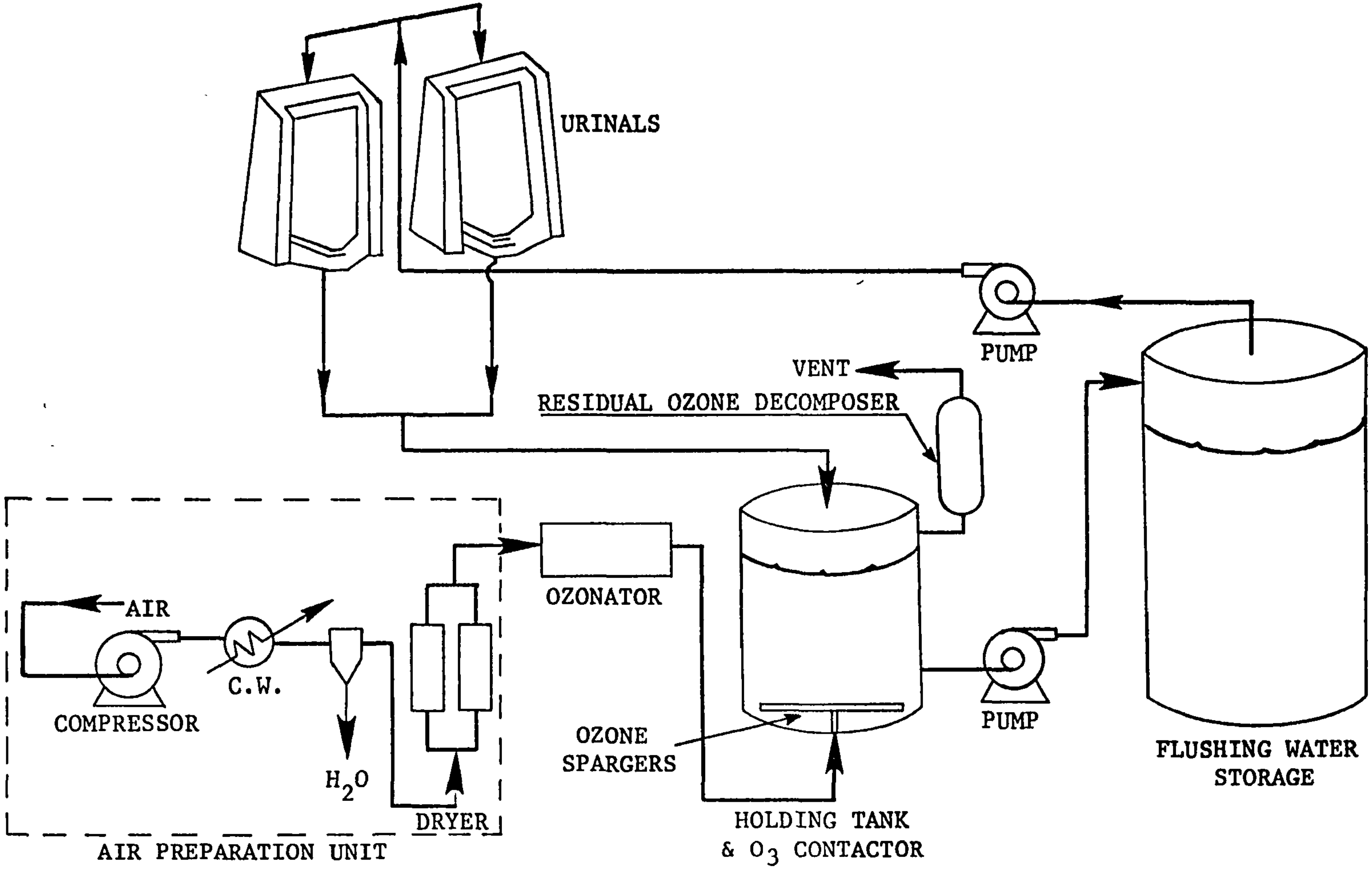


FIGURE 64. TWENTY-MEN OZONE FLUSH WATER PURIFICATION SYSTEM.

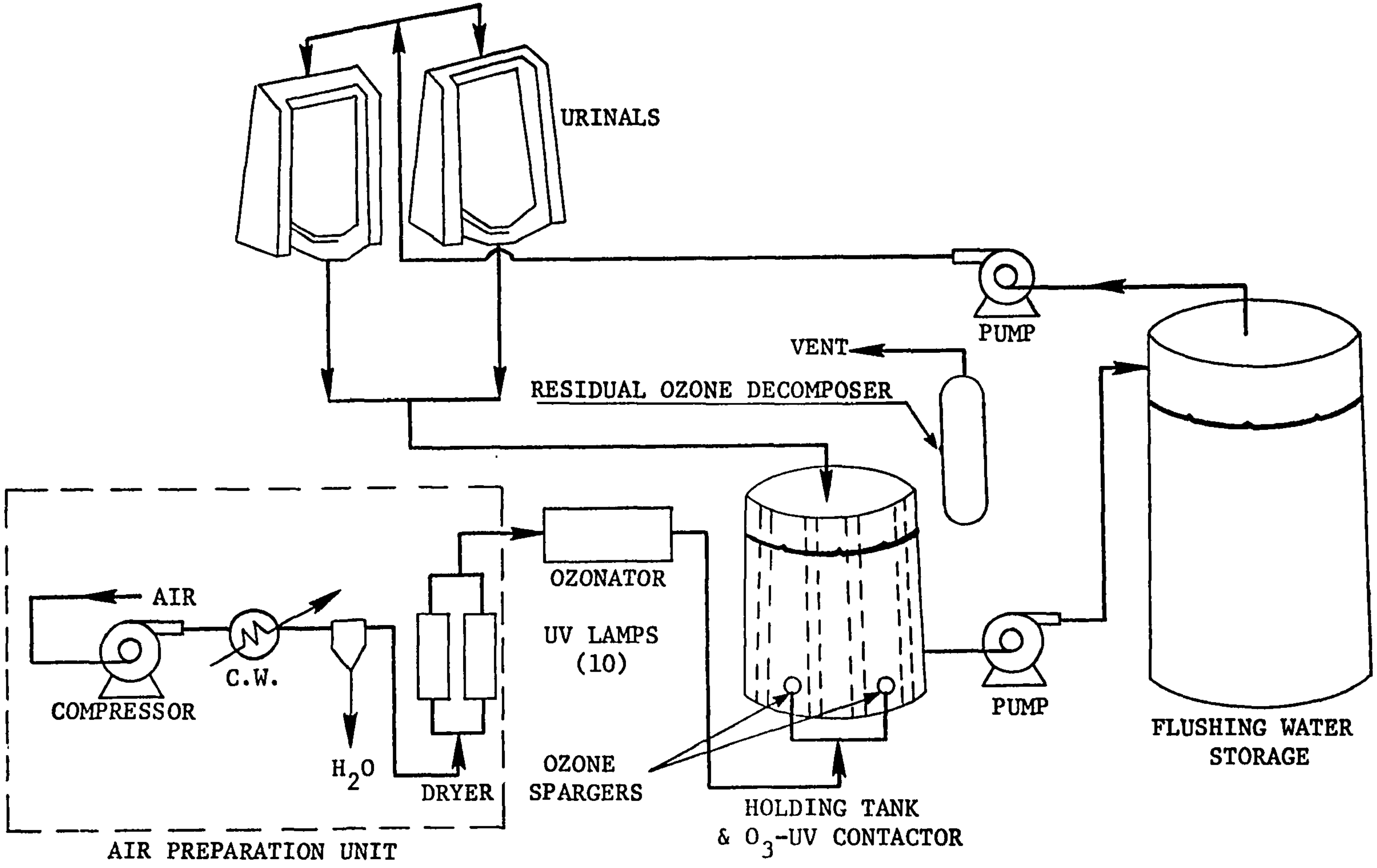


FIGURE 65. TWENTY-MEN OZONE-UV FLUSH WATER PURIFICATION SYSTEM.

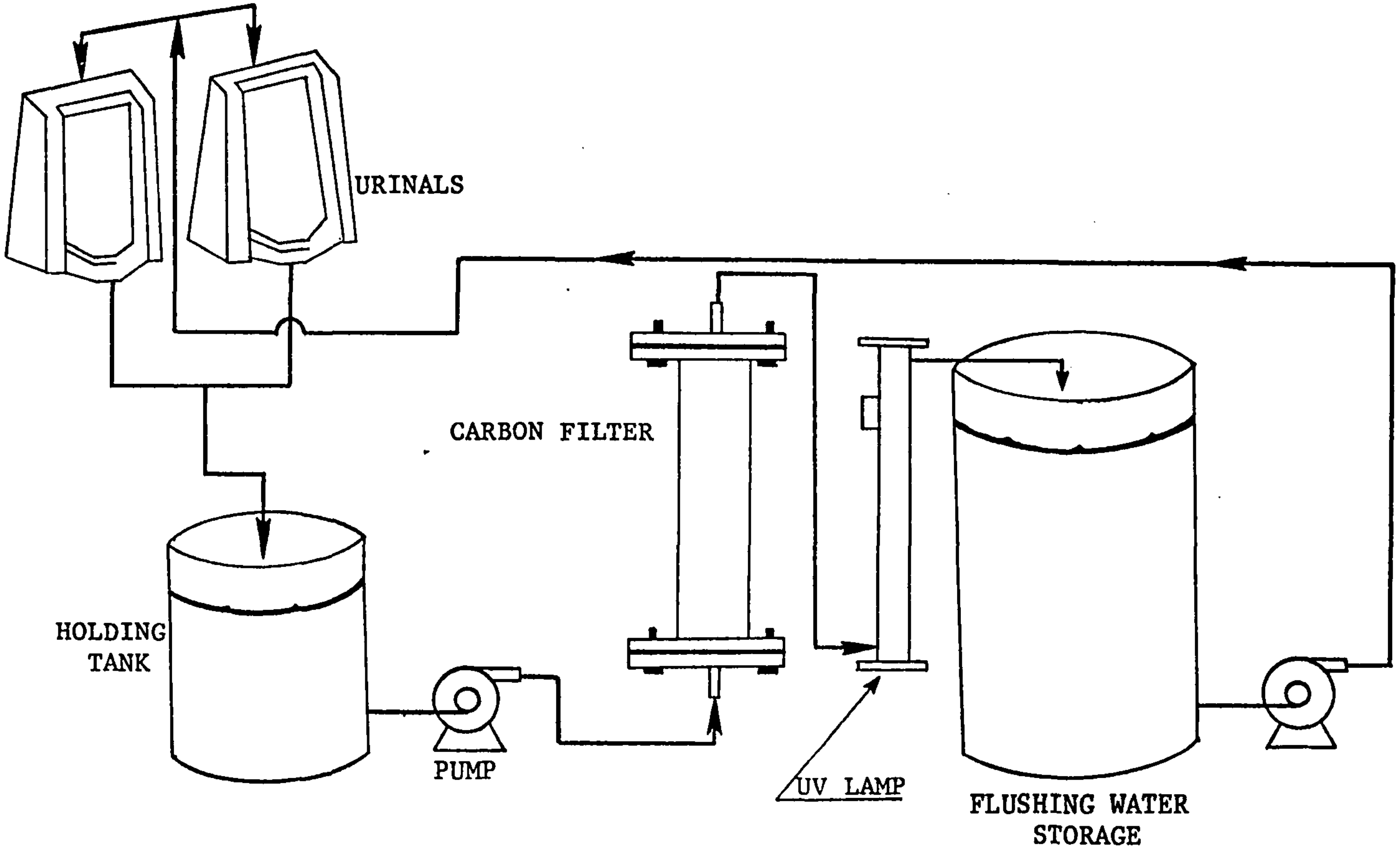
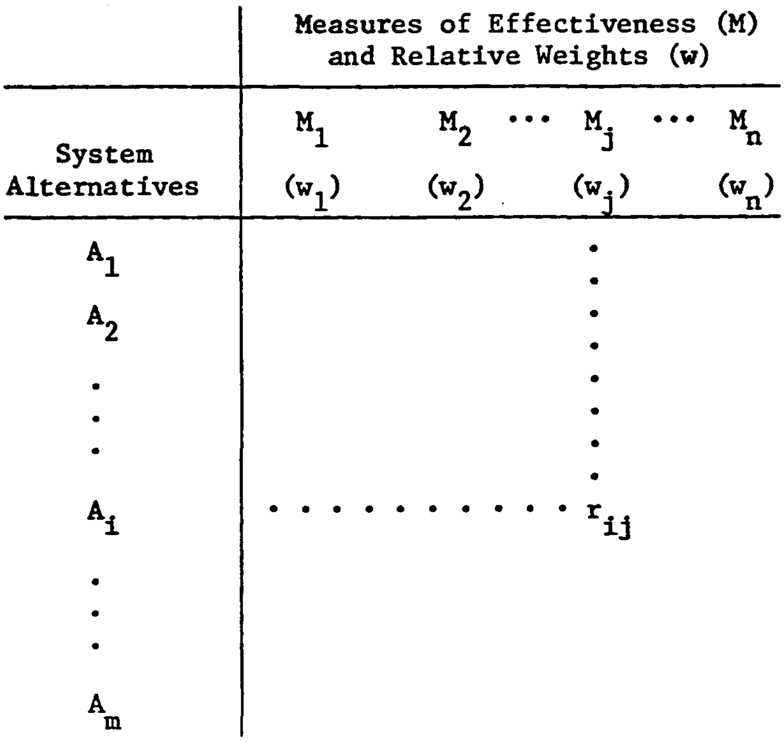


FIGURE 66. TWENTY-MEN ACTIVATED CARBON ADSORPTION FLUSH WATER PURIFICATION SYSTEM.



Overall Effectiveness of Alternative i $\equiv E[A_i] = \sum_{j=1} W_j r_{ij}$

where

$$\sum_{j=1}^{n} W_j = 1$$

$r_{ij} \equiv$ Rating of Alternative i with respect to Measure j

FIGURE 67. SYSTEM-EFFECTIVENESS ANALYSIS MODEL.

		Relative Effectiveness		
Effectiveness Measures	Alternative Systems*	With Respect to Next Alternative	With Respect to Last Alternative	Ratings, r_{ij}
M_1 Health Hazard	A_1	1.00	1.00	$r_{11} = 0.333$
	A_2	1.00	1.00	$r_{21} = 0.333$
	A_3	--	1.00	$r_{31} = 0.333$
			$\Sigma = 3.00$	$\Sigma = 1.000$
M_2 User Acceptability	A_1	1.00	1.00	$r_{12} = 0.333$
	A_2	1.00	1.00	$r_{22} = 0.333$
	A_3	--	1.00	$r_{32} = 0.333$
			$\Sigma = 3.00$	$\Sigma = 1.000$
M_3 Operation Reliability	A_1	0.50	0.25	$r_{13} = 0.143$
	A_2	0.50	0.50	$r_{23} = 0.286$
	A_3	--	1.00	$r_{33} = 0.571$
			$\Sigma = 1.75$	$\Sigma = 1.000$
M_4 Maintainability	A_1	1.00	2.00	$r_{14} = 0.400$
	A_2	2.00	2.00	$r_{24} = 0.400$
	A_3	--	1.00	$r_{34} = 0.200$
			$\Sigma = 5.00$	$\Sigma = 1.000$
M_5 Safety	A_1	1.00	0.90	$r_{15} = 0.321$
	A_2	0.90	0.90	$r_{25} = 0.321$
	A_3	--	1.00	$r_{35} = 0.358$
			$\Sigma = 2.80$	$\Sigma = 1.000$
M_6 Power Requirement	A_1	0.50	0.13	$r_{16} = 0.094$
	A_2	0.25	0.25	$r_{26} = 0.181$
	A_3	--	1.00	$r_{36} = 0.725$
			$\Sigma = 1.38$	$\Sigma = 1.000$
M_7 Space Requirement	A_1	1.00	1.30	$r_{17} = 0.361$
	A_2	1.30	1.30	$r_{27} = 0.361$
	A_3	--	1.00	$r_{37} = 0.278$
			$\Sigma = 3.60$	$\Sigma = 1.000$
M_8 Weight	A_1	1.00	1.25	$r_{18} = 0.357$
	A_2	0.25	1.25	$r_{28} = 0.357$
	A_3	--	1.00	$r_{38} = 0.286$
			$\Sigma = 3.50$	$\Sigma = 1.000$
M_9 Shelf Life	A_1	1.00	1.00	$r_{19} = 0.333$
	A_2	1.00	1.00	$r_{29} = 0.333$
	A_3	--	1.00	$r_{39} = 0.333$
			$\Sigma = 3.00$	$\Sigma = 1.000$

*A_1 = Ozonation-UV

A_2 = Ozonation

A_3 = Activated Carbon & UV Disinfection

FIGURE 68. SUMMARY OF RATINGS, r_{ij}

System Alternatives**	Measures of Effectiveness, (M)* and Relative Weights, (w) M_1 $w_1=0.304$	M_2 $w_2=0.202$	M_3 $w_3=0.135$	M_4 $w_4=0.123$	M_5 $w_5=0.094$	M_6 $w_6=0.063$	M_7 $w_7=0.031$	M_8 $w_8=0.029$	M_9 $w_9=0.019$
A_1	0.333	0.333	0.143	0.400	0.321	0.094	0.361	0.357	0.333
A_2	0.333	0.333	0.286	0.400	0.321	0.181	0.361	0.357	0.333
A_3	0.333	0.333	0.571	0.200	0.358	0.725	0.278	0.286	0.333

$$\begin{aligned} E[A_1] = \sum_{J=1}^{9} w_j r_{ij} &= (0.304)(0.333) + (0.202)(0.333) + (0.135)(0.143) + (0.123)(0.400) \\ &+ (0.094)(0.321) + (0.063)(0.094) + (0.031)(0.361) + (0.029)(0.357) \\ &+ (0.019)(0.333) = 0.299 \end{aligned}$$

$$\begin{aligned} E[A_2] = \sum_{J=1}^{9} w_j r_{ij} &= (0.304)(0.333) + (0.202)(0.333) + (0.135)(0.286) + (0.123)(0.400) \\ &+ (0.094)(0.321) + (0.063)(0.181) + (0.031)(0.361) + (0.029)(0.357) \\ &+ (0.019)(0.333) = 0.324 \end{aligned}$$

$$\begin{aligned} E[A_3] = \sum_{J=1}^{9} w_j r_{ij} &= (0.304)(0.333) + (0.202)(0.333) + (0.135)(0.571) + (0.123)(0.200) \\ &+ (0.094)(0.358) + (0.063)(0.725) + (0.031)(0.278) + (0.029)(0.286) \\ &+ (0.019)(0.333) = 0.373 \end{aligned}$$

*See Figure 68.

**A_1=Ozonation-UV, A_2=Ozonation, A_3=Activated Carbon & UV Disinfection

FIGURE 69. SUMMARY OF EFFECTIVENESS ANALYSES.

APPENDIX 2

TABLES

TABLE 1

OZONATION SYSTEM

EXPERIMENTAL SET-UP AND OPERATIONAL CHARACTERISTICS

Ozone Generator	
Type	Grace Ozone Generator (from Union Carbide), Model LG-2-L1
Size, HxLxW	8 in x 20 in x 17.5 in
Weight	115 lbs
Power requirements	125 watts at 120 volts, 60 Hz
Power consumption (90 min)	0.20 kwh
Ozone production	From Oxygen: 250 grams/day at 2% concentration by weight
Gas Supply	
Type	Oxygen
Flow	0.20 liters per minute, l/min.
Pressure	10 pounds per square inch gauge, psig
Contactor	
Type	Aquafine Electronic Liquid Sterilizer, Model SL-1*
Size, DxH	3¼ in x 29½ in
Diffusers	
number	Two
pore size	50 microns
surface area	0.442 square inch
Ozone Decomposition Device	Potassium Iodide Solution
Ozone Dose Applied	81 milligrams per liter

*Modified by the author

TABLE 2. OZONATION-ULTRAVIOLET RADIATION SYSTEM EXPERIMENTAL SET-UP AND OPERATIONAL CHARACTERISTICS.

Ozone Generator	
Type	Grace Ozone Generator (from Union Carbide), Model LG-2-L1
Size, HxLxW	8 in. x 20 in. x 17.5 in.
Weight	115 lbs
Power requirements	125 watts at 120 volts, 60 Hz
Ozone production	From Oxygen: 250 grams/day at 2% concentration by weight
Gas Supply	
Type	Oxygen
Flow	0.20 l/min.
Pressure	10 psig
Contactor	
Type	Aquafine Electronic Liquid Sterilizer, Model SL-1*
Lamp	Westinghouse Sterilamp 637T6VH, 2537 Angstrom (A) range,
power requirements	0.5 Amps, 118 Volts, 60 Hz
Diffusers	
number	Two
pore size	50 microns
surface area	0.442 square inch (sq.in.)
Ozone Decomposition Device	Potassium Iodide Solution
Ozone Dose Applied	81 milligrams per liter
UV Intensity	85 percent
Power consumption (90 min.)	0.30 kwh

*Modified by the author

TABLE 3. CARBON ADSORPTION COLUMN SYSTEM USING NUCHAR WV-L CONSTRUCTION AND OPERATIONAL CHARACTERISTICS.

Carbon Column	
Number	Two, 43.7 grams per bed
Diameter, I.D.	5/8 in.
Depth	21 in.
Arrangement	In series
Material	Plexiglass
Tubing	
Size	¼ in.
Type	Tygon
Liquid Storage	
Type	For influent - plastic For treated - glass
Operating Characteristics	
Flow Rate/Unit Area, Q/A	0.5 gallons/square foot (gpm/sq.ft.) or 4 ml/min.
Flow Rate/Unit Area, Q/A	1.0 gpm/sq.ft. or 8 ml/min.
Flow regime	Up flow
Type of operation	Continuous
Retention Time	~11 min/bed at Q/A = 0.5 ~5.5 min/bed at Q/A = 1.0
Pumps	
Type	Cole Parmer Peristaltic 22
Number	Three (two for waste, one for backwashing)
Energy requirements	0.5 Amps, 115 Volts, 60 Hz
Energy Consumption	
During Q/A=0.5gpm/sq.ft.	1.32 kWh
During Q/A=1.0gpm/sq.ft.	0.63 kWh

TABLE 4. CARBON ADSORPTION COLUMN SYSTEM USING FILTRASORB 400 CONSTRUCTION AND OPERATIONAL CHARACTERISTICS.

Carbon Column	
Number	Two, 42.2 grams per bed
Diameter, I.D.	5/8 in.
Depth	21 in.
Arrangement	In series
Material	Plexiglass
Tubing	
Size	1/4 in.
Type	Tygon
Liquid Storage	
Type	For influent - plastic For treated - glass
Operating Characteristics	
Flow Rate/Unit Area, Q/A	1.0 gpm/sq.ft. or 8 ml/min.
Flow Rate/Unit Area, Q/A	1.75 gpm/sq.ft. or 14 ml/min.
Flow regime	Up flow
Type of operation	Continuous
Retention time	∿5 minutes/bed at Q/A = 1 ∿3 minutes/bed at Q/A = 1.75
Pumps	
Type	Cole Parmer Peristaltic
Number	Three (two for waste, one for backwashing)
Energy Requirements	0.5 Amps, 115 Volts, 60 Hz
Energy Consumption	
During Q/A=1.0gpm/sq.ft.	0.63 kWh
During Q/A=1.75gpm/sq.ft.	0.80 kWh

TABLE 5. CARBON REGENERATION BY OZONATION SYSTEM CONSTRUCTION AND OPERATIONAL CHARACTERISTICS.

Ozone Generator	
Type	Grace Ozone Generator (from Union Carbide), Model LG-2-L-1
Size, H x L x W	8 in. x 20 in. x 17.5 in.
Weight	115 lbs
Power requirements	125 watts at 120 volts, 60 Hz
Ozone production	From Oxygen: 250 grams/day at 2% concentration by weight
Gas Supply	
Type	Oxygen
Flow	0.20 l/min.
Pressure	10 psig
Carbon-Ozone Contactor	
Diameter, I.D.	2 in.
Length	10 in.
Material	Plexiglass
Diffusers	
number	One
pore size	50 microns
surface area	3.14 sq. in.
Ozone Dose Applied	81 mg/l
Carbon Bed	
Diameter, I.D.	1/2 in.
Depth	9 in
Material	Plexiglass
Piping	
Size	1/4 in.
Type	Tygon
Liquid Storage	
Type	For influent - plastic For treated - glass

TABLE 5 (continued)

Operating Characteristics	
Q/A	2 gpm/sq.ft. or 11.4 ml/min.
Flow regime	Upflow
Type of Operation	Continuous
Retention Time	1.0 min.
Carbon	
Type	FILTRASORB 400
Pumps	
Type	Cole Parmer Peristaltic
Number	Two (one for waste, one for backwashing)
Energy requirements	0.5 Amps, 115 Volts, 60 Hz

TABLE 6. PERCENT IMPURITIES REMAINING NUCHAR WV-L (Q/A = 1.0 GPM/SQ.FT.)

COLUMN 1*					COLUMN 2*					
Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	TKN
0.96	27	26	50	51	0.92	18	24	30	48	
1.93	44	29	40	50	1.83	31	19	40	31	
3.38	32	29	50	50	3.20	26	11	30	14	72
4.34	48	33	60	67	4.12	37	20	60	45	
5.35	51	35	70	49	5.04	40	29	60	53	
6.75	65	51	80	96	6.45	45	37	80	68	
8.20	60	38	100	50	7.78	66	26	80	40	
9.65	61	46	100	64	9.16	42	31	90	68	81
11.10	32	49	100	57	10.53	43	35	90	57	
12.54	69	55	100	60	11.90	47	38	90	58	
13.99	67	48	100	47	13.28	55	30	90	37	
15.92	54	53	100	53	15.11	37	23	100	17	
17.37	62	60	100	74	16.48	47	30	100	40	

*Average initial impurities concentration

COD = 3783 mg/1
Color = 342 units
Odor = 10 OII
Turbidity = 77 JTU
TKN = 2900 mg/1

TABLE 7. PERCENT IMPURITIES REMAINING NUCHAR WV-L (Q/A = 0.5 GPM/SQ.FT.)

COLUMN 1*					COLUMN 2*					
Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	TKN
0.48	17	22	40	30	0.45	4	8	40	18	
0.96	23	20	50	30	0.91	17	6	40	29	
1.69	27	31	50	53	1.59	18	26	40	35	
2.65	35	33	60	59	2.49	27	28	60	29	
3.37	33	19	60	29	3.18	23	19	60	10	66
4.10	38	31	70	31	3.86	25	31	60	37	
4.82	42	26	80	31	4.54	29	21	60	35	26
5.54	46	26	90	40	5.22	34	21	70	10	
7.11	51	47	100	69	6.69	33	37	80	35	
8.07	46	45	100	69	7.60	33	32	90	25	
9.64	71	44	100	47	9.07	51	33	90	38	
10.85	79	47	90	63	10.21	60	42	90	50	79
12.29	51	44	100	72	11.57	36	33	90	42	
13.98	47	45	100	67	13.15	35	38	90	40	
15.67	41	60	100	77	14.74	62	35	100	28	
16.87	38	51	100	75	15.88	57	36	100	70	
18.08	50	55	100	63	17.01	40	39	100	50	
21.45	40	66	100	76	20.19	32	29	100	5	
24.58	67	50	100	40	23.13	52	39	100	30	
27.23	74	60	100	77	25.63	61	25	100	10	
29.16	89	50	100	71	27.44	65	41	100	42	
31.69	92	67	100	75	29.82	77	35	100	45	
35.55	89	77	100	81	33.34	85	54	100	60	
40.73	101	96	120	91	38.33	93	99	100	90	

*Average initial impurities concentration
COD=4034 mg/l COLOR=333 units ODOR=10 OII TURBIDITY=69 JTU TKN=3400 mg/l

TABLE 8. PERCENT IMPURITIES REMAINING FILTRASORB 400 (Q/A=1.0 GPM/SQ.FT.)

COLUMN 1*					COLUMN 2*					
Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	TKN
0.72	23	23	56	26	0.71	12	6	22	5	
5.01	37	10	67	44	3.57	27	12	56	11	
7.39	42	9	78	22	8.33	38	38	67	50	82
12.16	58	51	78	60	10.95	35	37	78	50	
14.79	52	50	89	60	12.85	67	39	89	56	82
16.70	89	55	100	64	14.75	70	45	89	70	
18.60	93	56	100	70	19.75	55	50	100	63	
23.61	71	47	100	50	22.13	46	42	100	62	82
26.00	55	53	100	60	30.94	61	30	100	33	
34.82	67	54	100	50	36.65	63	47	100	63	
40.55	78	65	111	75	40.46	68	50	100	69	
44.36	88	77	111	94	45.93	75	45	110	56	
49.85	95	84	111	105	49.03	88	79	122	97	
52.95	98	111	122	129	53.31	97	100	122	113	92
57.24	99	123	122	123						

*Average initial impurities concentration

COD = 3764 mg/l
COLOR = 325 units
ODOR = 9 OII
TURBIDITY = 80 JTU
TKN = 2800 mg/l

TABLE 9. PERCENT IMPURITIES REMAINING FILTRASORB 400 (Q/A = 1.75 GPM/Sq.Ft.)

COLUMN 1*					COLUMN 2*					
Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	Cum.Vol. Liters	COD	COLOR	ODOR	TURBIDITY	TKN
0.81	25	5	50	0	0.83	18	0	50	0	55
3.25	43	15	60	20	3.30	30	6	60	0	
11.39	59	41	80	50	11.56	42	33	70	55	
15.46	76	57	100	84	15.69	59	41	90	56	106
27.66	70	61	110	90	28.07	62	52	100	80	
39.05	80	77	110	86	39.63	76	46	110	43	
48.81	84	90	110	120	49.54	80	54	110	64	
56.55	85	78	120	96	57.39	102	78	110	115	130
60.20	97	98	120	103	61.10	97	91	110	96	

*Average initial impurities concentration

COD = 3667 mg/l
COLOR = 314 units
ODOR = 10 OII
TURBIDITY = 57 JTU
TKN = 2732 mg/l

TABLE 10. CAPITAL AND OPERATING COSTS FOR OZONE SYSTEM.

Items		Cost
Capital Cost		
Ozone Generator		$ 4000
Air Compressor		400
Dehumidifier		500
Holding Tank & Contactor		600
Flush Water Storage Tank		400
Pumps		200
	Subtotal	$ 6100
Accessories (25% of Subtotal)		1525
	Total Capital Cost	$ 7625
Annual Capital Cost [total capital cost ($7625) amotized over 5 years at 10 percent]		$ 915/year
Unit Capital Cost [annual capital cost ($915) x 1/ total annual system flow (7300 gal.)]		$ 0.13/gal
Annual Operating Cost		
Maintenance		Small
Power [2.4 kwh (Chapter II) x 365 x 0.05*		$ 44/year
Labor (12 hrs/year x $12**]		144/year
	Total Operating Cost	$ 188/year
Unit Operating Cost [annual operating cost ($188) x 1/total annual system flow (7300 gal.)]		$ 0.026/gal.
Total Unit Cost (unit capital cost and unit operating cost)		$ 0.16/gal.

* Power cost $0.05/kwh.

**Manpower cost $12.00/hr.

TABLE 11. CAPITAL AND OPERATING COSTS FOR OZONE-UV SYSTEM.

Items	Cost
Capital Cost	
Ozone Generator	$ 4000
Air Compressor	400
Dehumidifier	500
Holding Tank & Contactor	1500
Flush Water Storage Tank	400
Pumps	200
Subtotal	$ 7000
Accessories (25% of Subtotal)	$ 1750
Total Capital Cost	$ 8750
Annual Capital Cost [total capital cost ($8750) amortized over 5 years at 10 percent]	$ 1050/year
Unit Capital Cost [annual capital cost ($1050 x 1/total annual system flow (7300 gal.)]	$ 0.14/year
Annual Operating Cost	
Maintenance	Small
Power [2.8 kwh (Chapter II) x 365 x 0.05*]	$ 51/year
Labor (12 hr/year x $12**)	144/year
Total Operating Cost	$ 195/year
Unit Operating Cost [annual operating cost ($195) x 1/total annual system flow (7300 gal.)]	$ 0.027/gal
Total Unit Cost (unit capital cost and unit operating cost)	$ 0.17/gal

* Power cost $0.05/kwh.

**Manpower cost $12.00/hr.

TABLE 12. CAPITAL AND OPERATING COSTS FOR FILTRASORB 400 SYSTEM.

Items	Cost
Capital Cost	
Holding Tank	$ 400
Carbon Filter (without carbon, 16"x36")	200
One Year's Supply of Carbon [1300 lbs x ($0.67/lb)]	871
Pumps	300
UV Sterilizer	700
Subtotal	$ 2471
Accessories (25% of Subtotal)	$ 618
Total Capital Cost	$ 3089
Annual Capital Cost [total capital cost ($3089) amortized over 5 years at 10 percent]	$ 370/year
Unit Capital Cost [annual capital cost ($370) x 1/total annual system flow (7300 gal.)]	$ 0.05/year
Annual Operating Cost	
Maintenance	Small
Power [1.0 kwh x 365 x 0.05*]	$ 18
Labor (4 hrs x 12 x 12**)	576
Total Operating Cost	$ 594
Unit Operating Cost [annual operating cost ($594) x 1/total annual system flow (7300 gal.)]	$ 0.08/gal
Total Unit Cost (unit capital cost and unit operating cost)	$ 0.13/gal

* Power cost $0.05/kwh.

**Manpower cost $12.00/hr.

TABLE 13. CAPITAL AND OPERATING COSTS FOR NUCHAR WV-L SYSTEM.

Items	Cost
Capital Cost	
Holding Tank	$ 400
Carbon Filter (without carbon, 16"x36")	200
One Year's Supply of Carbon [1296 lbs x ($0.52/lb)]	674
Pumps	300
UV Sterilizer	700
Subtotal	$ 2274
Accessories (25% of Subtotal)	$ 569
Total Capital Cost	$ 2843
Annual Capital Cost [total capital cost ($3089) amortized over 5 years at 10 percent]	$ 341/year
Unit Capital Cost [annual capital cost ($341) x 1/total annual system flow (7300 gal.)]	$ 0.05/gal
Annual Operating Cost	
Maintenance	$ Small
Power [1.0 kwh x 365 x 0.05*]	18
Labor (4 hrs x 12 x 12**)	576
Total Operating Cost	$ 594
Unit Operating Cost [annual operating cost ($594) x 1/total annual system flow (7300 gal.)]	$ 0.08/gal
Total Unit Cost (unit capital cost and unit operating cost)	$ 0.13/gal

* Power cost $0.05/kwh

**Manpower cost $12.00/hr.

APPENDIX 3

OZONATION DATA*

Run	Cum. Contact Time,min.	COD mg/l		COLOR Units		ODOR OII		TURBIDITY JTU		TKN mg/l		pH		TEMP. °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	30	5808	3756	455	410	10	8	83	85	3920		6.53	5.79	20.0	20.5
	90	3756	3369	410	90	8	7	85	10			5.79	5.47	20.5	21.0
	180	3369	3059	90	25	7	6	10	0			5.47	5.08	21.0	21.5
	300	3059	2788	25	50	6	6	0	5		3700	5.08	4.45	21.5	22.0
2	30	3816	3549	390	320	11	8	75	75	3400		6.21	5.81	18.5	19.0
	90	3549	3205	320	120	8	7	75	25			5.81	5.69	19.0	19.0
	180	3205	3015	120	60	7	7	25	8			5.69	5.10	19.0	19.5
	300	3015	2595	60	10	7	6	8	0		3800	5.10	4.96	19.5	20.0
3	30	5724	4808	430	250	11	8	104	48	5400		6.22	6.04	19.5	20.0
	90	4808	4617	250	108	8	7	48	26			6.04	5.72	20.0	20.5
	180	4617	4464	108	53	7	6	26	11			5.72	5.60	20.5	21.5
	300	4464	3860	53	30	6	5	11	0		5700	5.60	5.05	21.5	22.0

* Ozone Dosage Applied: 81 mg/l
O_2 Flow Rate : 0.20 l/min
Pressure : 10 psig

APPENDIX 4

E. coli KILL BY MEANS OF OZONATION*

Contact Time, min.	Control # Colonies/100 ml	Sample # Colonies/100 ml
0	1.14×10^8	1.14×10^8
5	1.12×10^8	8.30×10^7
15	9.40×10^7	1.32×10^6
20	1.04×10^8	5.60×10^4
30	8.20×10^7	0

* Averages

APPENDIX 5

OZONATION-ULTRAVIOLET RADIATION DATA*

Run	Cum. Contact Time, min.	COD mg/l		COLOR Units		ODOR OII		TURBIDITY JTU		TKN mg/l		pH		TEMP. °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	30	5034	3291	380	370	11	8	70	70	3488		6.04	5.78	18	21
	90	3291	3098	370	50	8	7	70	0			5.78	5.41	21	27
	180	3098	2943	50	5	7	7	0	0			5.41	5.04	27	30
	300	2943	2323	5	30	7	5	0	10		3400	5.04	4.96	30	30
2	30	5221	4377	340	240	11	9	62	48	3672		6.24	5.74	18	21
	90	4377	3735	240	0	9	7	48	0			5.74	5.48	21	26
	180	3735	3494	0	0	7	6	0	0			5.48	5.42	26	30
	300	3494	2570	0	40	6	6	0	8		3600	5.42	5.03	30	30.5
3	30	4819	3414	330	250	11	9	70	39	5600		5.86	5.56	20	24
	90	3414	2932	250	115	9	7	39	18			5.56	5.12	24	28
	180	2932	2490	115	35	7	6	18	5			5.12	5.28	28	31
	300	2490	1928	35	20	6	5	5	0		5532	5.28	5.00	31	31.5

* Ozone Dosage Applied: 81 mg/l

O_2 Flow Rate: 0.20 l/min

Pressure: 10 psig

UV Intensity: 85%

APPENDIX 6

E. coli KILL BY MEANS OF OZONATION-ULTRAVIOLET RADIATION*

Contact Time, min.	Control # Colonies/100 ml	Sample # Colonies/100 ml
0	11.3×10^7	11.3×10^7
5	10.4×10^7	6.2×10^6
15	7.5×10^7	6.0×10^3
20	6.8×10^7	0
30	6.7×10^7	0

* Averages

APPENDIX 7

ULTRAVIOLET RADIATION DATA*

Run	Cum. Contact Time,min.	COD mg/l Inf.	COD mg/l Eff.	COLOR Units Inf.	COLOR Units Eff.	ODOR OII Inf.	ODOR OII Eff.	Turbidity JTU Inf.	Turbidity JTU Eff.	TKN mg/l Inf.	TKN mg/l Eff.	pH Inf.	pH Eff.	TEMP. °C Inf.	TEMP. °C Eff.
1	30	3956	2532	370	350	12	11	50	39	4500		6.13	6.15	15.0	19.0
	90	2532	2418	350	360	11	10	39	38			6.15	6.12	19.0	23.0
	180	2418	2400	360	400	10	10	38	36			6.12	6.06	23.0	25.5
	300	2400	2503	400	420	10	11	36	34		4100	6.06	6.05	25.5	27.5
2	30	4064	2642	300	260	10	9	75	68	--		6.34	6.33	17.5	20.0
	90	2642	2520	260	265	9	8	68	58			6.33	6.36	20.0	23.0
	180	2520	2479	265	328	8	8	58	53			6.36	6.38	23.0	25.5
	300	2479	2601	328	430	8	9	53	50		--	6.38	6.36	25.5	30.0

* UV Intensity: 85%

APPENDIX 8

E. coli KILL BY MEANS OF ULTRAVIOLET RADIATION*

Contact Time, min.	Control # Colonies/100 ml	Sample # Colonies/100 ml	Turbidity JTU	Temp. °C
0	9.6×10^7	9.6×10^7	70	22
30	6.4×10^7	6.6×10^7	52	26
90	5.5×10^7	TNTC**	50	27
180	5.4×10^7	TNTC	80	30
300	5.0×10^7	TNTC	80	37

* Averages

**Too numerous to count

APPENDIX 9

E. coli KILL BY MEANS OF ULTRAVIOLET RADIATION*

Contact Time, min.	Control # Colonies/100 ml	Sample** # Colonies/100 ml	Turbidity JTU	Temp. °C
0	16×10^7	16×10^7	3	21.5
5	14×10^7	11×10^6	0	22.0
20	13×10^7	10×10^5	0	23.5
35	13×10^7	5×10^5	0	25.0
50	15×10^7	2×10^5	5	26.5
65	13×10^7	4×10^4	0	28.5
75	12×10^7	0	0	29.5

* Averages

**Inoculated tap water

APPENDIX 10

NUCHAR WV-L
ADSORPTION ISOTHERM DATA*

(Using 800 ml diluted urine containing 2069 mg/l COD)

Sample Number	M Carbon Dose,ppm	Carbon Wt.,grams	C_f Remaining COD,mg/l	X COD Adsorbed,mg/l	X/M
C_o	0	0	2069	0	
1	1,250	1	958	1111	0.889
2	2,500	2	996	1073	0.429
3	5,000	4	705	1364	0.273
4	10,000	8	490	1579	0.158
5	25,000	20	286	1783	0.071

* 10 minutes contact time

APPENDIX 11

NUCHAR WV-G
ADSORPTION ISOTHERM DATA*

(Using 200 ml diluted uring containing 1515 mg/l COD)

Sample Number	M Carbon Dose,ppm	Carbon Wt.,grams	C_f Remaining COD,mg/l	X COD Adsorbed,mg/l	X/M
C_o	0	0	1515	0	
1	200	0.05	1439	76	0.0340
2	1000	0.20	1010	505	0.5050
3	2000	0.40	1167	348	0.1740
4	4000	0.80	866	649	0.1623
5	8000	1.60	682	833	0.1041
6	100,000	20.00	366	1149	0.0115

* 10 minutes contact time

APPENDIX 12

DARCO HD-3000
ADSORPTION ISOTHERM DATA*

(Using 200 ml diluted urine containing 1015 mg/l COD)

Sample Number	M Carbon Dose,ppm	Carbon Wt.,grams	C_f Remaining COD, mg/l	X COD Adsorbed,mg/l	X/M
C_o	0	0	1015	0	
1	5,000	1	966	49	0.010
2	10,000	2	551	464	0.046
3	20,000	4	442	573	0.029
4	50,000	10	251	764	0.015
5	150,000	30	203	812	0.005

* 10 minutes contact time

APPENDIX 13

FILTRASORB 300
ADSORPTION ISOTHERM DATA*

(Using 800 ml diluted urine containing 2170 mg/l COD)

Sample Number	M Carbon Dose,ppm	Carbon Wt.,grams	C_f Remaining COD, mg/l	X COD Adsorbed,mg/l	X/M
C_o	0	0	2170	0	
1	1,250	1	2054	116	0.093
2	2,500	2	1318	852	0.341
3	5,000	4	1008	1162	0.232
4	10,000	8	674	1496	0.150
5	25,000	20	543	1627	0.065

* 10 minutes contact time

APPENDIX 14

NUCHAR WV-L, COLUMN 1 ADSORPTION SYSTEM

CONDITIONS AND DATA*

Cumulative Time, hours	Cumulative Vol., liters	COD, mg/l		COLOR, units		ODOR, OII		TURB., JTU		TKN, mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
2	0.96	3920	1058	340	90	10	5	80	41	2900		6.45	6.99	17.5	20.5
4	1.93	3136	1372	310	90	10	4	70	35			6.43	7.30	20.5	22.5
7	3.38	5488	1764	315	90	10	5	70	35			6.45	6.71	21.5	21.5
9	4.34	3920	1882	300	100	10	6	67	45			6.41	6.66	20.5	19.5
11	5.35	3434	1755	340	120	10	7	79	39			6.50	6.72	20.5	22.5
14	6.75	3053	1984	350	180	10	8	73	70			6.51	6.65	22.5	22.5
17	8.20	3053	1832	365	140	10	10	88	40			6.46	6.59	25.0	22.0
20	9.65	3435	2080	350	160	10	10	77	49			6.48	6.55	;0/5	19.5
23	11.10	4961	1603	370	180	10	10	90	51			6.45	6.52	20.0	22.0
26	12.54	3485	2404	390	215	10	10	100	60			6.47	6.49	21.5	23.5
29	13.29	3731	2518	420	200	10	10	102	48			6.55	6.50	20.5	21.0
33	15.92	3783	2024	300	160	10	10	60	32			6.45	6.47	21.5	19.5
37	17.37	3780	2335	300	180	10	10	50	37			6.42	6.41	21.5	22.0

* Q/A = 1 gpm/sq.ft.

APPENDIX 15

NUCHAR WV-L, COLUMN 2 ADSORPTION SYSTEM

CONDITIONS AND DATA*

Cumulative Time, hours	Cumulative Vol., liters	COD, mg/l		COLOR, units		ODOR, OII		TURB., JTU		TKN, mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
2	0.92	3920	706	340	80	10	3	80	38			6.99	7.71	20.5	20.5
4	1.83	3136	902	310	60	10	4	70	22			7.30	7.70	22.5	22.0
7	3.20	5488	1411	315	35	10	3	70	10		2092	6.71	6.76	21.5	21.5
9	4.12	3920	1450	300	60	10	6	67	30			6.66	6.74	19.5	19.0
11	5.04	3434	1374	340	100	10	6	79	42			6.72	6.71	22.5	22.0
14	6.45	3053	1374	350	130	10	8	73	50			6.65	6.65	22.5	23.0
17	7.78	3053	2022	365	95	10	8	88	35			6.59	6.61	22.0	21.5
20	9.16	3435	1450	350	110	10	9	77	47		2340	6.55	7.59	19.5	19.0
23	10.53	4961	2137	370	130	10	9	90	51			6.52	6.61	22.0	21.5
26	11.90	3485	1641	390	150	10	9	100	58			6.49	6.60	23.5	23.5
29	13.28	3731	2060	420	125	10	9	102	38			6.50	6.58	21.0	20.0
33	15.11	3783	1401	300	70	10	10	60	10			6.57	6.58	19.5	20.0
37	16.94	3780	1790	300	90	10	10	50	20			6.41	6.50	22.0	22.0

* Q/A = 1 gpm/sq.ft.

APPENDIX 16
NUCHAR WV-L, COLUMN 1 ADSORPTION SYSTEM CONDITIONS AND DATA*

Cumulative Time,hours	Cumulative Vol.,liters	COD, mg/l		COLOR,units		ODOR, OII		TURB.,JTU		TKN,mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
2.0	0.48	3936	669	250	55	10	4	50	15	3400		6.43	7.22	16.5	20.0
4.0	0.96	3936	905	250	50	10	5	50	15			6.42	6.92	19.5	22.0
7.0	1.69	3936	1063	270	85	10	5	57	30			6.42	6.77	19.5	19.5
11.0	2.65	3936	1378	320	105	10	6	68	40			6.44	6.54	19.0	19.0
14.0	3.37	3936	1299	360	70	10	6	70	20			6.37	6.61	20.5	20.5
17.0	4.10	3936	1485	360	110	10	7	80	25			6.38	6.60	21.5	22.5
20.0	4.82	3908	1641	340	90	10	7	70	22			6.47	6.51	18.5	20.0
23.0	5.54	3908	1798	340	90	10	8	50	20			6.51	6.58	19.5	21.0
29.5	7.11	3908	1993	350	160	10	9	65	45			6.42	6.52	21.0	21.0
33.5	8.07	4689	2149	330	150	10	10	65	45			6.46	6.51	22.5	23.0
40.0	9.64	2713	1917	390	170	10	10	85	40			6.67	6.77	19.5	20.5
45.0	10.85	2713	2132	360	170	10	10	80	50			6.44	6.58	20.5	18.0
51.0	12.29	3910	2007	330	145	10	9	58	42			6.60	6.68	20.0	21.5
58.0	13.98	4632	2200	290	130	10	10	43	29			6.55	6.69	17.5	18.0
65.0	15.67	6176	2509	310	185	10	10	65	50			6.66	6.56	22.5	22/5
70.0	16.87	6176	2355	440	223	10	10	100	75			6.43	6.56	20.0	18.5
75.0	18.08	5018	2509	465	200	10	10	89	50			6.60	6.84	20.5	20.5
89.0	21.45	6589	2636	280	185	10	10	38	29			6.49	6.73	17.0	16.5
102.0	24.58	3101	2093	270	135	10	10	50	20			6.47	6.63	21.0	19.0
113.0	27.23	3101	2287	285	170	10	10	48	37			6.78	6.77	17.0	20.0
121.0	29.16	3340	2960	380	190	10	10	63	45			6.31	6.74	18.5	20.0
131.5	31.69	2980	2750	460	310	10	10	100	75			6.35	6.58	15.5	17.5
147.5	35.55	2778	2470	390	300	10	10	90	73			6.58	6.71	15.5	17.0
169.0	40.73	3571	3610	270	260	10	12	120	109			6.67	6.78	16.5	16.5

* Q/A = 0.5 gpm/sq.ft.

APPENDIX 17
NUCHAR WV-L, COLUMN 2 ADSORPTION SYSTEM CONDITIONS AND DATA*

Cumulative Time,hours	Cumulative Vol.,liters	COD, mg/l		COLOR,units		ODOR, OII		TURB.,JTU		TKN, mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
2.0	0.45	3936	157	250	20	10	4	50	18			7.22	8.68	20.0	19.0
4.0	0.91	3936	669	250	15	10	4	50	29			6.92	8.16	22.0	20.5
7.0	1.59	3936	708	270	70	10	4	57	35			6.77	7.04	19.5	20.0
11.0	2.49	3936	1063	320	90	10	6	68	29			6.54	6.67	19.0	19.0
14.0	3.18	3936	905	360	70	10	6	70	10		2260	6.61	6.64	20.5	19.5
17.0	3.86	3936	977	360	112	10	6	80	37			6.60	6.63	22.5	21.5
20.0	4.54	3908	1133	340	70	10	6	70	35		900	6.51	6.76	20.0	19.5
23.0	5.22	3908	1329	340	70	10	7	50	10			6.58	6.52	21.0	21.0
29.5	6.69	3908	1290	350	129	10	8	65	36			6.52	6.51	21.0	20.5
33.5	7.60	4689	1563	330	105	10	9	65	25			6.51	6.41	23.0	22.5
40.0	9.07	2713	1395	390	130	10	9	85	38			6.77	6.70	20.5	20.0
45.0	10.21	2713	1628	360	150	10	9	80	50		2700	6.58	6.61	18.0	18.5
51.0	11.57	3910	1390	330	110	10	9	58	42			6.68	6.56	21.5	20.5
58.0	13.15	4632	1621	290	110	10	9	43	40			6.69	6.76	18.0	17.5
65.0	14.74	6176	1969	310	110	10	10	65	28			6.56	6.58	22.5	21.5
70.0	15.88	6176	1819	440	160	10	10	100	70			6.56	6.65	18.5	19.0
75.0	17.01	5018	2007	365	142	10	10	89	50			6.84	6.87	20.5	21.0
89.0	20.19	6589	2093	280	80	10	10	38	5			6.73	6.79	16.5	16.5
102.0	23.13	3101	1628	270	105	10	10	50	30			6.63	6.65	19.0	19.0
113.0	25.63	3101	1899	285	70	10	10	48	10			6.77	6.81	20.0	19.5
121.0	27.44	3340	2169	380	155	10	10	63	42			6.74	6.87	20.0	23.0
131.5	29.82	2280	2290	460	160	10	10	100	45			6.58	6.70	17.5	16.5
147.0	33.34	2778	2352	390	210	10	10	90	60			6.71	6.73	17.0	16.0
169.0	38.33	3571	3308	270	268	10	11	120	95			6.78	6.72	16.5	16.5

* Q/A = 0.5 gpm/sq.ft.

APPENDIX 18

FILTRASORB 400, COLUMN 1 ADSORPTION SYSTEM

CONDITIONS AND DATA*

Cumulative Time, hours	Cumulative Vol., liters	COD, mg/l		COLOR, units		ODOR, OII		TURB., JTU		TKN, mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1.5	0.72	3226	726	345	80	9	5	95	25	2800		6.51	7.34	20.5	20.5
10.5	5.01	3629	1331	335	35	9	6	90	40			6.69	6.76	19.5	18.0
15.5	7.39	3520	1492	340	30	9	7	90	20			6.58	7.16	19.0	20.0
25.5	12.16	3520	2056	370	190	9	7	100	60			6.66	6.74	16.0	16.5
31.0	14.79	4312	2234	380	190	9	8	100	60			6.37	6.53	21.5	22.5
35.0	16.70	2446	2180	330	180	9	9	90	58			6.85	6.87	21.5	24.0
39.0	18.60	2335	2179	320	180	9	9	90	63			6.70	6.78	21.5	22.5
49.5	23.61	3114	2218	340	155	9	9	80	40			6.40	6.44	20.5	20.0
54.5	26.00	4461	2440	265	140	9	9	50	30			6.68	6.94	22.0	24.5
73.0	34.82	4461	2991	230	125	9	9	40	20			6.48	6.98	20.0	23.0
85.0	40.55	4461	3480	340	220	9	10	80	60			6.37	7.02	16.5	17.5
93.0	44.36	4690	4127	350	270	9	10	80	75			6.45	7.08	19.0	20.5
104.5	49.85	4080	3876	310	260	9	10	62	65			6.45	7.21	16.5	17.0
111.0	52.95	4080	3998	315	350	9	11	70	90			6.57	7.46	22.0	22.5
120.0	57.24	4130	4115	310	380	9	11	80	98			6.51	7.38	20.0	21.0

* Q/A = 1 gpm/sq.ft.

APPENDIX 19

FILTRASORB 400, COLUMN 2 ADSORPTION SYSTEM

CONDITIONS AND DATA*

Cumulative Time,hours	Cumulative Vol.,liters	COD, mg/l		COLOR,units		ODOR, OII		TURB.,JTU		TKN, mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1.5	0.71	3226	400	345	20	9	2	95	5			7.34	8.75	20.5	26.5
7.5	3.57	3520	967	340	40	9	5	90	10			6.76	7.73	18.0	19.0
17.5	8.33	3520	1331	370	140	9	6	100	50		2300	7.16	7.24	20.0	20.5
23.0	10.95	4312	1528	380	140	9	7	100	50			6.74	6.86	16.5	16.5
27.0	12.85	2446	1635	330	130	9	8	90	50		2300	6.53	6.59	22.5	22.5
31.0	14.76	2335	1635	320	145	9	8	90	63			6.87	7.03	24.0	23.0
41.5	19.75	3114	1712	340	170	9	9	80	50			6.78	6.96	22.5	23.0
56.5	22.13	4461	2047	265	110	9	9	50	31		2300	6.44	6.78	20.0	19.5
65.0	30.94	4461	2716	230	70	9	9	40	13			6.94	7.06	24.5	24.0
77.0	36.65	4461	2795	340	160	9	9	80	50			6.98	7.00	23.0	22.5
85.0	40.46	4690	3182	350	175	9	9	80	55			7.02	7.07	17.5	18.0
96.5	45.93	4080	3060	310	140	9	10	62	35			7.08	7.12	20.5	20.5
103.0	49.03	4080	3590	315	250	9	11	70	68			7.21	7.02	17.0	17.0
112.0	53.31	4130	4006	310	310	9	11	80	90		2572	7.46	7.27	21.0	21.5

* Q/A = 1 gpm/sq.ft.

APPENDIX 20

FILTRASORB 400, COLUMN 1 ADSORPTION SYSTEM

CONDITIONS AND DATA*

Cumulative Time,hours	Cumulative Vol.,liters	COD, mg/l		COLOR,units		ODOR, OII		TURB.,JTU		TKN, mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1.0	0.81	3098	760	260	5	10	5	38	0	2732		6.36	6.85	19.0	21.5
4.0	3.25	3098	1320	260	40	10	6	50	10			6.34	6.64	19.0	21.0
14.0	11.39	3872	2280	270	110	10	8	40	20			6.52	6.54	17.0	19.5
19.0	15.46	3098	2360	290	165	10	10	50	42			6.55	6.46	20.0	21.5
34.0	27.66	3485	2439	305	185	10	11	50	45			6.52	6.32	18.5	19.0
48.0	39.05	3872	3097	350	270	10	11	70	60			6.52	6.81	20.0	21.0
60.0	48.81	3916	3291	410	370	10	11	75	90			6.42	6.87	17.5	17.5
69.5	56.55	3892	3291	360	280	10	12	68	65			6.70	6.80	18.0	20.5
74.0	60.20	4670	4518	326	319	10	12	68	70			6.61	6.76	22.0	23.5

* Q/A = 1.75 gpm/sq.ft.

APPENDIX 21

FILTRASORB 400, COLUMN 2 ADSORPTION SYSTEM

CONDITIONS AND DATA*

Cumulative Time,hours	Cumulative Vol.,liters	COD, mg/l		COLOR,units		ODOR, OII		TURB.,JTU		TKN, mg/l		pH		TEMP., °C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1.0	0.83	3098	570	260	0	10	5	38	0		1500	6.85	7.54	21.5	22.0
4.0	3.30	3098	920	260	15	10	6	50	0			6.64	6.74	21.0	22.0
14.0	11.56	3872	1640	270	90	10	7	40	22			6.54	6.48	19.0	21.0
19.0	15.69	3098	1840	290	120	10	9	50	28		2900	6.46	6.49	21.5	19.5
34.0	28.07	3485	2168	305	160	10	10	50	40			6.32	6.29	19.0	21.5
48.0	39.63	3872	2942	350	160	10	11	70	30			6.81	6.59	21.0	19.5
60.0	49.54	3916	3136	410	220	10	11	75	48			6.87	6.87	17.5	20.5
69.5	57.39	3892	3970	360	280	10	11	68	78		3560	6.80	6.86	20.5	17.5
74.0	61.10	4670	4548	326	298	10	11	68	65			6.76	6.67	23.5	23.5

* Q/A = 1.75 gpm/sq.ft.

APPENDIX 22

FILTRASORB 400, COLUMN ADSORPTION SYSTEM CONDITIONS AND DATA*

Cumulative Time, hours	Cumulative Vol., liters	COD, mg/l		COLOR, units		ODOR, OII		TURB., JTU		TKN, mg/l		pH		TEMP., ^{o}C	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	0.69	3816	1908	365	140	10	6	70	45	2960	2810	6.86	6.63	18.5	21.0
14	9.61	4579	3205	490	310	10	7	110	80			6.78	6.61	18.0	21.0
18	12.35	4198	3587	430	400	10	10	100	100	3400	3800	6.67	6.67	19.0	22.0
The results below were obtained after 5 hours of oxygenation															
1	0.69	2388	2176	350	240	10	10	100	80	2960	2900	7.00	7.00	18.5	20.5
0.75	0.35	2866	2157	270	80	10	7	48	30	3200	2500	7.17	7.17	19.0	20.0
13.50	6.24	3732	2687	275	248	10	9	65	52			6.81	6.81	18.0	19.0
18.50	8.55	3732	2799	325	250	10	9	74	55			7.03	7.03	18.5	22.5
22.50	10.40	2866	2800	264	240	10	10	50	50			6.92	6.92	20.0	24.0
25.50	11.78	2649	2751	300	310	10	10	58	58		2900	7.00	7.00	16.0	19.0
The results below were obtained after 5 hours of ozonation															
1	0.46	2426	2239	380	290	10	10	90	73	3200	2900	7.11	7.10	18.5	19.0

* O_2 Flow Rate: 0.20 l/min
O_3 Dosage Applied: 81 mg/l
Pressure: 10 psig

APPENDIX 23

VOLUME (LITERS) PROCESSED BEFORE ACCEPTABLE VALUES WERE EXCEEDED

Flow Rate gpm/sq.ft.	NUCHAR WV-L*						FILTRASORB 400**					
	Turbidity		Color		Odor		Turbidity		Color		Odor	
	Col.1	Col.2	Col.1	Col.2	Col.1	Col.2	Col.1	Col.2	Col.1	Col.2	Col.1	Col.2
1.00	8.8	14.0	2.0	12.0	2.6	4.8	16.0	19.0	8.7	7.0	2.0	4.8
0.50	3.5	6.5	3.5	10.5	2.6	2.4						
1.75							14.6	24.3	8.7	16.7	3.0	3.0

* 43.7 grams/column

**42.2 grams/column

APPENDIX 24

CRITERIA FOR THE EFFECTIVENESS ANALYSIS

Health Hazard - Based on the tests conducted all three systems rendered a safe flush water, therefore, they are being considered equally effective.

User Acceptability - Careful consideration of the factors involved in this measure of effectiveness (outlined in Chapter IV) revealed that all three systems are equally effective.

Operation Reliability - The system alternatives under this measure were weighted based on the assumption that the more sophisticated the system such as Ozonation-UV, the more it could be subject to more operational problems.

a. Ozonation - This system was rated as 1/2 as reliable as carbon due to the complexity of the system. Carbon is a more simple system.

b. Ozonation-UV - This system was rated as 1/2 as reliable as Ozonation because the addition of UV lamps which make it more complex than Ozonation.

Maintainability - Ozonation and Ozonation-UV systems were believed to require twice as much maintenance since they are more complex than carbon.

Safety - Ozonation and Ozonation-UV systems were believed to be less safe due to possible escape of ozone gas into the immediate area as a result of a malfunction.

Power Requirements - The power requirements were based on those of the major electrical components.

a. Carbon Adsorption with UV disinfection: 100 watts (UV lamps)

b. Ozonation: 400 watts (Ozone Generator)

c. Ozonation-UV: 900 watts (Ozone Generator + UV Lamps)

Space Requirement - Due to the air preparation unit the Ozonation and Ozonation-UV were rated as occupying more space than the carbon system.

Weight - The weight of the Carbon system was considered to be higher due to the required six-month carbon supply ($\sim$650 pounds). The principal components of the Ozonation and Ozonation-UV weight approximately 220 and 250 pounds respectively.

Shelf Life - All three systems were rated as having the same shelf life.