Spring 1989

An Experimental Study of Dewatering of Alum Sludge

Uday G. Kelkar
Old Dominion University

Recommended Citation

Kelkar, Uday G.. "An Experimental Study of Dewatering of Alum Sludge" (1989). Master of Science (MS), Thesis, Civil & Environmental Engineering, Old Dominion University, DOI: 10.25777/nbkt-m546
https://digitalcommons.odu.edu/cee_etds/147

AN EXPERIMENTAL STUDY OF
DEWATERING OF ALUM SLUDGE

BY

UDAY G. KELKAR
B.E. (CIVIL) 1985,
COLLEGE OF ENGINEERING, PUNE, INDIA

A Thesis Submitted to the Faculty of
Old Dominion University in partial Fulfillment
of the Requirements for the Degree of

MASTER OF SCIENCE
CIVIL ENGINEERING

Old Dominion University
May, 1989

Approved By:

Dr. William A. Drewry (Director)

Dr. Gary C. Schafran

Dr. A. Osman Akan

-:<u>ABSTRACT</u>:-

AN EXPERIMENTAL STUDY OF DEWATERING OF ALUM SLUDGE

Uday G. Kelkar
Old Dominion University, 1989
Director: Dr. W. A. Drewry

The use of aluminum sulfate (Alum) as a coagulant for treating surface water was introduced in 1884. When this salt is added to water, the aluminum Ion hydrolyzes by reaction that consumes alkalinity in water. The gelatinous hydroxide thus formed in the reaction, carries suspended material with it as it settles. In addition, however, it is likely that positively charged hydroxyl-bridge dimmers and higher polymers are formed which interact specifically with the colloidal particles, bringing about coagulation. These gelatinous flocs settle by gravity, called sludge, consists of relatively large quantities of suspended and colloidal inorganic and organic materials.

The disposal of these wastes from water treatment plants is not a new problem. These sludges are highly variable in composition containing the concentrated materials removed from raw water and the chemicals added in the treatment processes.

This sludge dewatering remains perhaps the most difficult and elusive of the environmental engineering challenges. One of sludge dewatering's most bothersome aspect is that there seems to be no accepted means to evaluate the case with which a sludge will release it's water.

The purpose of this study was to investigate the effect of hydrogen peroxide addition on sludge dewaterability utilizing sludge macroproperties such as pH, capillary suction time (CST), viscosity, and specific resistance. Hydrogen Peroxide resembles Ozone in its strong oxidizing qualities. Dilute solutions of hydrogen peroxide when reacted with the $Al(OH)_3$ floc appears to liberate oxygen and water. Specific dewatering processes investigated include sand beds, centrifugation, vacuum filtration, and pressure filtration. Water treatment plant sludges generated at the four major treatment plants in the South Eastern Virginia were examined.

Experimental results indicated that: hydrogen peroxide generally aids in sludge dewatering, providing higher cake solids concentrations. A laboratory (and possible Pilot) investigation is required in order to determine the optimum hydrogen peroxide dosage and the appropriate dewatering process for any particular sludge.

ACKNOWLEDGEMENTS

Greatful appreciation is expressed to the following for their assistance and encouragement:

To my advisor, Dr. W. A. Drewry, for his interest in my development and guidance throughout the graduate program.

To my committee members Dr. Gary C. Schafran and Dr. A. Osman Akan, for their support and advice.

To Mr. Vernon R. Land and Mr. Richard Ricksaul, from Moores Bridges Water Treatment Plant, Norfolk, VA and Mr. Edward G. Snyder, III from Lee Hall Water Treatment Plant, Newport News, VA for their assistance in collecting the sludge samples.

To my friend Greg for his valuable assistance in transporting the sludge samples from the various treatment plants.

Finally, to Mary and Sue for their assistance in formatting the typing of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

CHAPTER ONE

INTRODUCTION

Chapter 1

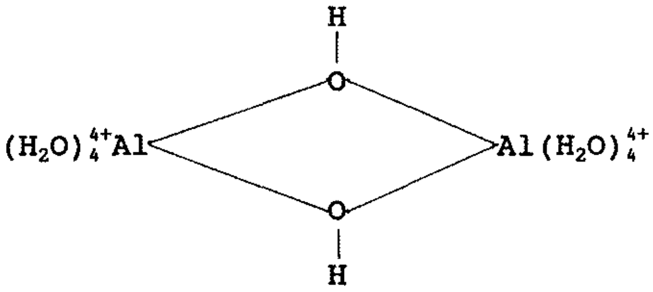
Introduction

1.1 Introduction

The use of aluminum sulfate (alum or filter alum) as a coagulant for treating surface water was introduced in 1884 [6]. When this salt is added to water, the aluminum ion hydrolyzes by reactions that consume alkalinity in water, such as

$$Al(H_2O)_6^{3+} + 3HCO_3^- \text{----->} Al(OH)_3 \cdot 3H_2O\ (s) + 3CO_2 + 3H_2O$$

A gelatinous hydroxide is formed by this reaction, which carries suspended material with it as it settles. In addition, it is likely that positively charged hydroxyl bridged dimers such as



and higher polymers are formed which interact specifically with colloidal particles, bringing about coagulation. These gelatinous flocs are heavier than water and settle by gravity.

A typical surface water treatment plant might include the following treatment processes: Presedimentation, coagulation (rapid mix, flocculation), sedimentation, and filtration. The relatively large quantities of suspended and colloidal inorganic and organic material removed in this type of plant are generally concentrated in sidestreams from four of these units. The mixture of soil, micro-organisms, organics and hydrous oxides, that accumulate at the bottom of the settling basin and the finer fraction of the same mixture collected in the filtering medium constitutes the sludge. Each type of sludge is removed hydraulically as an aqueous suspension after a varying period of operation.

The disposal of these wastes (sludges) from water treatment plants is not a new problem. The majority of water treatment plants dispose of these sludges by returning them to the surface waters [2]. Under the new federal and state laws, these sludges are considered as pollutants, as are the wastes from any industry [47,27].

Water plant sludges are often characterized by high water content (low suspended solids concentration), high resistance to mechanical or gravity dewatering , and other problems associated with their handling and ultimate disposal. These sludges are highly variable in composition, containing the concentrated materials removed from raw water and the chemicals added in the treatment processes. Since sludge from each water treatment plant is different, no specific treatment process will yield the same result for all plants. In fact, while a spectrum of sludge treatment methods are available, there may be only one or two methods applicable to a specific location.

Alum sludge dewatering remains one of the most difficult and elusive of the environmental engineering challenges. One of sludge dewatering's most bothersome aspects is that, there seems to be no accepted means to evaluate the ease with which a particular sludge will release its water.

1.2 Study Objective

The purpose of this study was to investigate the effect of hydrogen peroxide addition on alum sludge dewaterability, considering sludge macroproperties such as p^H, capillary suction time (CST), viscosity, and specific resistance. Specific dewatering processes investigated included sand beds, centrifugation, vacuum filtration, and pressure filtration . Water treatment plant sludges generated at four major water treatment plants in Southeastern Virginia were examined.

CHAPTER TWO

LITERATURE REVIEW

Chapter 2

Literature Review

2.1 Introduction

Alum sludge is the byproduct that results from coagulation processes at the conventional water treatment plants. The gelatinous precipitate produced by aluminum sulfate has long posed problems of disposal. The disposal of these wastes has grown into a challenge for the water utility industry, especially in light of the current emphasis on a clean environment.

2.2 Sludge Characteristics

An alum sludge consists of aluminum hydroxide in addition to silt and clay particles, color colloids, microorganisms, and other organic and inorganic matter removed from the water being treated. Generally, alum sludge has a high water (low solids) content. It varies in color from a light yellow to black depending upon the character of the source water, the chemicals used for the treatment, and the time it is retained in the sedimentation basin and filters, before withdrawal for treatment and/or disposal.

While many methods exist for treatment and disposal of alum sludge, only a few are in widespread use. Each treatment method has its own particular problems and drawbacks.

Operating costs and inability to dewater the alum sludge to a required solids content are two of the major problems with current alum sludge dewatering and disposal techniques. The objectives of a dewatering system are, generally, to produce a sludge cake suitable for land disposal and a liquid stream suitable for recycling or discharge.

2.3 Treatment Alternatives

Much of the reported research on water treatment plant sludges has had as its goals, the alteration of the physical and/or chemical properties to facilitate removal of water [2, 3, 6, 47, 51, 54]. Based on the actions taken by the water industry to date, sludge treatment alternatives generally can be divided into three categories:

1) Direct discharge to surface waters.
2) Nonmechanical dewatering methods.
3) Mechanical dewatering methods.

2.3.1 Direct Discharge to Surface Waters

Directly discharging alum sludge to a watercourse was once a standard practice as an economical method of disposal. The potential effects of alum sludge discharge to receiving bodies of water can be broadly classified as aesthetic or toxic. Aluminum toxicity remains a major concern as regards the effects of alum sludge discharge [46]. Most of the investigative work that has been reported on mass concentration changes resulting from alum sludge discharge has been conducted by the Ohio River Valley Water Sanitation

Commission (ORSANCO) [46]. The ORSANCO studies present conclusions that would be expected for a high-flow, turbid river. These results could be adapted for application to other situations, and conclusions could then be drawn regarding changes in pollutant loadings attributable to a discharge. This approach does not address the effects of those changes, and only generalizations can be made regarding their significance.

Over the past ten years, the proprieties of continuing direct discharge to surface waters have been questioned. Due to the new strict pollution control laws and regulations, the water industry has been forced to look for alternative methods of disposal.

2.3.2 Nonmechanical Dewatering

For water treatment plants, especially the smaller plants in cities where land is readily available at reasonable cost, nonmechanical dewatering is frequently a suitable and feasible alternative that can lead to the economic treatment of water plant sludge. Nonmechanical dewatering can be accomplished either in open lagoons or in sand-drying beds. With the use of either of these alternatives, freeze-thawing of the sludge might be considered to improve the sludge dewaterabilty.

Dewatering of alum sludge using nonmechanical methods, either lagoons or sand-drying beds, has been found to occur via two basic mechanisms:

1) Sludge concentration - draining or evaporation of the free water from the sludge.

2) Sludge drying - evaporation of water remaining after solids have been concentrated.

Lagoons

Lagoons have been used extensively to thicken and/or store water treatment plant sludges. Although lagoons perform satisfactorily in settling the sludge, there is little evidence of significant consolidation [34]. Lagoons are typically designed with an impermeable bottom to minimize sludge drainage [38]. As a result, lagoon drying generally requires large land areas and is often a temporary solution and/or standby facility for a more sophisticated dewatering system. While the operational costs of lagoons are low, factors such as climate, intermittent or continuous input, varying solids concentration, etc., have a bearing on the land area required.

It is a well-known fact that alum sludge is difficult to dewater by lagooning [38,4]. Some sludges have not thickened beyond 9 percent solids, even after years of settling. A survey of the Shoremont Water Treatment Plant near Rochester, New York [4] showed that by using lagooning, sludge containing 5 percent solids can be separated and concentrated only to an average of 6 percent solids. Naubaur [41] reported that after three years of operating a 400 feet by 320 feet and 17 feet deep lagoon with a 7 foot sludge depth, it had an average solids concentration of only 4.3 percent at a loading rate of 0.37 gallons per day per square feet (gpd/ft^2).

To utilize lagoons as a nonmechanical dewatering facility it is necessary to include an underdrainage system, except when evaporation rates are extremely high. If a lagoon includes this feature, basin sludge can be discharged to the lagoon, decanted, then allowed to drain and air dry to a handleable condition. Without a drainage feature, lagoons can easily become a major problem due to seepage which can cause ground water pollution [34].

Sand Drying Beds

Use of sand beds (similar to wastewater sludge drying beds) has been found to be effective for dewatering water plant sludges [1, 2, 3, 44]. A sand drying bed is designed with sand over a gravel bottom to enhance drainage of water from the sludge and maximize air drying. Filtrate from the sand drying beds can either be recycled, treated or discharged to a water course, depending upon the quantity and other factors. A number of parameters affect the ability of the drying beds to dewater the sludge. These include air temperature and humidity, wind currents, and viscosity of the sludge [15].

Bench scale tests performed on alum sludge by Naubauer [41] indicated that a solids concentration of 20 percent can be obtained in 70 to 100 hours with 97 percent of the suspended solids removed from the filtrate. Testing conditions varied with temperatures fluctuating from 69 to 81 °C, relative humidity from 72 to 93 percent, and a constant 5 mph wind. Tests conducted by Bishop and Cornwell [5] at Durham, North Carolina showed that sand drying studies were very encouraging and provided excellent dewatering of alum sludge by acidifying the sludge with sulfuric acid. In these studies, a maximum cake solids concentration of 26 percent was obtained once the aluminum had been removed from the sludge. Research conducted by Novak and Calkins [44], investigating the physical properties of sludges and their relationship to various dewatering processes, indicates that only vacuum filtration or sand draining and evaporation can be expected to provide a handleable sludge (Cake Solids ≥ 20%). However, other methods of dewatering, such as pressure filtration, have also provided successful results (Cake Solids 19 to 25%)[12,16].

Freeze Treatment

Dewatering alum sludge via either nonmechanical method may be enhanced by physical conditioning of the sludge through natural freezing and thawing cycles. The freeze-thaw process dehydrates the sludge particles by freezing the water that is closely associated with the particles. The freezing process takes place in two stages. The first stage reduces sludge volume by selectively freezing the water molecules. Next, the solids are dehydrated in the second stage of freezing. The solid mass, when thawed, forms granular-shaped particles.

This coarse material readily settles and retains its new shape and size. The residue sludge dewaters rapidly and makes suitable landfill material [47].

Farrell et al. [18] reported that after natural freezing and thawing, the solids content of alum sludge increased from 0.32 percent to 18 percent. To obtain a maximum solids concentration, freezing had to be complete. Partial freezing had little effect on improving the solids concentration of the sludge, even if repeated a number of times. Snow cover, even during extremely cold periods, produced undesirable effects due to unevenness of freezing. While the top layer of the snow cover may be frozen solid, the layers underneath may remain partially frozen.

Numerous investigators have studied the application of freezing and thawing to water treatment plant sludges prior to final disposal. Doe et al. [13], Plain [47], Fulton [19], Farrell et al. [18], and Logsdon et al. [39], worked with aluminum hydroxide sludges and arrived at conclusions that may be summarized as follows:

Freezing and thawing (1) improves the dewatering characteristics of sludge; (2) results in higher sludge cake solids; (3) results in a physical change which is irreversible; and (4) is more effective when the rate of freezing is slow.

Natural freezing and thawing is obviously performed by the environment and is a more common practice in areas with long, cold winters. In fact some cities in the northern United States and Canada routinely use natural freeze/thaw processes to enhance the dewatering of alum sludge. Several natural freeze-thaw installations are located in the state of New York [6]. In the United Kingdom, a freezing process for the treatment of alum sludge has also been successfully operated at various plants showing improvement in the dewatering characteristics of the sludge [55].

Eliminating the seasonal restrictions in natural methods, sludge freezing may also be accomplished using mechanical refrigeration. Research has been conducted in this area, namely in indirect freezing and direct freezing [35]. Freezing has proven to be beneficial, although it is expensive to implement and increases the power costs for the treatment plant [35]. However, Wilhelm and Silverblatt [54] found that the power costs of the mechanical freezing method can be competitive with the precoat or pretreatment chemicals required for the pressure or vacuum filtration method in certain situations.

2.3.3 Mechanical Dewatering

The objectives of mechanical dewatering systems are to produce sludge cakes suitable for land disposal and liquid streams suitable for recycle or discharge. Various dewatering systems have been tested on all types of water treatment plant sludges. Centrifugation, vacuum filtration, and pressure filtration have been the most widely tested methods.

Centrifugation

Two types of centrifuges are currently used for sludge dewatering: the solid bowl and the basket bowl. For dewatering alum sludges, the solid bowl has proved to be more successful than the basket bowl [3]. In most cases, polymers are added to condition the sludge prior to centrifugation.

Performance data obtained during pilot testing with a basket bowl centrifuge ranged from no effect to acceptable performance [2]. A cake dryness of 15 to 17 percent is considered good performance for a centrifuge on alum sludge. Sludge generated from treating low turbidity raw water could not be dewatered by the basket centrifuge. However, with high turbidity raw water, a 15 percent cake could be produced by using 2.0 to 2.5 kg polymer per ton of dry solids [42].

Using solid bowl centrifuge, Albrecht [1] reported solids concentrations of 15 to 17 percent with feed solids between 0.4 and 6 percent. Loading rates varied depending on the size of the centrifuge. Albrecht noted that the best performance was obtained when the feed rate was 75 to 85 percent of the machine's total solids or hydraulic capacity. While using the centrifuge method, solid concentrations of 6 to 12 percent have been reported by Naubaur [41]. However, these solid concentrations are too low to be handled by conventional earth-moving equipment or to be landfilled.

Disadvantages of centrifuges include low final solids concentration, high power and maintenance costs, and sensitivity to changes in feed solids content. Advantages are small space requirement and the potential for process automation.

Vacuum Filtration

The rotary drum vacuum filter applies a vacuum to a porous medium to separate solids from sludge. Two basic types of rotary drum vacuum filters are used in water treatment, (1) the traveling medium, and (2) the precoated medium filters. The traveling medium is continuously removed from the drum, allowing it to be washed from both sides without diluting the sludge in the sludge vat. Because of the continuous washing, the filter medium is always clean.

Under good conditions with suitable pretreatment, solids concentrations above 20 percent are possible with travelling belt filters [38]. Young [55] reported that a precoat is required with hydroxide sludges when using vacuum filtration for dewatering. His numerous bench scale tests show that a precoat was required at 2 percent solids content, giving filter loadings of 5.6 gallons per hour per square feet (gph/sq ft) with a precoat of 1 lb for each 10 gallons of sludge. This resulted in cake solids of up to 15 percent.

Gates and McDermott [22] found the specific resistance of alum sludge to be 0.1×10^{10} to 0.44×10^{10} square second per gram (sq sec/gr.) in Buchner funnel tests. Experiments conducted by Glenn et al. [23] on the filterability of water treatment sludge showed that the specific resistance of the sludge decreased with increasing solids concentrations, showing contrast to the Carman's Theory where Carman stated that the specific resistance is independent of solids concentration [8].

Novak and Calkins [44] indicated that vacuum filtration or sand bed draining and evaporation can be expected to produce handleable sludge. Similar results were found by Knocke and Wakeland [37] in their study, utilizing the floc property effect on sludge dewatering characteristics. Based on the experimental and pilot studies, Mahoney and Duensing [40] concluded that rotary precoat vacuum filtration can successfully dewater alum sludge, providing a filtrate virtually free of suspended solids. Precoating vacuum filters with diatomaceous earth can be beneficial when filtering alum sludge [53]. It appears to help provide for successful operation under varying sludge conditions.

Even with the improvements in sludge solids concentrations and suitability for direct disposal, the high cost of procurement, installation and operation of vacuum filters is still a major determining factor in feasibility. Another disadvantage is the inability of the vacuum filters to filter very dilute sludges, such as those obtained from basins having continuous sludge removal facilities.

Pressure Filtration

Filter presses are a relatively new method of sludge dewatering in the United States. At the end of 1976, five plants were using pressure filters for sludge dewatering and four others were planned [3]. Successful pilot and bench scale testing for filter presses has been conducted by many researchers [12,14,20,31,32,41]. In general, the tests show that cake solids concentrations of 35 to 40 percent could be economically obtained and process yields of 0.50 to 0.75 lb/sq ft./hr could be expected. Disadvantages of the pressure filter method include additional sludge storage facilities caused by the batch system, high initial costs, and relatively high maintenance and operation costs. Examples of successful locations include the Erie County Plant and the Shoremont Water Treatment in Rochester, New York [16], and the Moores Bridges Water Treatment Plant in Norfolk, Virginia [14].

2.4 Conclusions

At present, the absence of well defined water treatment plant sludge discharge regulations has jeopardized the implementation of new methods. The water treatment plant residual management problem could be resolved if formal regulations were adopted permitting controlled discharges, where applicable, and requiring all others to adopt new dewatering and disposal methods. Where controlled discharge is not feasible, it appears that similar approaches to those found commonly at the Wastewater facilities would be required. These options include dewatering and landfilling or land application, possibly coupled with some recycling method, while meeting the disposal requirements and standards.

CHAPTER THREE

THEORETICAL CONSIDERATION

Chapter 3

Theoretical Consideration

3.1 Introduction

Aluminum salts have been used extensively by water treatment plants for the clarification of raw water for drinking purposes. These aluminum salts are commonly called coagulants and the process is generally called coagulation. The mechanism of coagulation with aluminum salts as the coagulant agent has been investigated and reported by numerous researchers [7,24,25,26,30]. For the full potential of coagulation to be realized, it is essential that the right coagulant, the correct dosage, and the proper combination of operating conditions be selected for each water treatment plant.

3.2 Structure of Aqueous Aluminum Species

The aluminum ion is relatively small and has a high charge when compared to water molecules. When dissolved in water it can be surrounded by a tightly bound shell of water molecules (Figure 3-1), aluminum-water octahedron. The size of the aluminum ion and the water molecules are such that the aluminum ion will lie in the center of the octahedron and a water molecule is attached at each vertex [24,29].

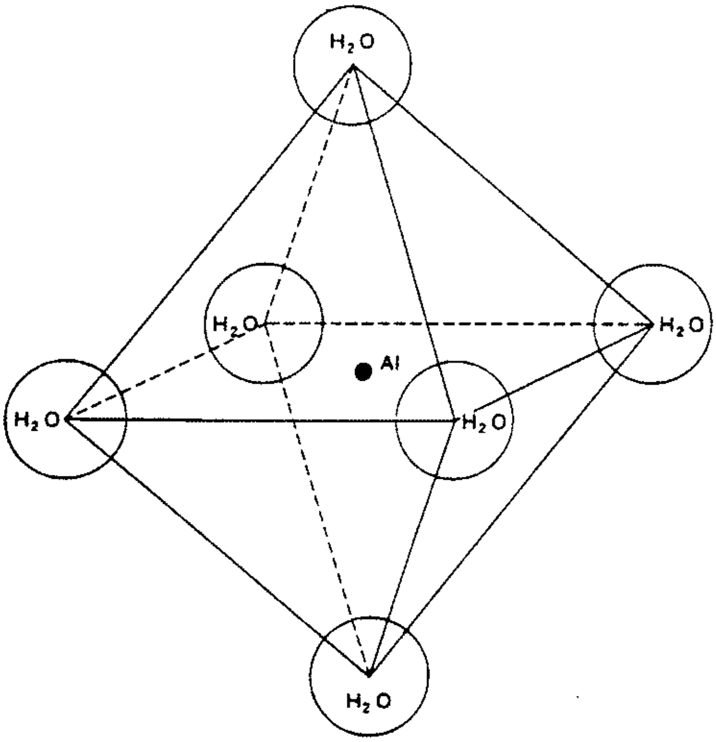


Figure 3-1 Schematic Representation of Hydrolysed Aluminum Ion.

In the presence of polynuclear aluminium species, it is water and organic matter, locked into the floc that is responsible for the jellylike consistency of the hydroxides. It was thought that if a strong oxidizing agent was used prior to dewatering these sludges, not only would it weaken the bond between the aluminum species and water molecules but it would also react with the organic particulate matter, resulting in increased dewatering efficiency.

Literature review indicated that hydrogen peroxide has been used in the waste water industry either as an oxidizing agent or as a source for treating filamentous bulking in activated sludge [10,33,50].

Preliminary investigations showed that dilute solutions of hydrogen peroxide when reacted with $Al(OH)_3$ appeared to liberate oxygen and water.

e.g. $2\ Al(OH)_3 + H_2O_2 \dashrightarrow Al_2O_3 \cdot H_2O + 3\ H_2O + 1/2\ O_2$

Based on the preliminary findings it was decided to investigate the possibility of hydrogen peroxide as an aid in dewatering of these sludges.

3.3 Hydrogen Peroxide

Hydrogen peroxide was discovered by Thenard (1818), who prepared it from barium peroxide and nitric acid. He first interpreted his results as a formation of an "Oxygenated Nitric Acid", but soon realized that the new compound was 'oxidized water' [17]. In 1821, Thenard established the correct composition of hydrogen peroxide by the gasometric determination of the oxygen evolved from what must have been nearly 100 percent hydrogen peroxide.

Hydrogen peroxide is a colorless liquid miscible with water and glycerine in all proportions. The boiling point of pure hydrogen peroxide is 155.5 °C. Other properties of hydrogen peroxide are given in table 3-1.

Highly purified aqueous solutions of hydrogen peroxide are fairly stable. In the presence of impurities, such as metal ions, hydrogen peroxide is decomposed into water and nascent oxygen.

The reagent decomposes on standing, especially in a warm place or in warm weather. For this reason it should be purchased in small lots. After the container has been opened, it should be tightly closed and the strength of the solution should be ascertained periodically.

The greatest use of hydrogen peroxide is as a bleaching agent. The bleaching effect of hydrogen peroxide is due to its decomposition to water and nascent oxygen in the presence of hydroxyl ions and the oxidizing properties of the nascent oxygen obtained.

Property	H_2O_2	H_2O
Molecular Weight	34.016	18.016
Density of solid, fp, g/cm^3	1.71	0.917
Density of liquid, 20 °C, g/cm^3	1.450	0.998
Viscosity of liquid, 20 °C, centipoises	1.245	1.002
Surface tension, 20 °C, dyn cm^{-1}	80.4	72.75
Heat of sublimation, fp, kcal $mole^{-1}$	15.58	12.17
Melting point, °C	-0.43	0
Heat of fusion, mp., Kcal $mole^{-1}$	2.987	1.436
Boiling point, °C	150.2	100.0
Heat of vaporization, kcal $mole^{-1}$	12.33	10.51
Critical temperature, °C	457	374.2
Critical pressure, atm	214	218.2
Heat capacity of solid, fp, cal $gram^{-1}$ °C	0.39	0.50
Heat capacity of liquid, cal $gram^{-1}$ °C	0.628	0.998
Heat capacity of vapor, cal $mole^{-1}$ °C	10.22	8.025
Heat of formation in vapor, kcal $mole^{-1}$	-32.53	-57.80
Free energy of formation in vapor, kcal $mole^{-1}$	-25.20	-54.64
Dielectric constant, 20 °C	73.1	80.4
Magnetic susceptibility, 10^6 cgs emu/g	-0.50	-0.720
Refraction index	1.4067	1.3325
Specific conductivity, 10^{-7} ohm^{-1} cm^{-1}	3.9	

Table 3-1: Physical Properties of Hydrogen Peroxide and Water [28, 29]

CHAPTER FOUR

EXPERIMENTAL PROCEDURES

CHAPTER 4

EXPERIMENTAL PROCEDURES

4.1 Sludge Source Description

Water treatment plant sludges generated at four major treatment plants in the Hampton Roads area of Southeastern Virginia were examined. Plant selection was based on their capacity to generate alum sludge and their accessibility. Sludge sources were:

A. Moores Bridges Water Treatment Plant Norfolk, VA
Norfolk (Basin 8 & 9) (date sample taken: 07/01/88)

B. Moores Bridges Water Treatment Plant Norfolk, VA
Norfolk (Basin 2 & 3) (date sample taken: 08/05/88)

C. Lee Hall Water Treatment Plant Newport News, VA
(date sample taken: 10/04/88)

D. Portsmouth Water Treatment Plant Portsmouth, VA
(date sample taken: 09/05/88)

E. Chesapeake Water Treatment Plant Chesapeake, VA
(date sample taken: 10/28/88)

4.2 Sludge Sample Collection and Handling

Alum sludge samples from Moores Bridges, Chesapeake, and Portsmouth Water Treatment Plants were collected by pumping sludge from the bottom of the sedimentation basin. Sludge samples from Lee Hall Water Treatment Plant were collected at the sludge discharge point. All sludge samples were transported to the environmental engineering laboratory located at Old Dominion University, in 5 gallon plastic containers. At the laboratory all sludge samples were stored at 6°C to minimize changes in sludge properties from biological activity during the experimentation period. All samples were immediately tested for solids determination, p^H and CST (Capillary Suction Time).

4.3 Preliminary Investigations

Preliminary investigations were carried out on the Moores Bridges Water Treatment Plant (Basin 8 & 9) sludge to determine the optimum carrier water addition for an adequate reaction between varying hydrogen peroxide (H_2O_2) concentrations and the raw sludge. For each four concentrations of hydrogen peroxide (H_2O_2) chosen (0, 2.5, 7.5, and 15 mg/l), the carrier water addition was varied from 0, 5, 10, 20 and 30 percent. Preliminary tests were conducted by using sandbed drainage, vacuum filtration, and pressure filtration tests (filter press). Based on the preliminary findings, successful results on the sludge samples from the different plants could be obtained using a 5 percent carrier water addition.

4.4 Sample Preparation

Sludge samples were transferred from the storage containers to 2 liter coagulation jars and allowed to reach room temperature prior to the experiment. Mixing for chemical addition was performed using a digital Phipps and Bird, Model 7790-400, (Richmond,VA) six place jar test apparatus. This test procedure consisted of an initial five to ten second rapid mixing period (300 rpm), following the addition of the desired water and hydrogen peroxide dosage. Then, the samples were mixed slowly (50 rpm) for one minute to develop an adequate reaction time between the sludge and the Hydrogen Peroxide. Before further testing, the samples were allowed to stand for 20 minutes.

4.5 Testing Procedures and Equipment

4.5.1 Solids Determination

Each sludge sample (raw) was tested for its total and volatile solids content. Because it was impossible to pipet an exact amount of raw sludge, total solids were determined on a weight basis. Sludge samples were poured into previously tared porcelain dishes and then the procedure for total and volatile residue, as outlined in the Standard Methods (1979) [47], was followed. In order to provide reliable results for volatile solids, the porcelain dishes were previously ignited to a constant weight and stored in a desiccator prior to use. Cake solids contents were determined only on a total solids basis. This was assumed to provide good representation of the suspended solids content after the dewatering.

4.5.2 P^H Measurement

The p^H of all the filtrates generated in the dewatering tests was measured using an Orion p^H Meter, Model 811. Measurements of p^H for all the raw sludges were carried out before any dosage of H_2O_2 and carrier water addition.

4.5.3 Capillary Suction Time (CST)

The Capillary Suction Time (CST) device consists of two teflon blocks, a teflon collar, a piece of filter paper, four electrical contacts that are fixed in the upper plastic block, and a digital timer. This equipment and timer were built in the machine shop and environmental engineering laboratory at Old Dominion University (figure 4-1).

The equipment was assembled with a filter paper placed between the two teflon blocks and the collar placed in the opening of the upper teflon block. To eliminate moisture in the filter paper before assembly, the paper was oven dried and placed in a desiccator. The test was started by pouring a measured amount of sludge into the collar. Water from the sludge sample flowed through the filter paper, forming a circular wet blot in the filter paper. After the liquid interface moved about 0.5 cm past the collar edge, it reached the first pair of contacts causing an electrical signal (logic low) to start the timer. After the front moved another 1 cm, it reached a second pair of contacts, sending another electrical signal (logic high) to stop the timer. The capillary suction time was then read directly from the timer and reported in seconds. A 50 ml sample size was used in this test.

4.5.4 Sandbed Drainage Test

To evaluate sludge dewatering on a sandbed, a drainage test apparatus as shown in figure 4-2 was used. Each drainage

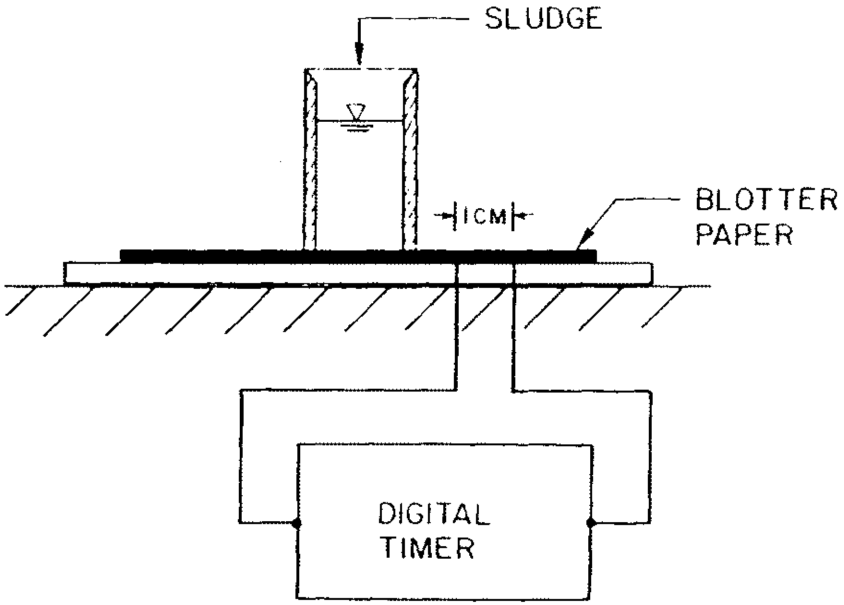


Figure 4-1 Schematic of Capillary Suction Time Apparatus.

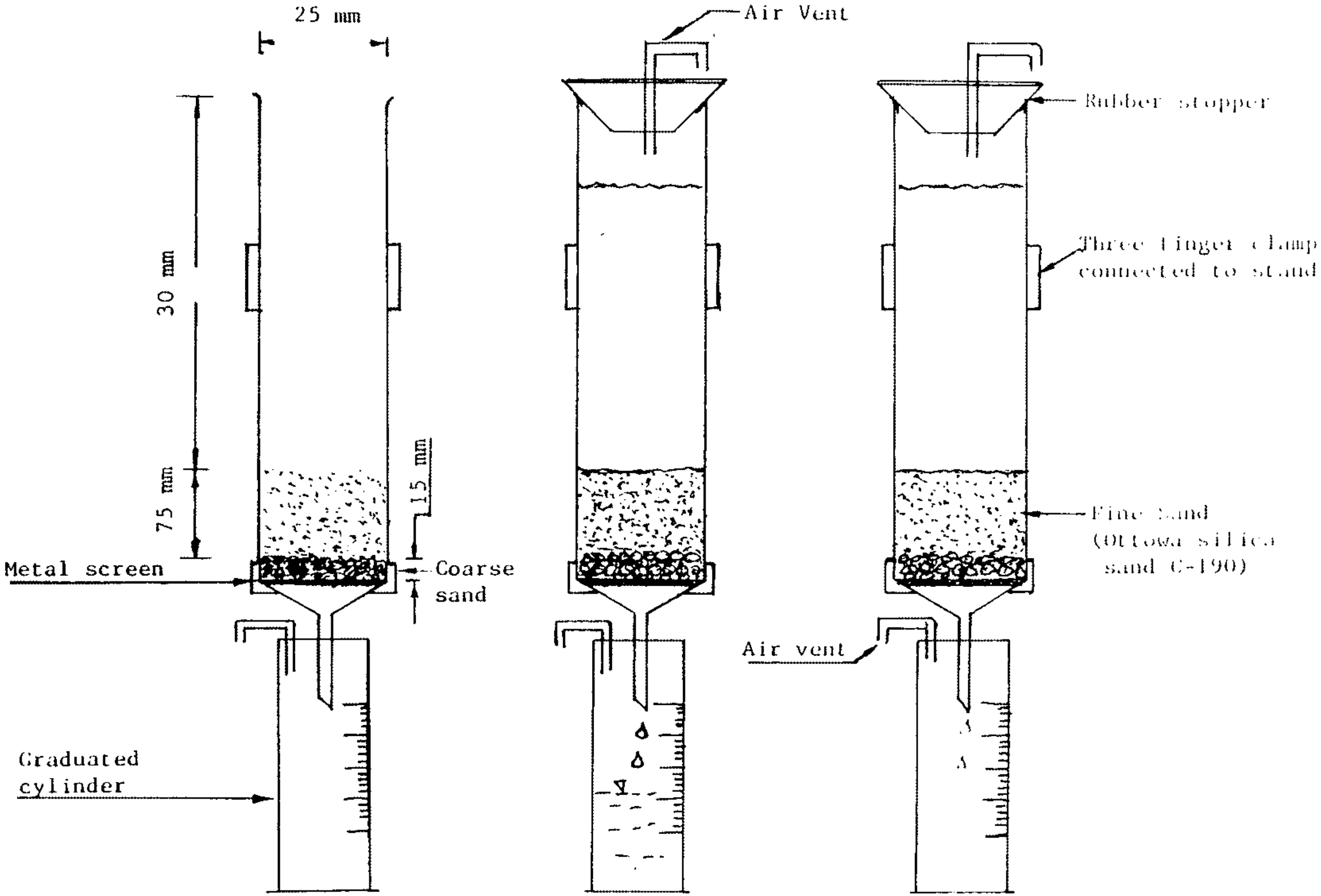


Figure 4-2 Schematic of Sand Bed Drainage Test.

cylinder was 25 mm in diameter and contained 15 mm of coarse sand (grain size 3 mm), resting on a fine metal mesh. Seventy five mm of fine sand (ottowa silica sand C-190) was placed on the coarse sand to serve as the filter medium.

Before each sandbed drainage test was performed, the sand was saturated with distilled water and allowed to drain. This drained distilled water was collected in a plastic bottle for further analysis to be used as a blank for metal analysis in the filtrate. When the drainage was complete, a relatively small amount of water remained in the sand due to the combined effects of wetting and surface tension of the water. A 100 ml sludge sample was then poured into the sand bed cylinder. The filtrate was collected in a 100 ml graduated cylinder. The filtrate collected was measured as a function of time for a 100 hour period at four hour intervals. To minimize losses due to evaporation, the sandbed column and the 100 ml graduated cylinder were plugged by rubber stoppers. The rubber stoppers contained inverted U tubes as air vents providing the necessary arrangements for gravity drainage.

In this test, cake solids concentration was calculated by multiplying the initial solids concentration of the individual sludge samples to the ratio of initial to final sludge height (after dewatering), in the sand bed column.

4.5.5 Buchner Funnel Test (Vacuum Filtration)

The standard Buchner Funnel test measures vacuum filtration rates of a sludge sample. A millipore filtration

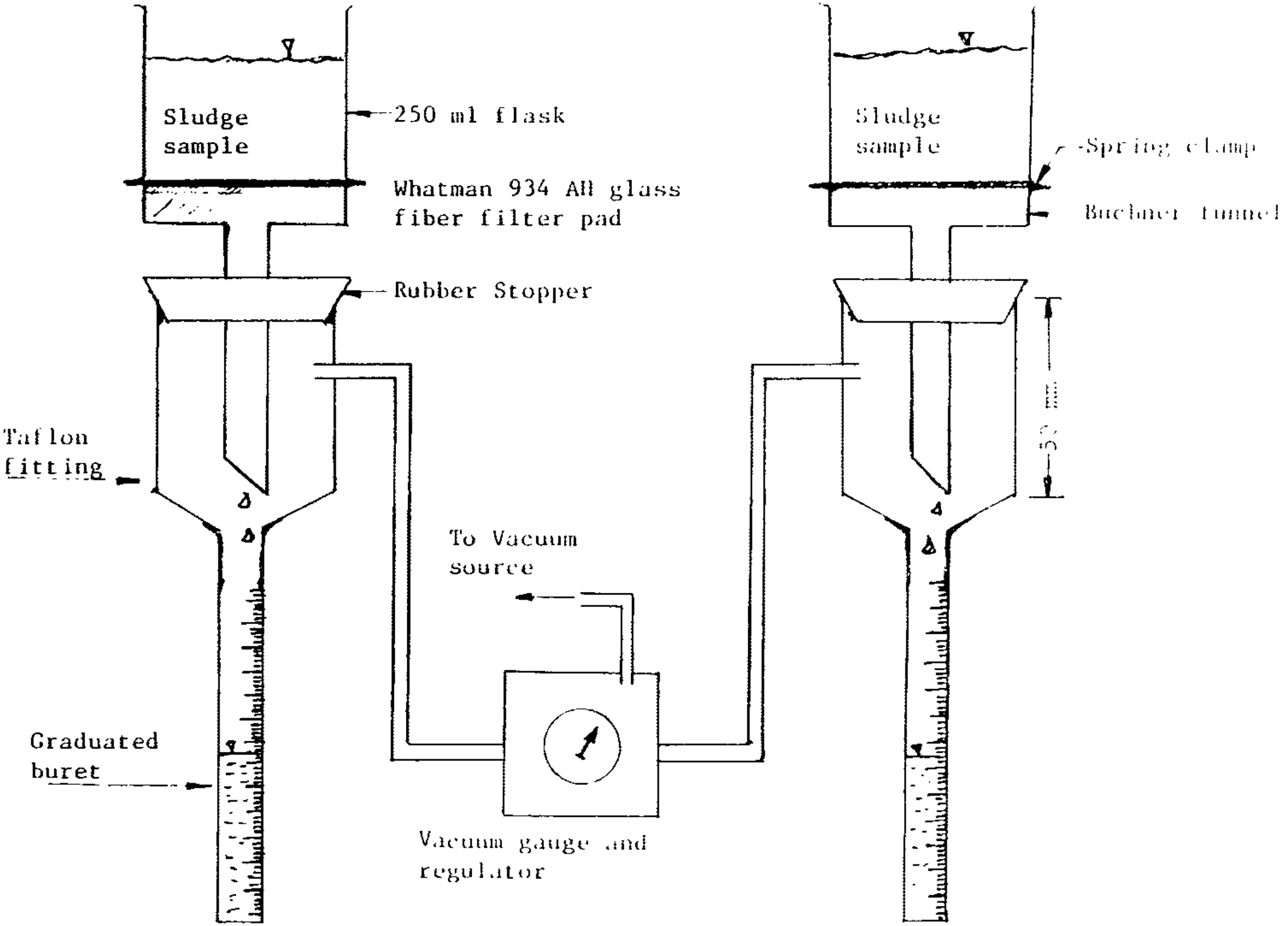


Figure 4-3 Schematic of Buchner Funnel Test.

unit was used for this test. The apparatus was modified to provide an accurate measurement of filtrate. A 100 ml graduated buret was coupled to the funnel by means of an adaptor. The adaptor was sealed to the buret. A typical experimental setup is shown in figure 4-3. A 4.25 cm diameter Whatman 934 AH glass fiber filter pad was placed on the top of the funnel. Without disturbing the filter pad, the flange of the holder flask was centered on the top of the funnel. Then, the whole assembly was clamped together with a spring clamp and fitted into the adaptor with the help of a neoprene stopper which was provided with the millipore filtration unit. Approximately 100 ml of distilled water was poured into the flask and the vacuum applied. The applied vacuum pulled the water through the filtering medium, which effectively sealed the filter pad to the funnel top. Excess distilled water, which passed through the filter pad to the buret, was collected and stored in small plastic bottles. This water was used as a blank in the metal analysis.

After the filter pad was sealed, 20 ml of the sludge sample was slowly poured into the flask to minimize the turbulence. Approximately, thirty seconds was allowed as a soaking period for the filter pad to minimize the resistance given by the filtering medium. Vacuum was applied after this soaking period. Timing was initiated as soon as the desired vacuum was reached. Reading and recording of the filtrate volume was performed at one minute intervals for the duration of the test. Test duration depended on the filtration rate and varied for different sludge samples with different hydrogen peroxide dosages.

Filtration was continued until the cake started cracking, breaking the vacuum pressure. The cake solids concentration was determined on a weight basis by carefully removing the filter pad from the funnel assembly, and following the procedure as described in the Section 4.5.1, "Solids Determination".

By measuring the volume of filtrate collected as a function of time and using a logarithmic plot of filtration time and filtrate volume, the sludge specific resistance (r) was calculated using equation (10) as outlined in Appendix B. Vacuum levels used in this study were 10, 15 and 20 inches of Hg.

4.5.6 Filter Press Test (Pressure Filtration)

The filter press apparatus used in this study is shown in figure 4-4. The filter press components included a 4.7 cm diameter stainless steel filter holder, a porous metal support, and a 200 ml reservoir. To complete the assembly a piston, manufactured in the machine shop at Old Dominion University, and a regulator were added. Compressed air, as a source of pressure, and a 5.0 cm diameter Whatman 934 AH glass fiber filter pad were used in this test.

A 20 ml sludge sample was placed in the filter holder. The filter holder was then fixed to the 200 ml reservoir with

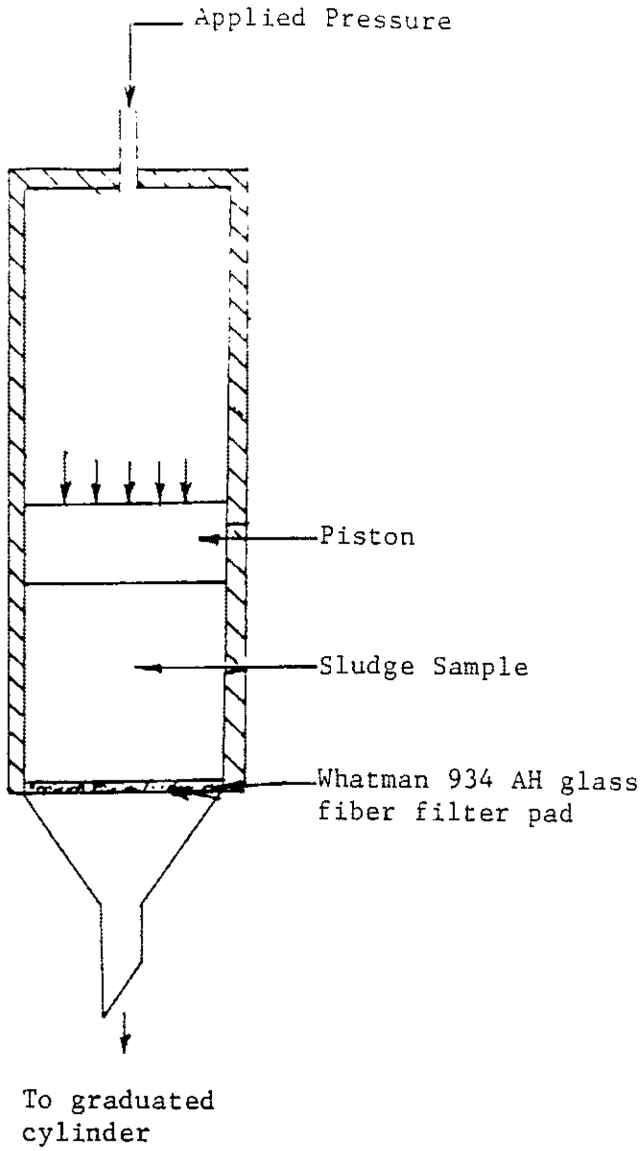


Figure 4-4 Schematic of Pressure Filtration Test.

the piston inside it. The sample size was chosen in order to produce a filter surface loading rate similar to that used for the vacuum filtration and sandbed drainage tests. A pressure differential was applied across the sludge sample using compressed air.

All filter press dewatering tests were controlled at pressure levels of 40, 60 and 80 psi. The filtrate was collected into a graduated cylinder and recorded as a function of time.

Before each filter press test was performed, the unit was rinsed with distilled water. This washing was collected in plastic bottles to be used as a blank in the metal analysis of the filtrate.

To determine filter cake solids concentration the test was continued until a slight loss in the applied pressure occurred. After the completion of the test the filter pad was carefully removed from the filtering assembly, and placed in a preweighed aluminum pan, and the total solids on a weight basis was calculated as outlined previously (Section 4.5.1).

4.5.7 Centrifuge Test

Cake solids determinations were carried out using a high speed Damon\IEC HT centrifuge. A 40 ml sludge sample was poured into 50 ml round bottom centrifuge test tubes. Runs were made at centrifuge speeds of 1000, 3000 and 5000 rpm and from one to three minutes residence time. The run duration was measured from the time at which the centrifuge reached the desired rpm. Based on the dimensions of the centrifuge head and rotational speed, the centrifugal accelerations values were calculated. Following centrifugation, the centrate volume was measured by pouring it into a graduated cylinder. The difference in the initial poured volume and the final volume is the cake volume. The compacted solids were carefully scraped from the tube and placed in a preweighed aluminum pan and the total solids concentration as a percentage of initial weight was calculated as described in "solid determinations" (Section 4.5.1).

4.5.8 Alkalinity Determination

Alkalinity was determined for all the filtrates generated in the different dewatering tests and raw sludge samples. The procedure described in the Standard Methods (1979) [49], was followed.

4.5.9 Turbidity (NTU)

Using a Hach 2100 A Turbidimeter, the turbidity of the filtrates were determined using the procedures described in the Standard Methods (1979) [49]. The turbidity was reported as Nephelometric Turbidity Units (NTU).

4.5.10 Viscosity Measurements

Following each dewatering test, filtrate viscosities were measured with the Brookfield LVTDV-II model and a UL adaptor assembly. The LVTDV-II model is designed to give a digital reading of the viscosity measurement, which is reported in centipoise units. With the UL adaptor attached to the viscometer, it was possible to record the viscosity of the filtrate, in the 1 centipoise range.

To determine the Thixotropic behaviour of the raw sludge samples, a viscosity measurement was taken using two cylindrical spindles, #1 and #4, provided with the Brookfield LVTDV-II model.

4.5.11 Metal Analysis

Metal analysis was performed using a flame atomic absorption spectroscopy (Perkin-Elmer, Model HG 603) to determine the concentrations of aluminum, iron and manganese both in the raw sludges and in the filtrates from various dewatering tests. Standards were prepared using Fisher Scientific AAS Standard Solution. A Seventy-five fold dilution factor was used in diluting the samples. The procedure was followed as outlined in the Standards Methods [1975] [50], Section 301 A pp. 144.

4.5.12 Strength of Hydrogen Peroxide

Hydrogen Peroxide decomposes on standing, especially in a warm place or warm weather. For this reason the strength of hydrogen peroxide was checked during the experimentation period. A weighted sample of the H_2O_2 solution was acidified and titrated with a standard potassium permanganate solution until the first permanent pink color persisted for 30 seconds or longer [51].

CHAPTER FIVE

EXPERIMENTAL RESULTS

Chapter 5

Experimental Results

5.1 Sludge characteristics

The characteristics of sludges produced in water treatment plants can vary greatly, due to the tremendous differences in the raw water source, its design, and operation. In order to distinguish between individual sludge samples prior to any testing, it is necessary to measure its characteristics.

Table 5-1 lists the raw sludge characteristics for each sludge sample. Graph 5-1 shows the variation of p^H and alkalinity with respect to initial solids concentration (Co) for all sludge samples.

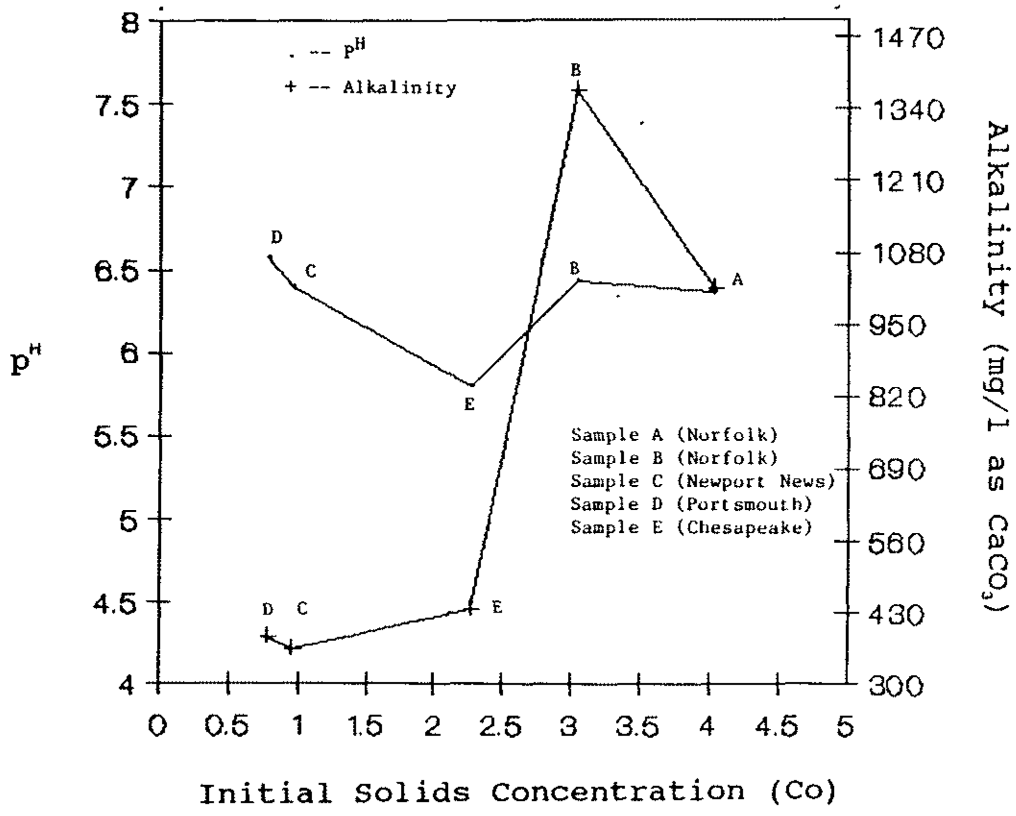
Capillary Suction Time (CST)

To provide a rapid measurement of the drainability of each sludge samples, capillary suction time test was performed. Capillary Suction Time (CST) was measured prior to and after the addition of the desired H_2O_2 dose with each sludge [Table 5-2].

The variation of CST with respect to the initial solids concentration (Co) for the individual sludge samples is shown in Graph 5-2. Graph 5-3 and 5-4 represent the variation of

Sludge Sample	Initial Solid Concentration (C_o) (percent)	pH	Alkalinity mg/L as $CaCO_3$	Volative Solids Concentration Percent Total
A Norfolk	3.04	6.43	1375	54.92
B Norfolk	4.03	6.36	1015	38.92
C Newport News	0.95	6.39	364.4	38.82
D Portsmouth	0.78	6.57	386.66	29.4
E Chesapeake	2.26	5.80	438.0	40.38

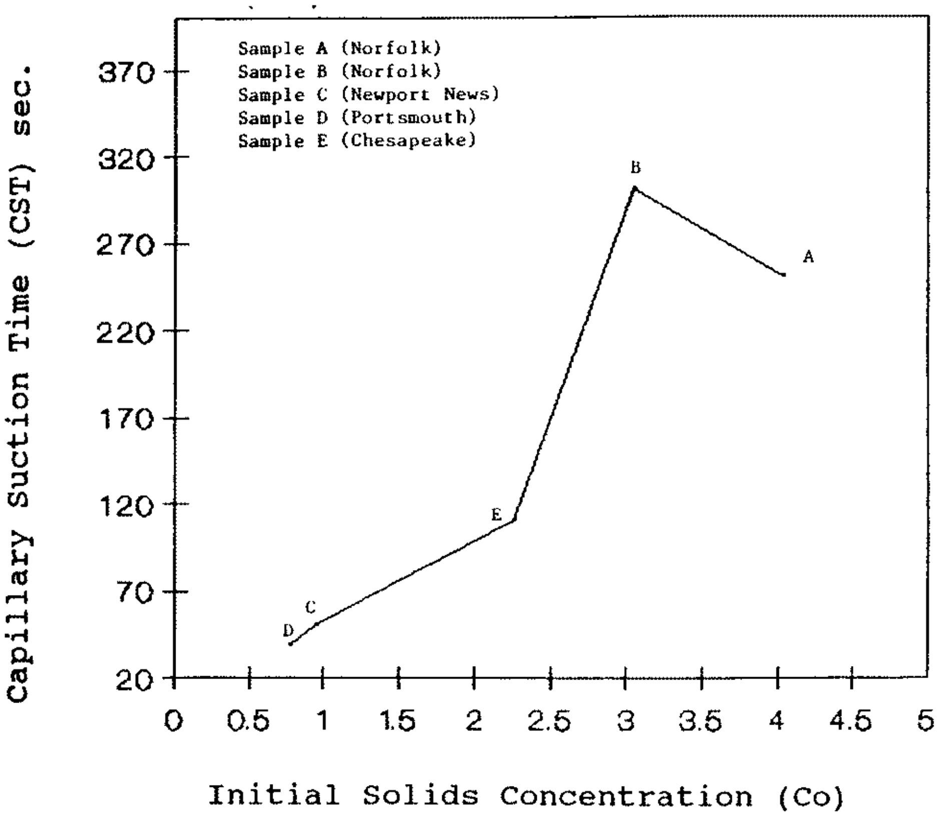
Table 5-1: Sludge Characteristics



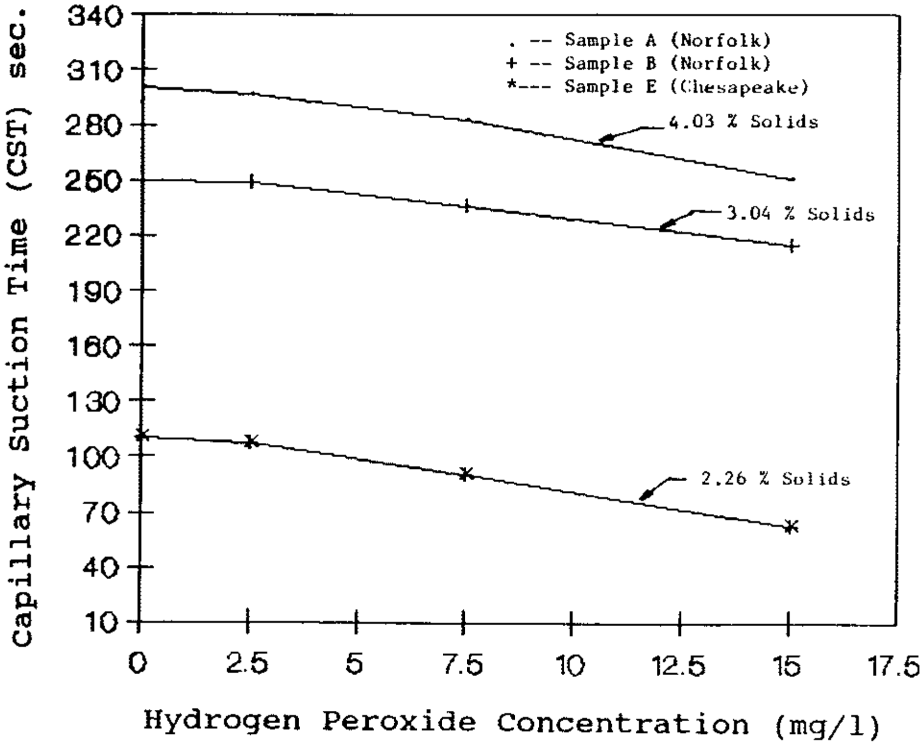
Graph 5-1 Variation of Alkalinity and p^H with Initial Solids Concentration (Co).

Sample	Initial CST (sec) Prior To Testing	CST (sec) After H_2O_2 and 5% carrier water Addition H_2O_2 mg/L			
		0	2.5	7.5	15
A Norfolk	300.8	300.5	296.0	282.70	250.25
B Norfolk	250.30	250.10	248.30	235.28	215.34
C Newport News	50.10	50.0	40.00	30.60	20.70
D Portsmouth	38.80	38.60	38.00	30.20	20.50
E Chesapeake	110.20	110.0	107.0	90.10	62.40

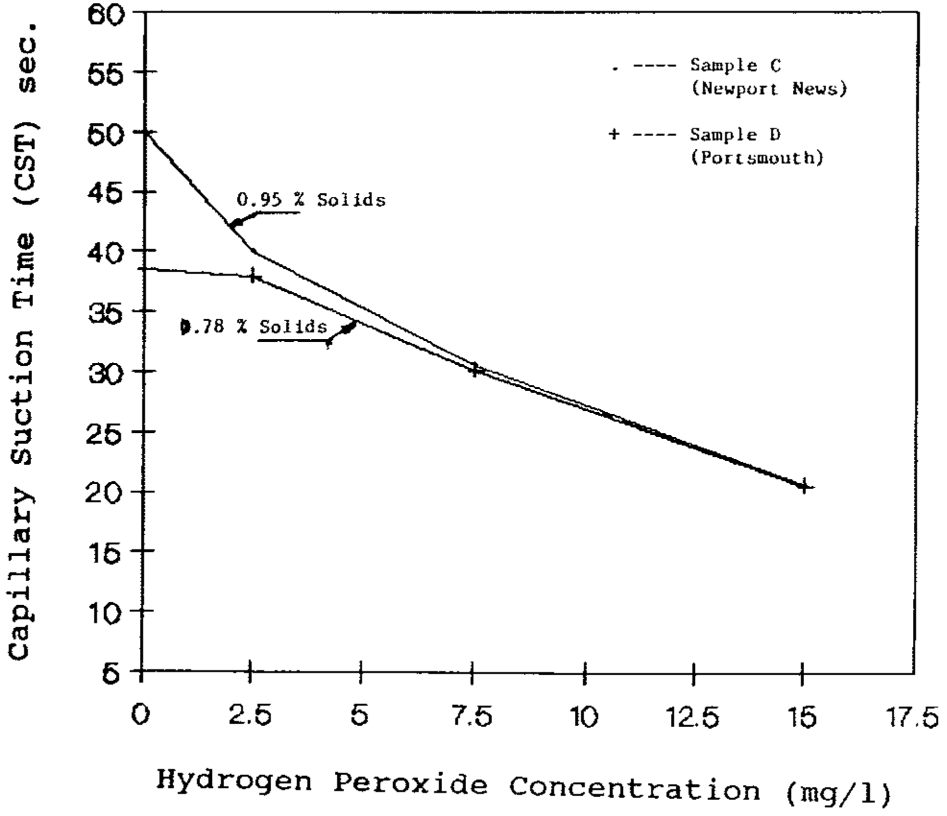
Table 5-2: Capillary Suction Times (CST) for Sludge Samples Before and After Hydrogen Peroxide Addition.



Graph 5-2 Capillary Suction Time as a Function of Initial Solids Concentration (Co).



Graph 5-3 Variation of Capillary Suction Time with Hydrogen Peroxide Concentration (Samples A,B, and E).



Graph 5-4 Variation of Capillary Suction Time with Hydrogen Peroxide Concentration (Samples C and D).

CST with respect to the addition of different hydrogen peroxide concentrations.

5.2 Sludge Dewatering Processes

Sand Bed Drainage:

Graphs 5-5 through 5-9 show the variation in percent drainage for each sample over a 100 hour drainage time and various H_2O_2 concentrations. The cake solids concentration (Ck), obtained in this dewatering test for individual samples, is tabulated in Appendix A.

Buchner Funnel Test (Vacuum Filtration)

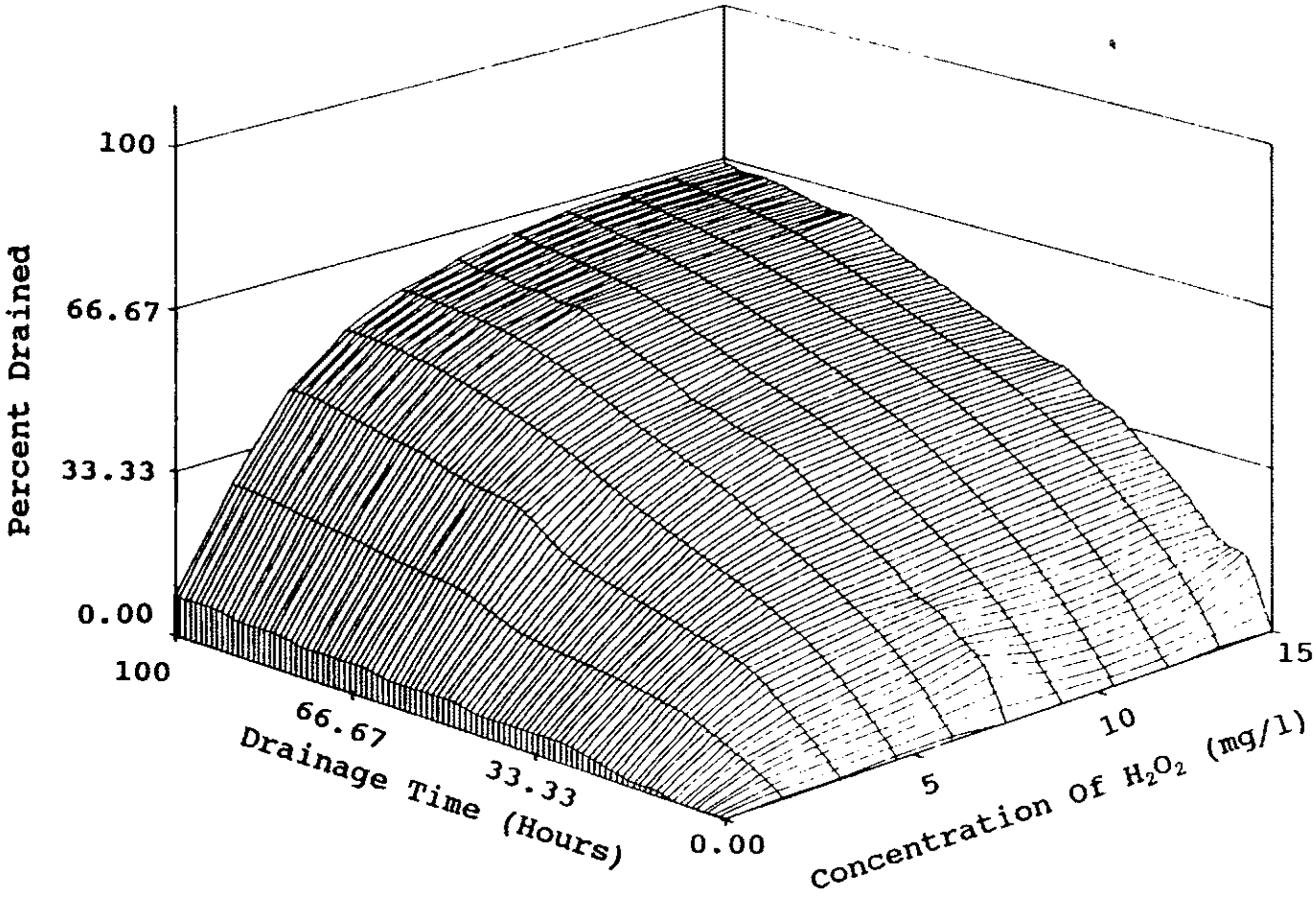
Graphs 5-10 through 5-14 represent the variation in Ck for the five sludge samples with respect to applied vacuum pressure and hydrogen peroxide dosages.

The specific resistance (r) to dewatering and the blinding coefficient (β) was calculated for each sample from the data obtained in the Buchner funnel test. A sample calculation is shown in the Appendix B.

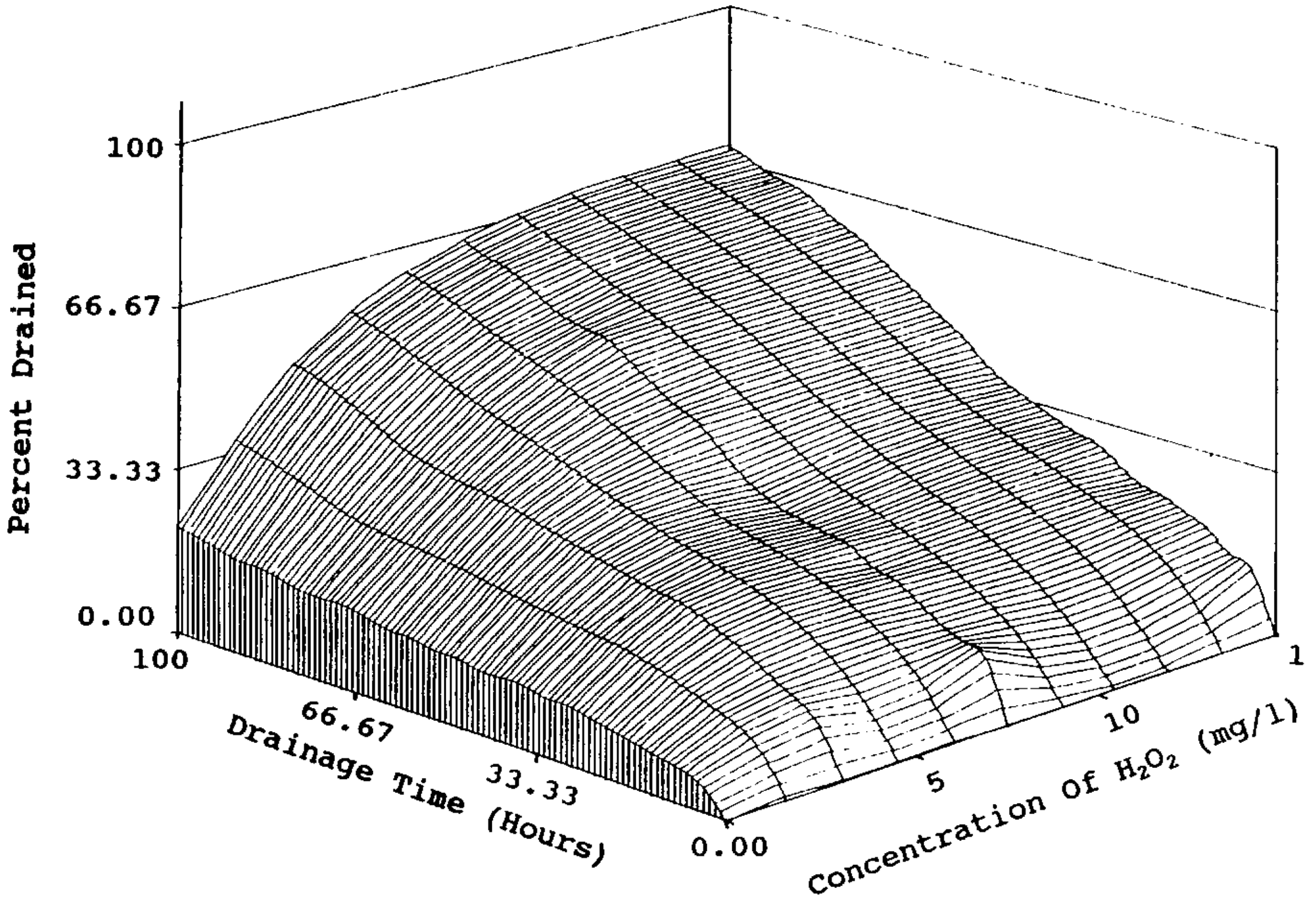
Graphs 5-15 through 5-19 illustrate the relationship between specific resistance (r), applied vacuum pressure and varying hydrogen peroxide concentrations for each sludge sample. Appendix B-I lists the specific resistance and the blinding coefficient values for each sample with four H_2O_2 dosages and the applied vacuum pressure.

Filter Press Test (Pressure Filtration)

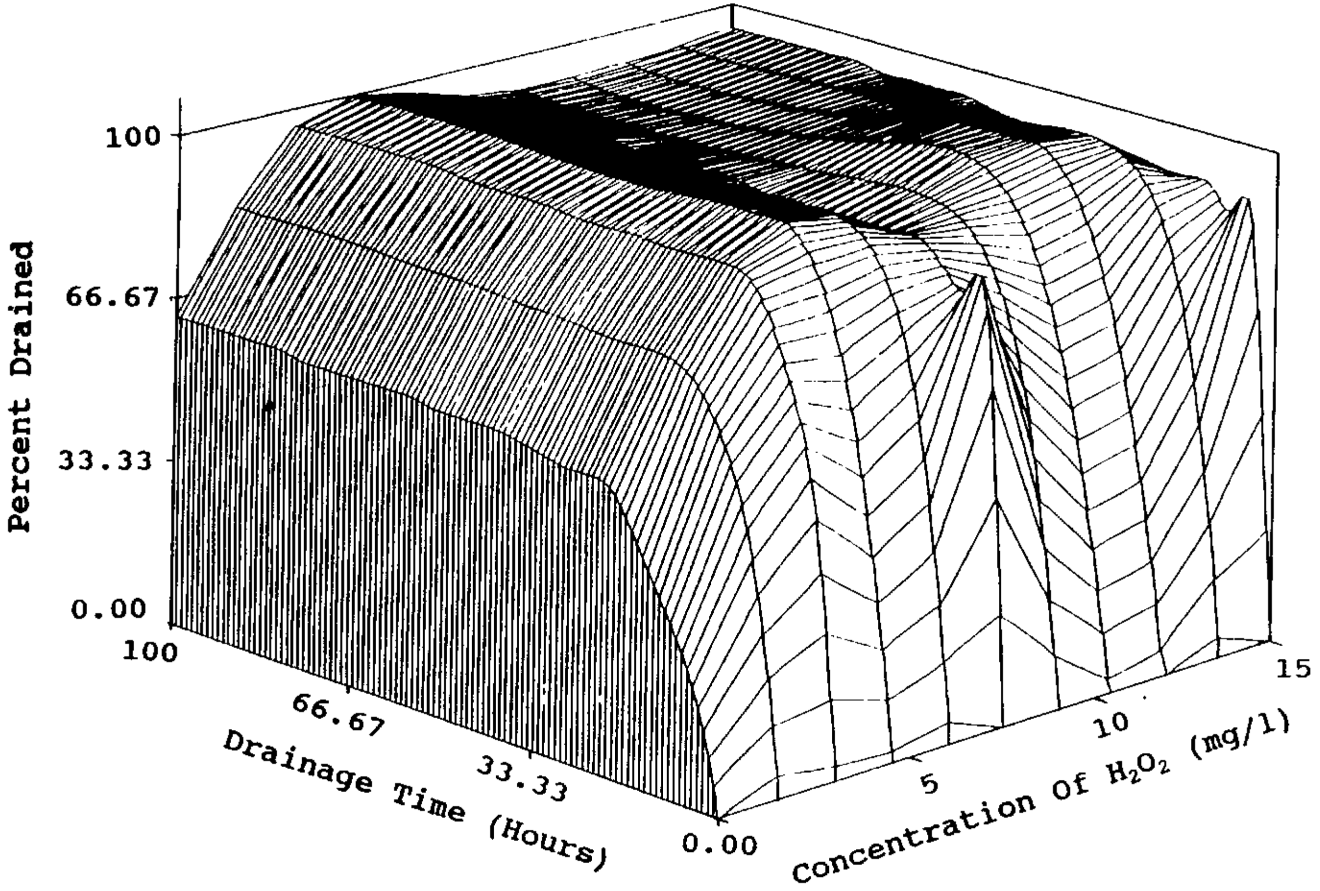
For each sample, a relationship between the cake solids concentration (Ck) obtained during this test, and applied



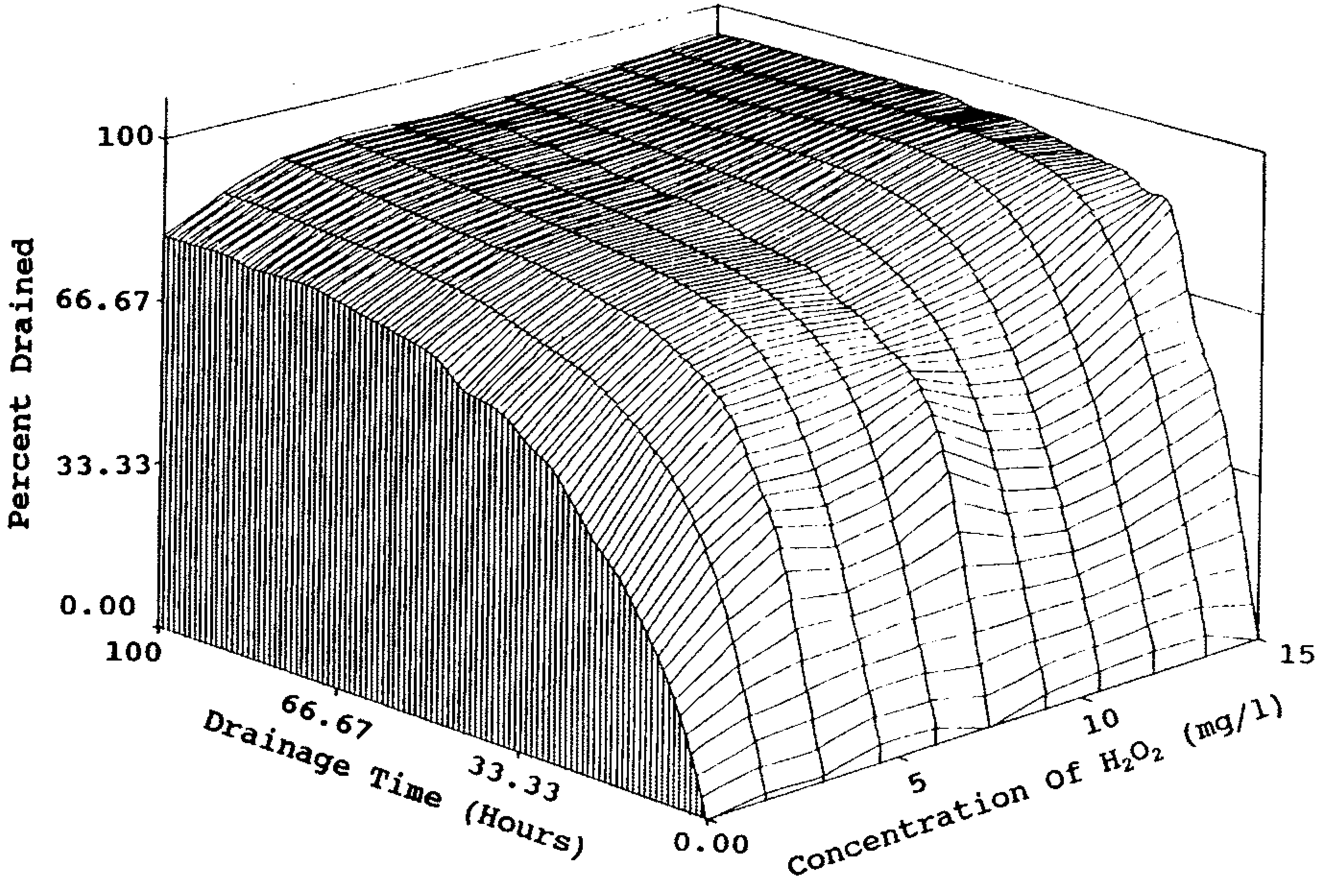
Graph 5-5 Variation of Percent Drainage with Hydrogen Peroxide Concentration and Drainage time: Sample A (Norfolk).



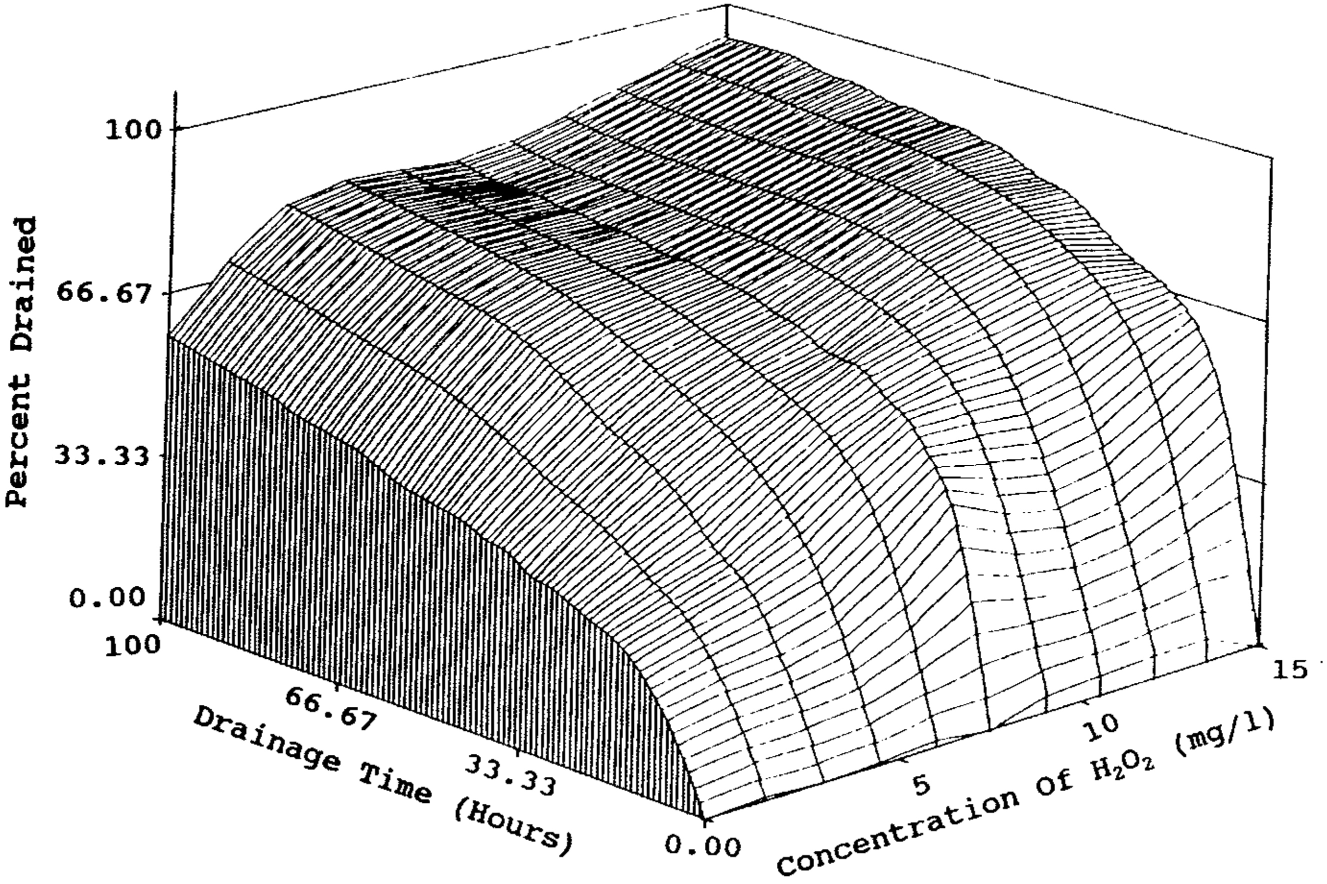
Graph 5-6 Variation of Percent Drainage with Hydrogen Peroxide Concentration and Drainage time: Sample B (Norfolk).



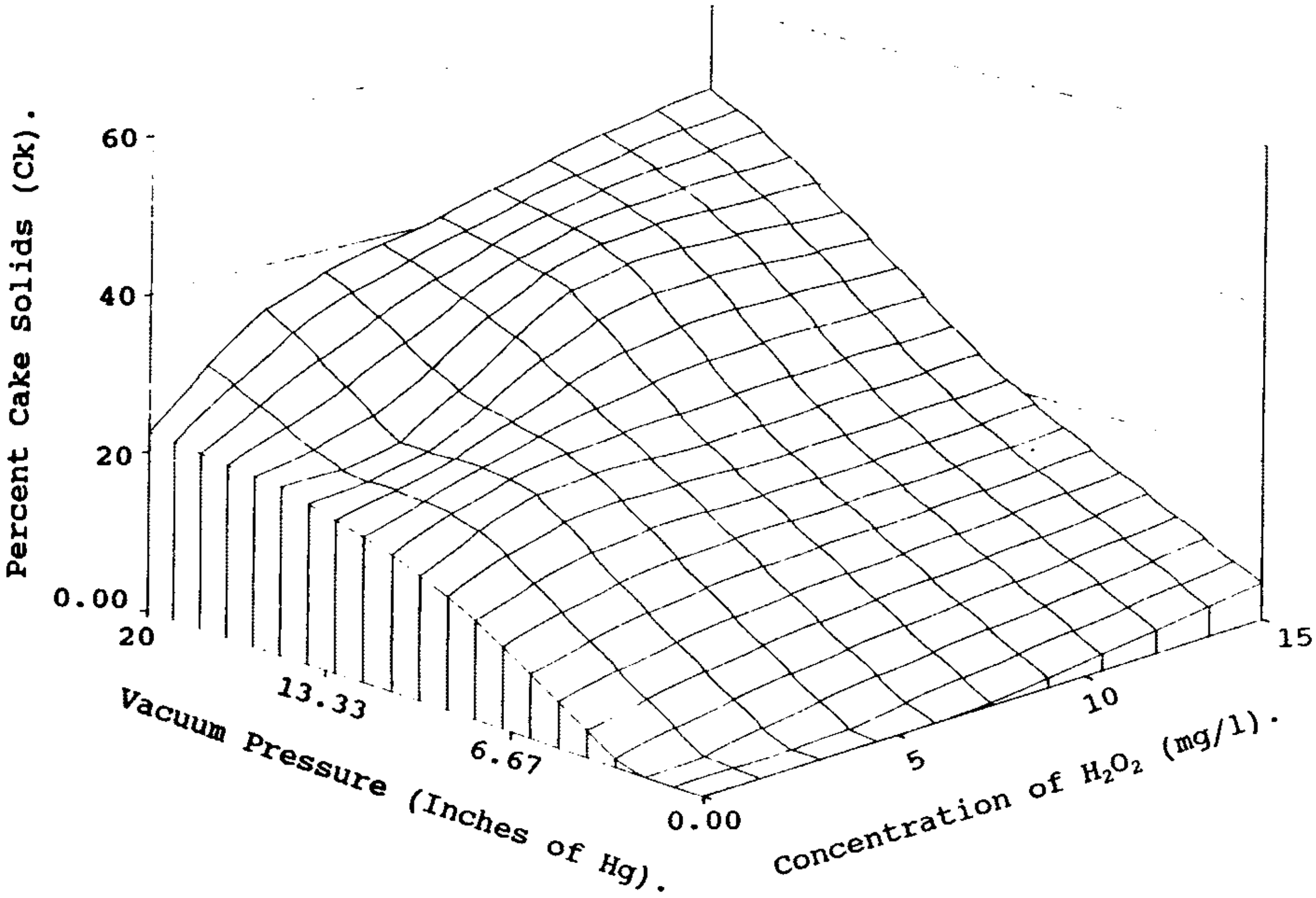
Graph 5-7 Variation of Percent Drainage with Hydrogen Peroxide Concentration and Drainage time: Sample C (Newport News).



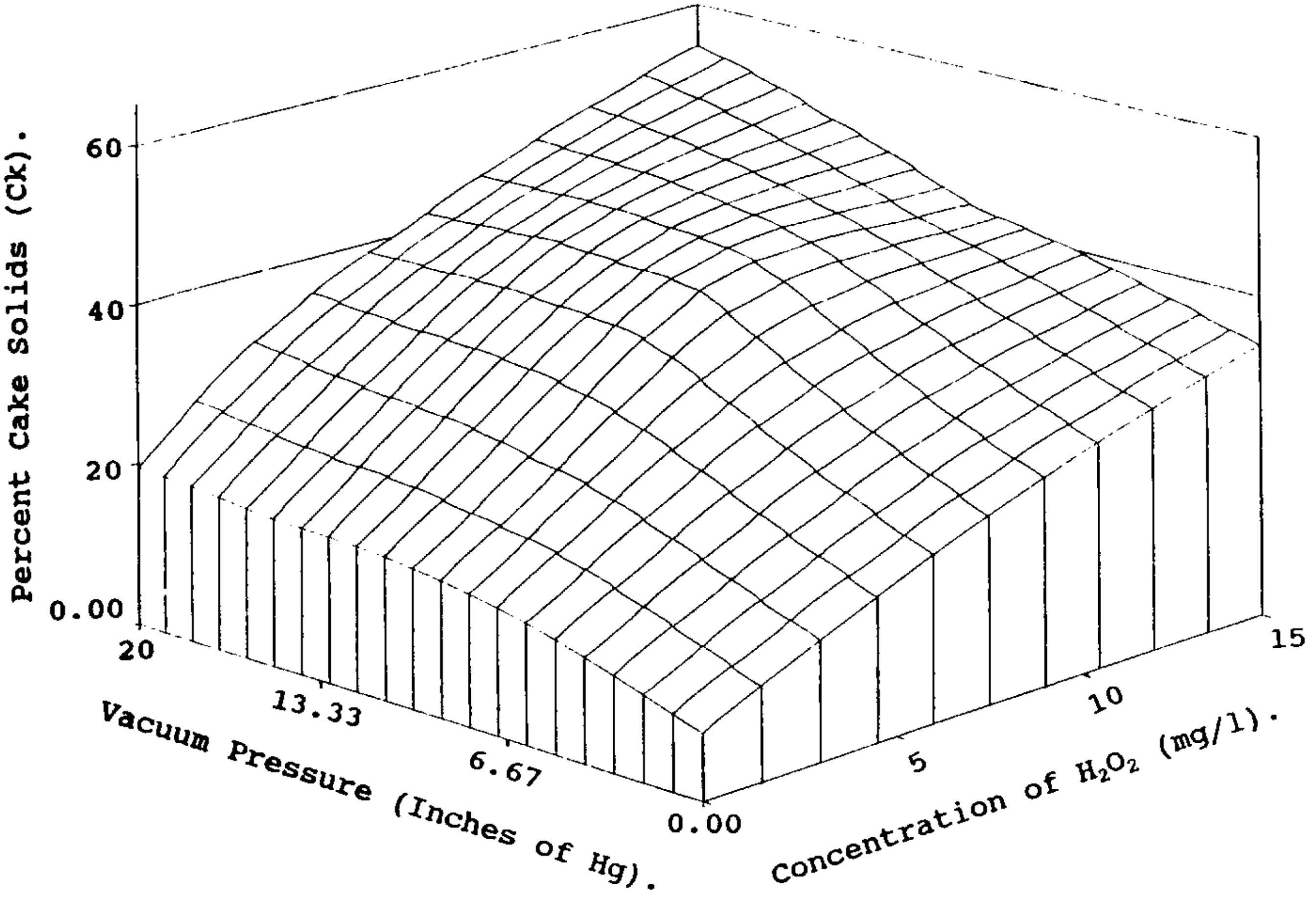
Graph 5-8 Variation of Percent Drainage with Hydrogen Peroxide Concentration and Drainage time: Sample D (Portsmouth).



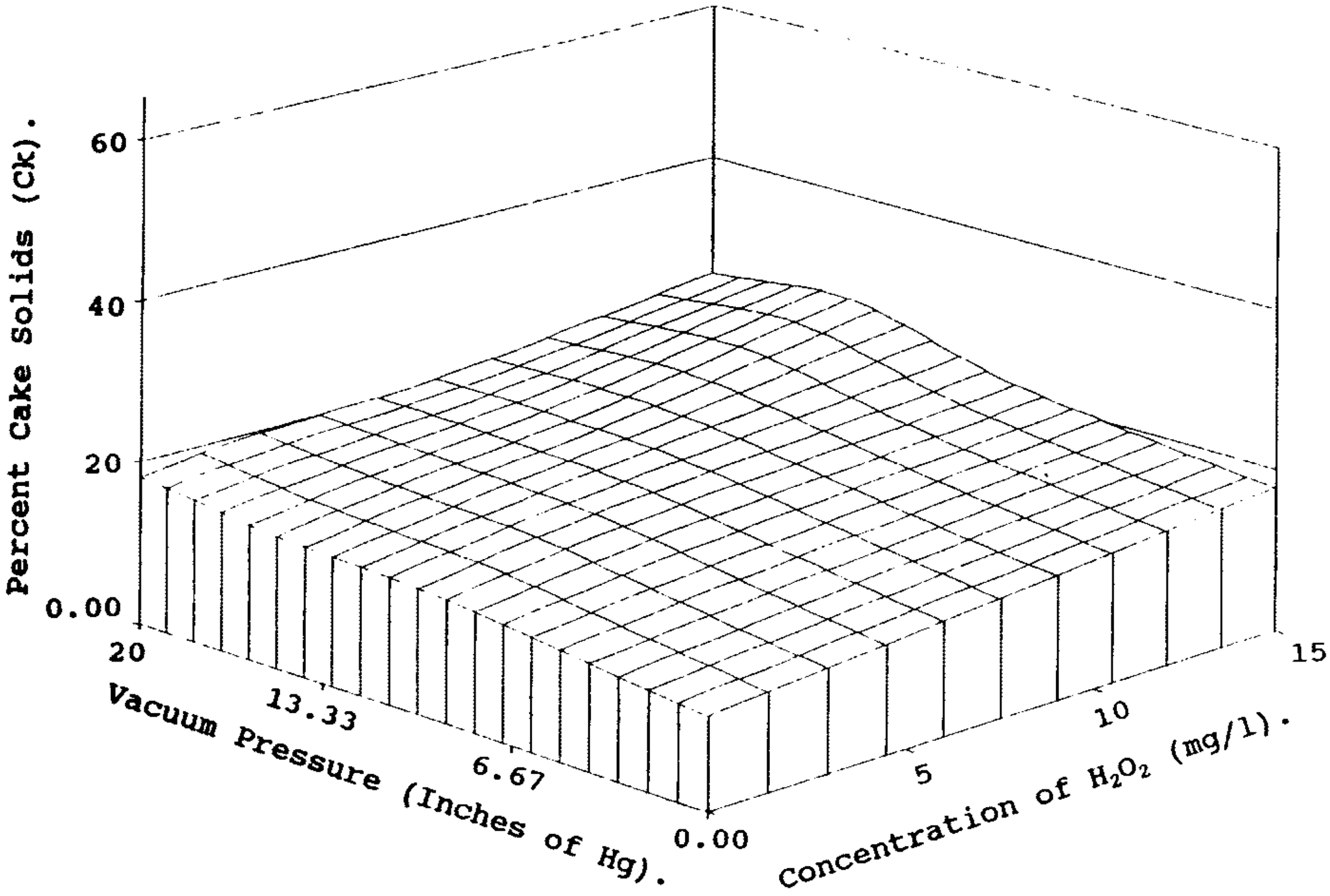
Graph 5-9 Variation of Percent Drainage with Hydrogen Peroxide Concentration and Drainage time: Sample E (Chesapeake).



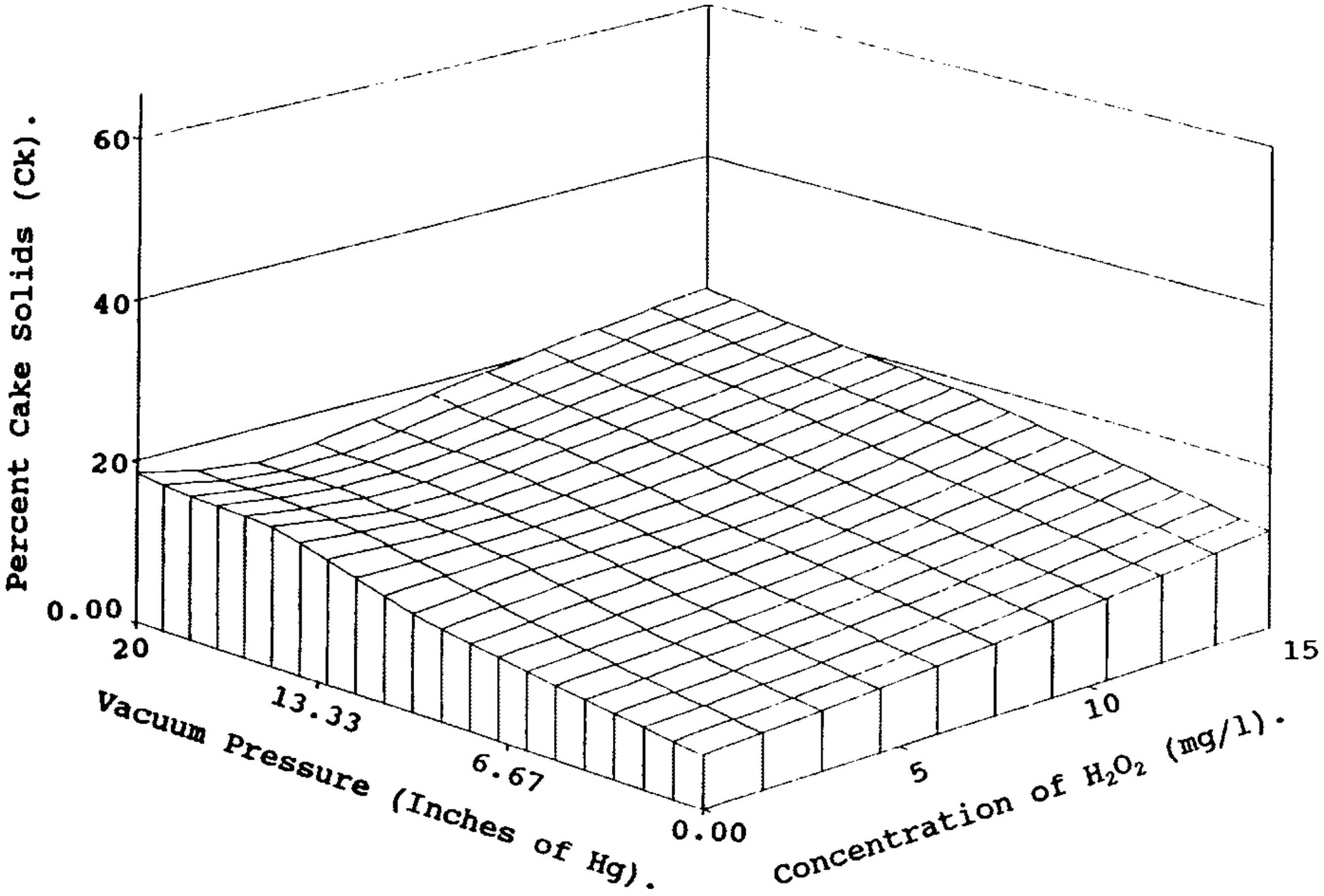
Graph 5-10 Variation of Cake Solids Concentration (Ck) with Respect to Applied Vacuum Pressure and Hydrogen Peroxide Dosage: Sample A (Norfolk).



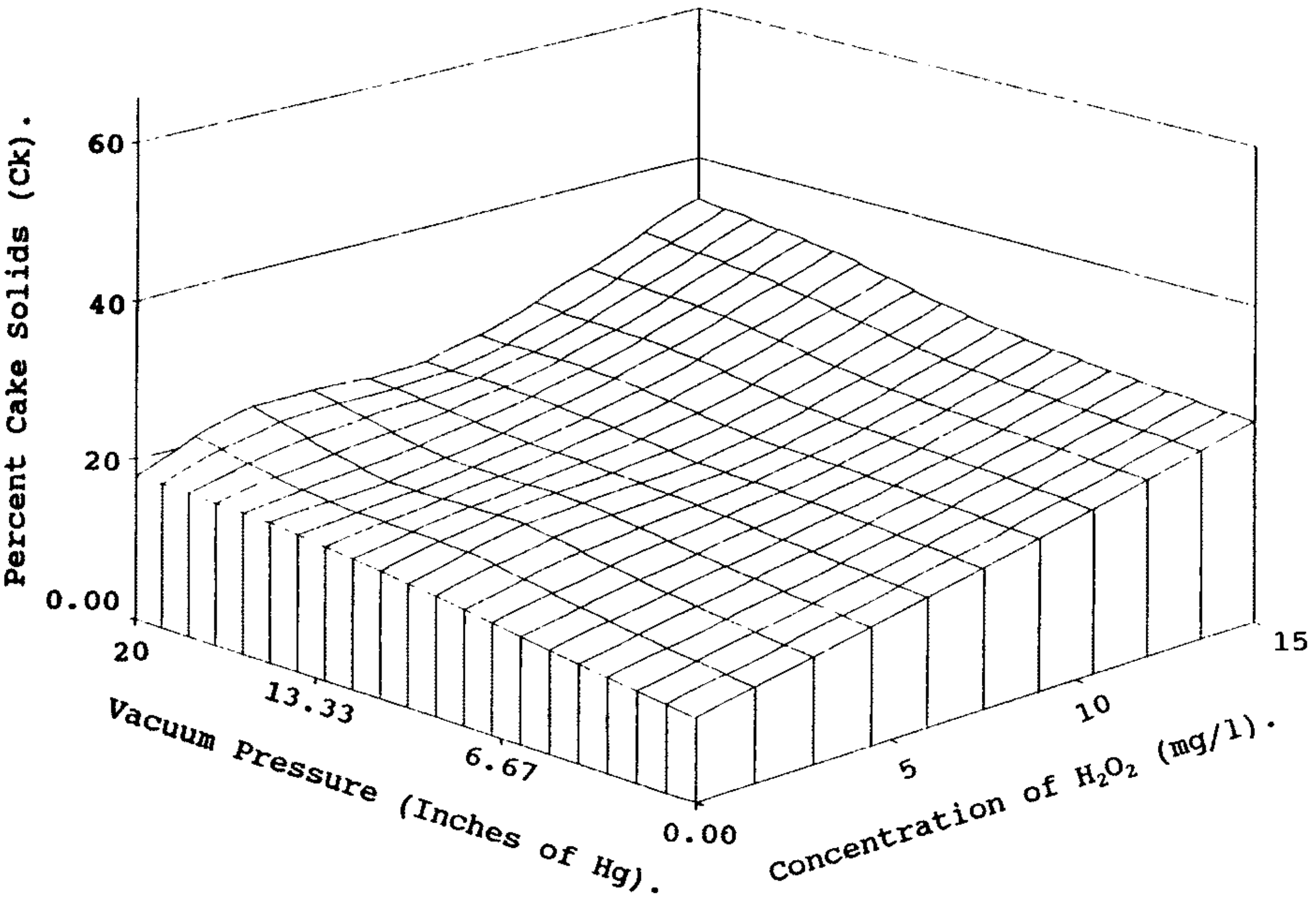
Graph 5-11 Variation of Cake Solids Concentration (Ck) with Respect to Applied Vacuum Pressure and Hydrogen Peroxide Dosage: Sample B (Norfolk).



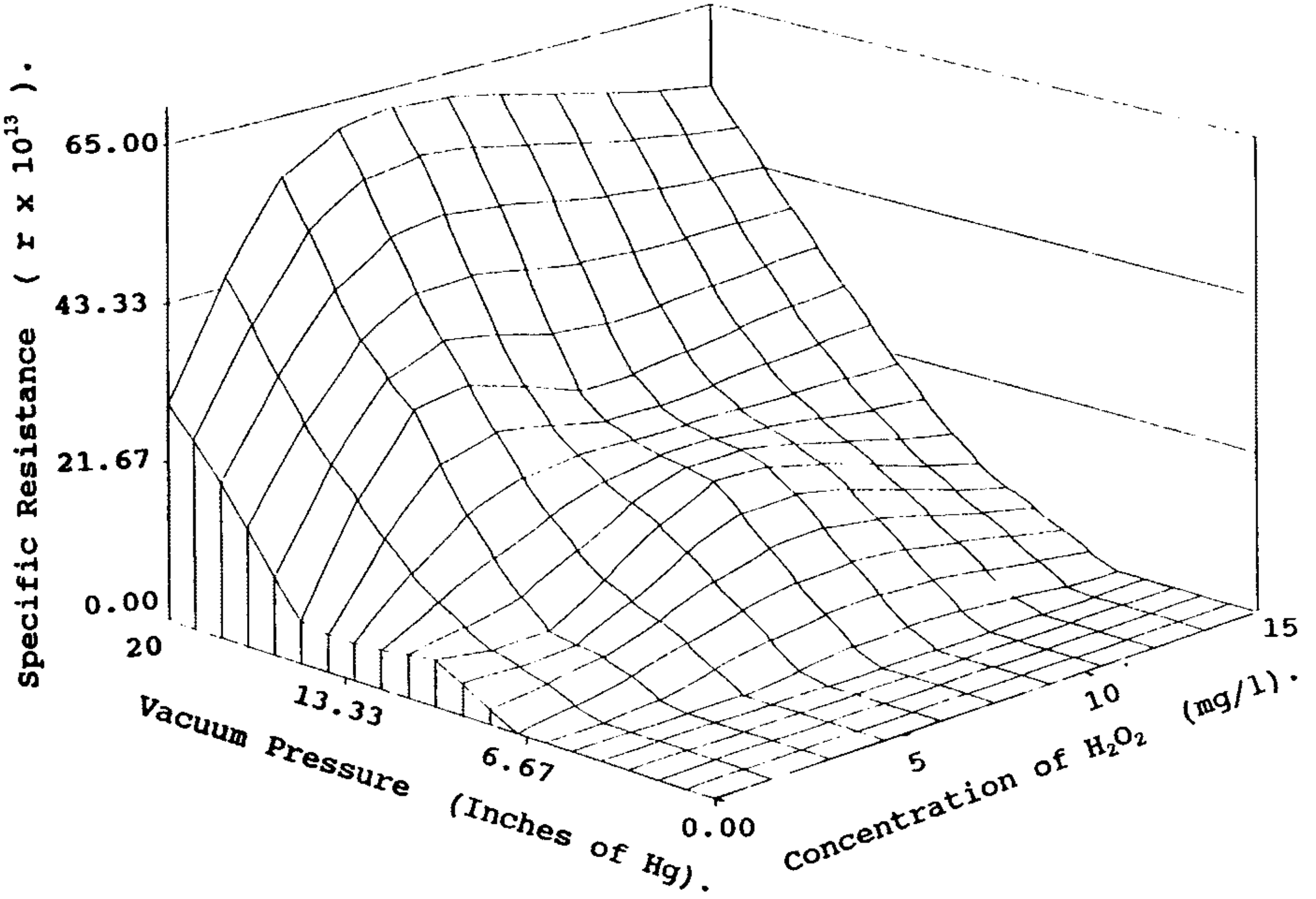
Graph 5-12 Variation of Cake Solids Concentration (Ck) with Respect to Applied Vacuum Pressure and Hydrogen Peroxide Dosage: Sample C (Newport News).



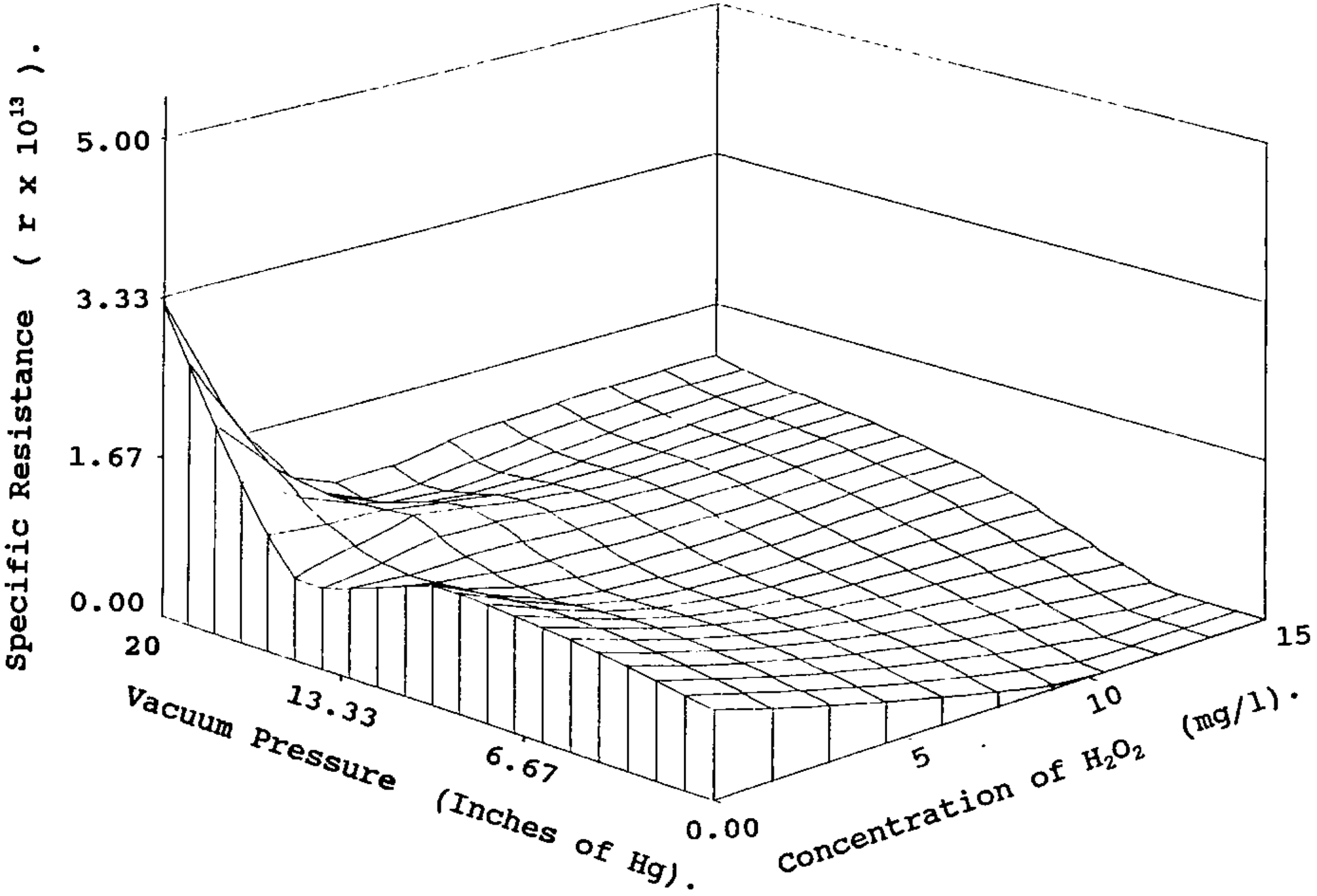
Graph 5-13 Variation of Cake Solids Concentration (Ck) with Respect to Applied Vacuum Pressure and Hydrogen Peroxide Dosage: Sample D (Portsmouth).



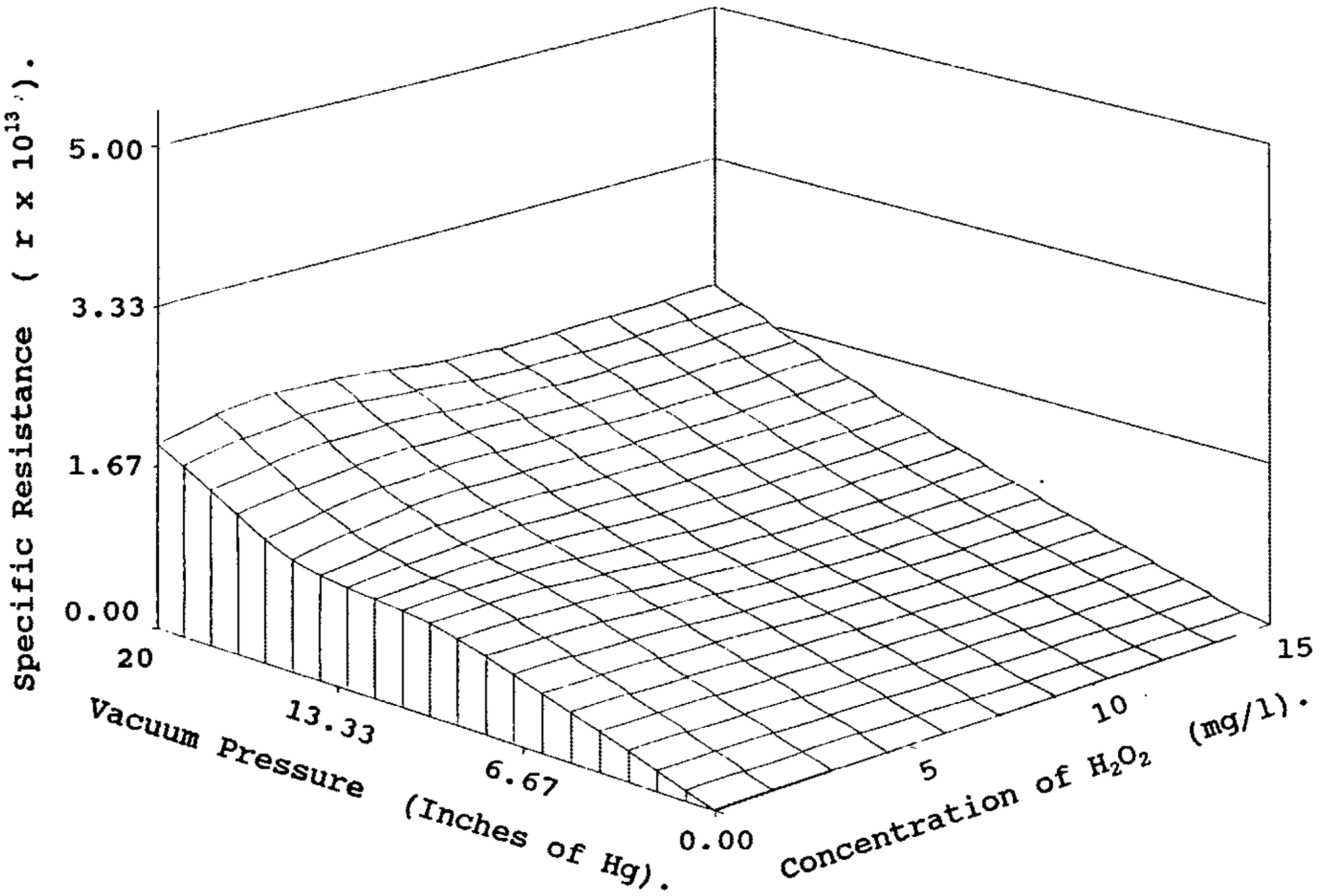
Graph 5-14 Variation of Cake Solids Concentration (Ck) with Respect to Applied Vacuum Pressure and Hydrogen Peroxide Dosage: Sample E (Chesapeake).



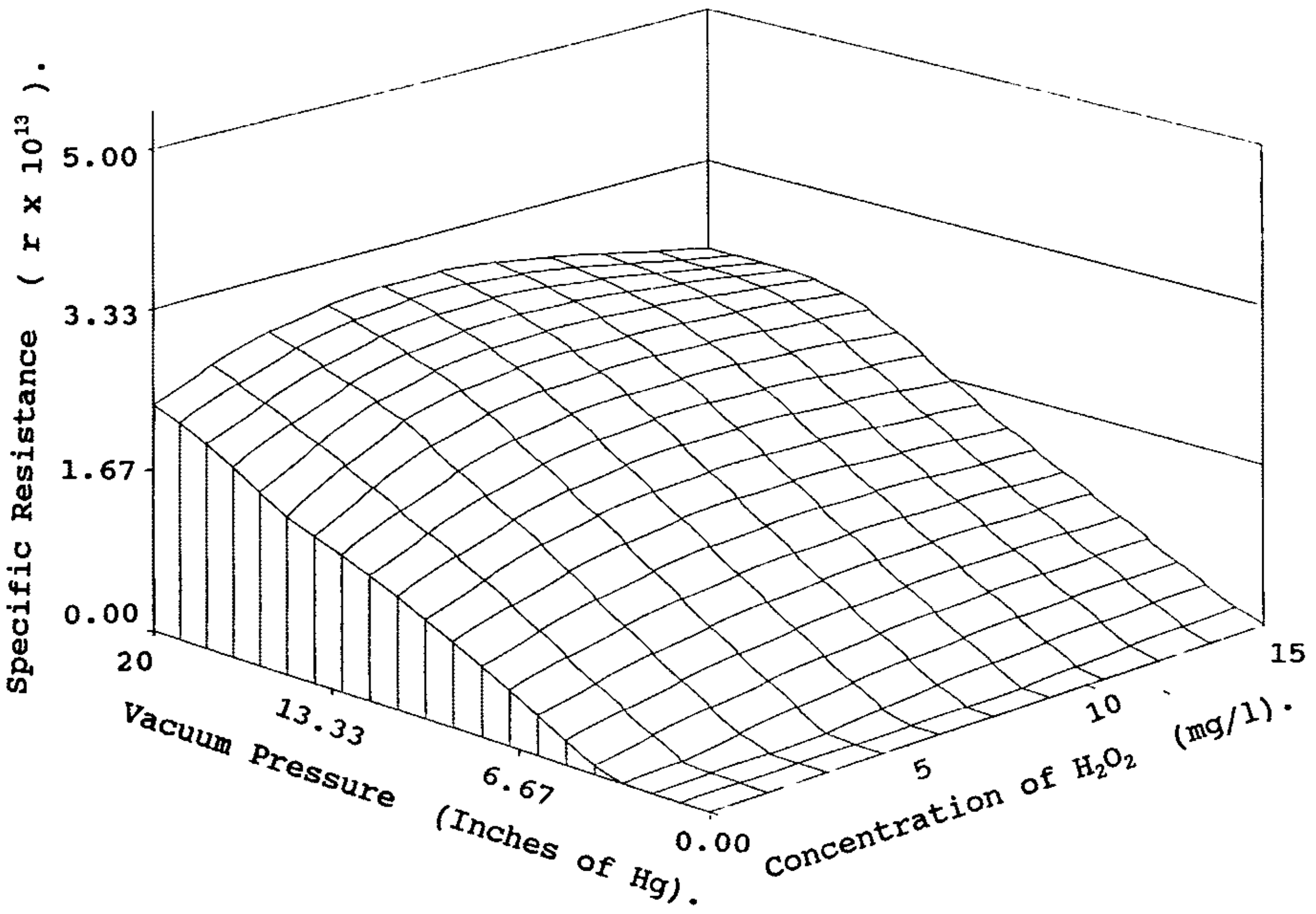
Graph 5-15 Specific Resistance as a Function of Applied Vacuum Pressure and Hydrogen Peroxide Concentration: Sample A (Norfolk).



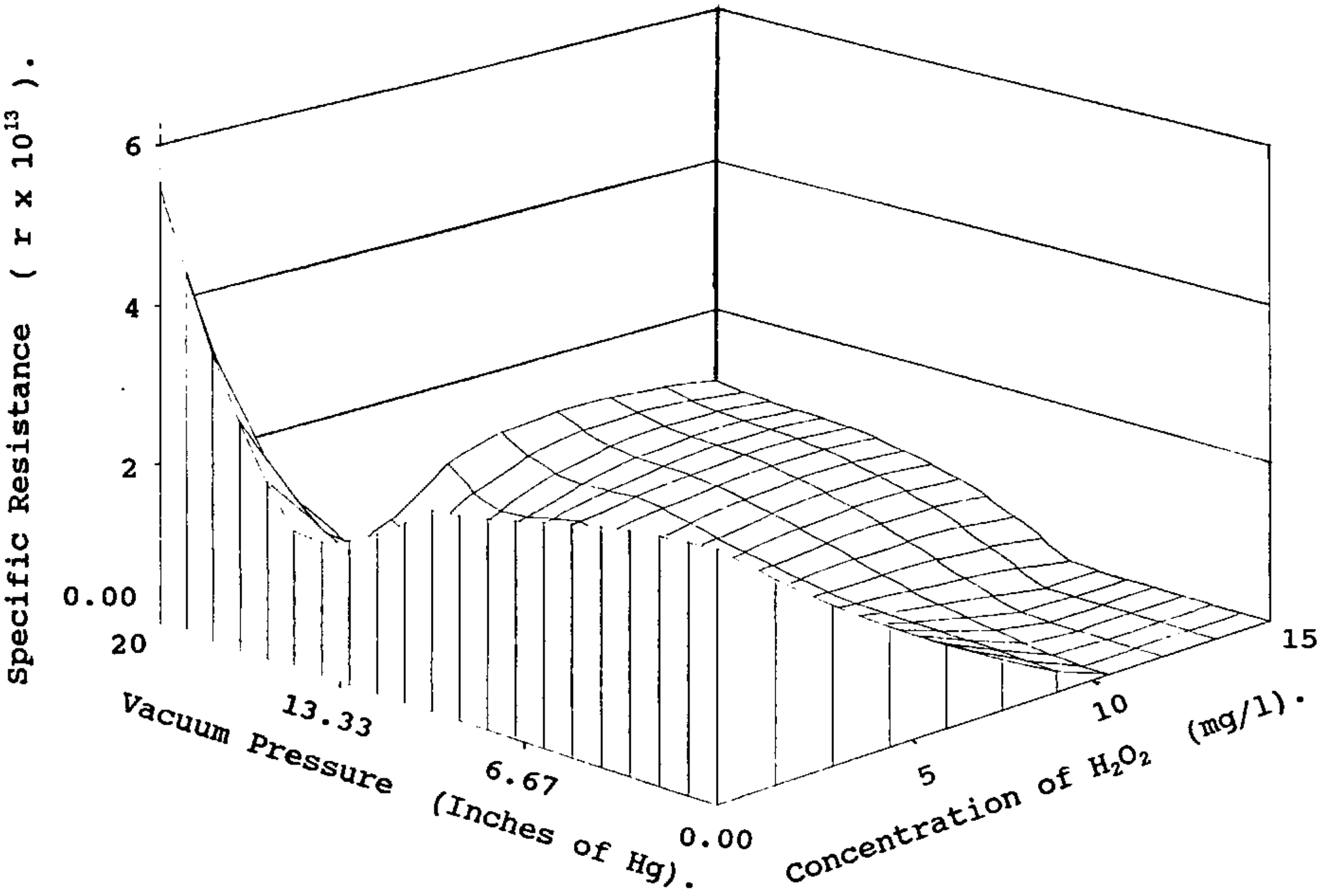
Graph 5-16 Specific Resistance as a Function of Applied Vacuum Pressure and Hydrogen Peroxide Concentration: Sample B (Norfolk).



Graph 5-17 Specific Resistance as a Function of Applied Vacuum Pressure and Hydrogen Peroxide Concentration: Sample C (Newport News).



Graph 5-18 Specific Resistance as a Function of Applied Vacuum Pressure and Hydrogen Peroxide Concentration: Sample D (Portsmouth).



Graph 5-19 Specific Resistance as a Function of Applied Vacuum Pressure and Hydrogen Peroxide Concentration: Sample E (Chesapeake).

pressure and hydrogen peroxide, is shown in Graphs 5-20 through 5-24. Graphs 5-25 through 5-29 represent the variation of specific resistance, calculated for individual sludge samples with different H_2O_2 concentrations and applied pressure. The specific resistance values are tabulated in Appendix B-II.

Centrifuge Test

Cake solids concentrations obtained in this particular test were very low (2 to 15 percent) as compared to other dewatering processes (Appendix C). Graphs 5-30 through 5-34 show the variation of Ck with differing speeds, spin time, and hydrogen peroxide concentrations for each sludge sample tested.

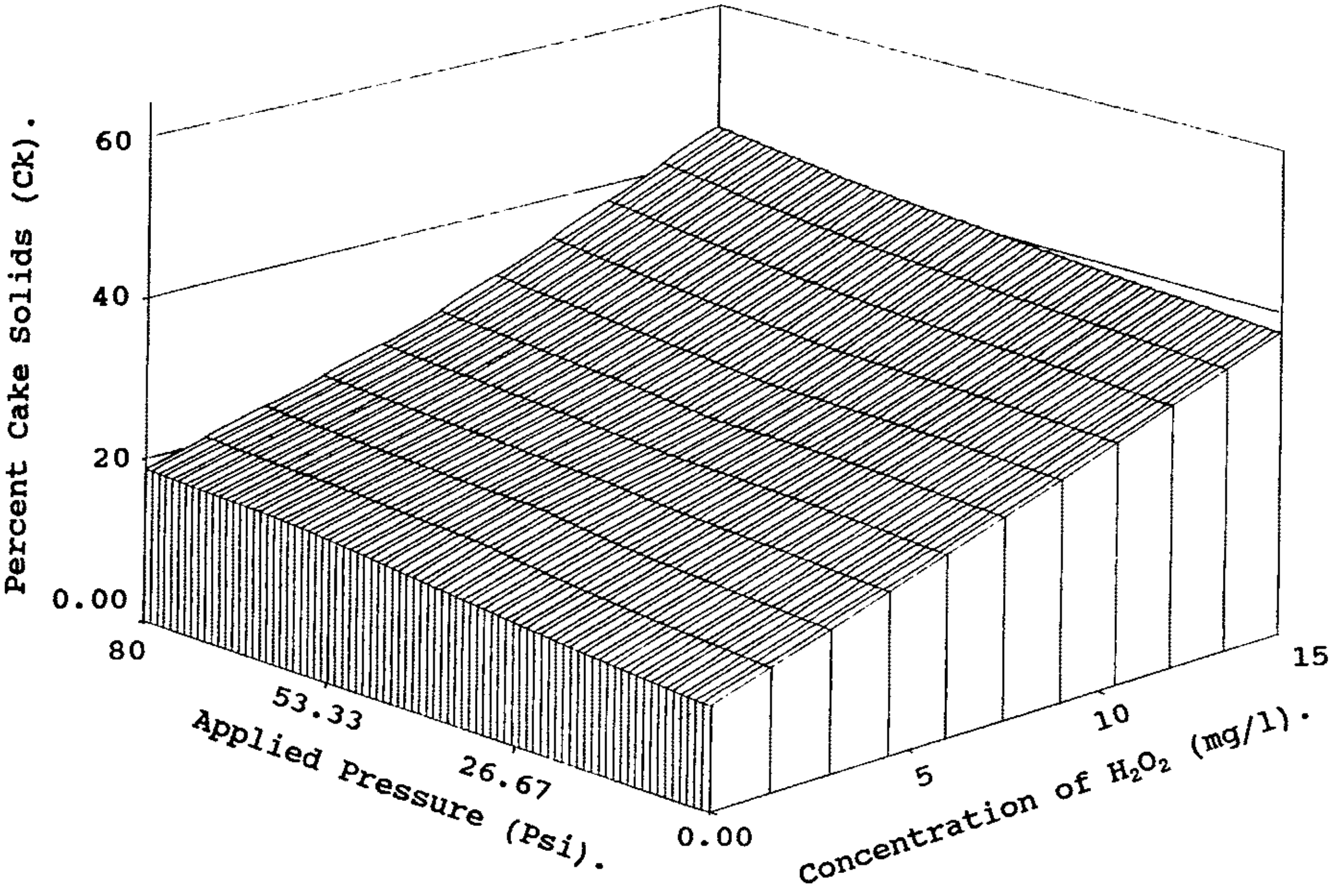
5.3 Viscosity Measurement

In general, the filtrate viscosity values determined in this study did not vary significantly from those of water at the same temperature, thus the substitution of water viscosity during the calculation of specific resistance appeared valid for all the sludges.

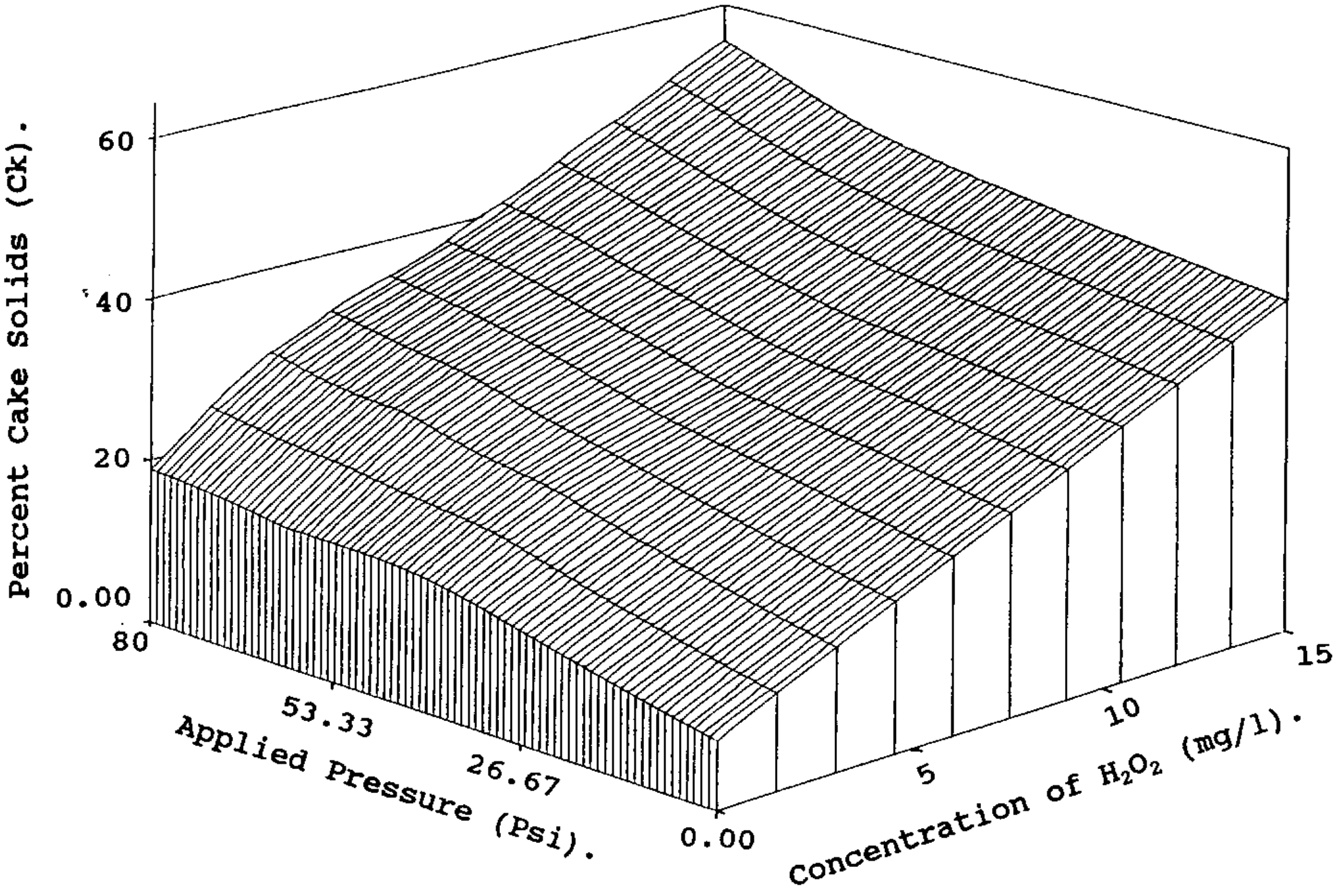
The raw sludge samples were also tested for their viscosities. All the sludge samples showed a change in viscosity with time while subjected to constant shearing. Graph 5-35 shows the thixotropic behaviour of individual sludge samples tested during this study.

5.4 Metal Analysis

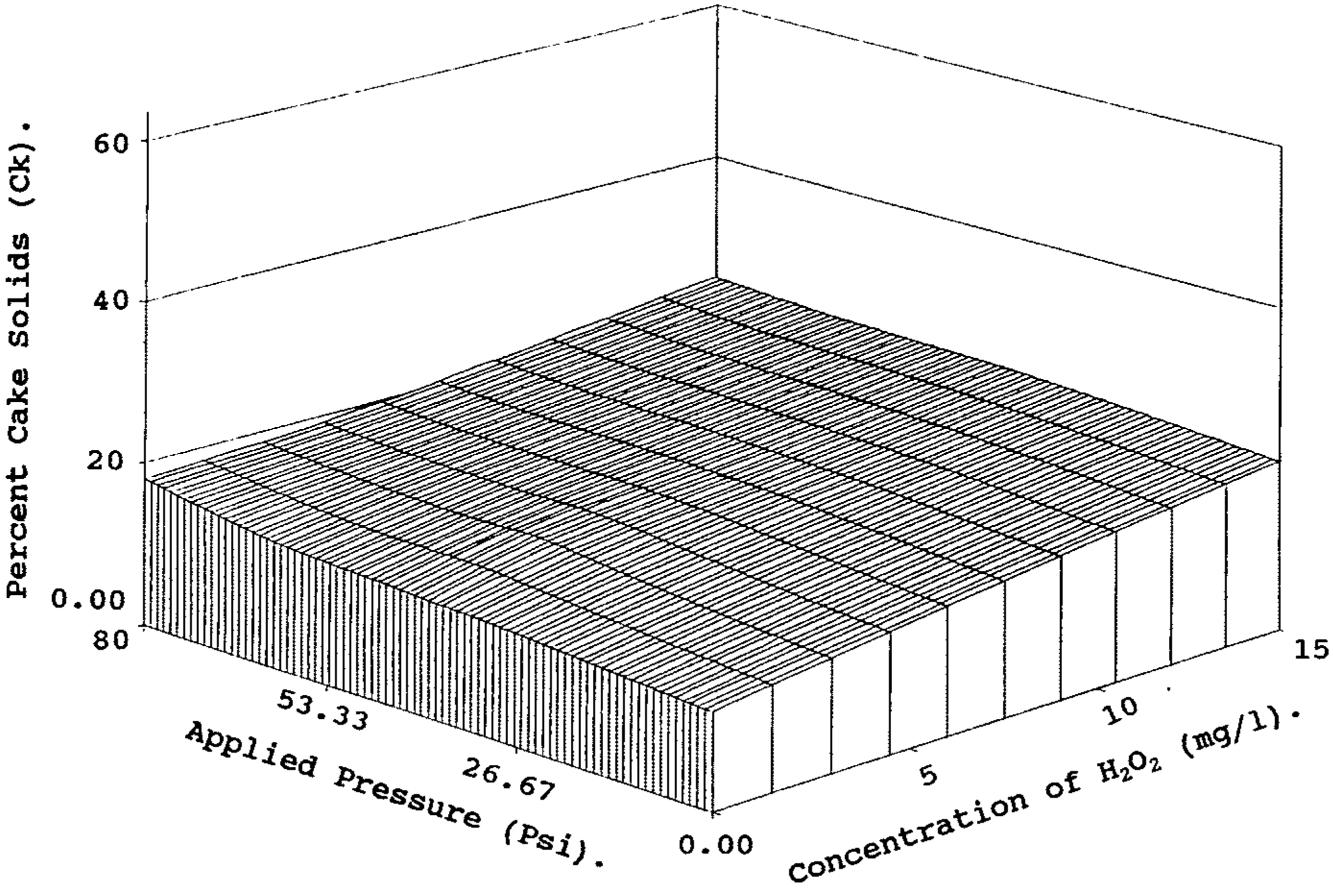
Tables 5-3 through 5-8 list the results of the metal



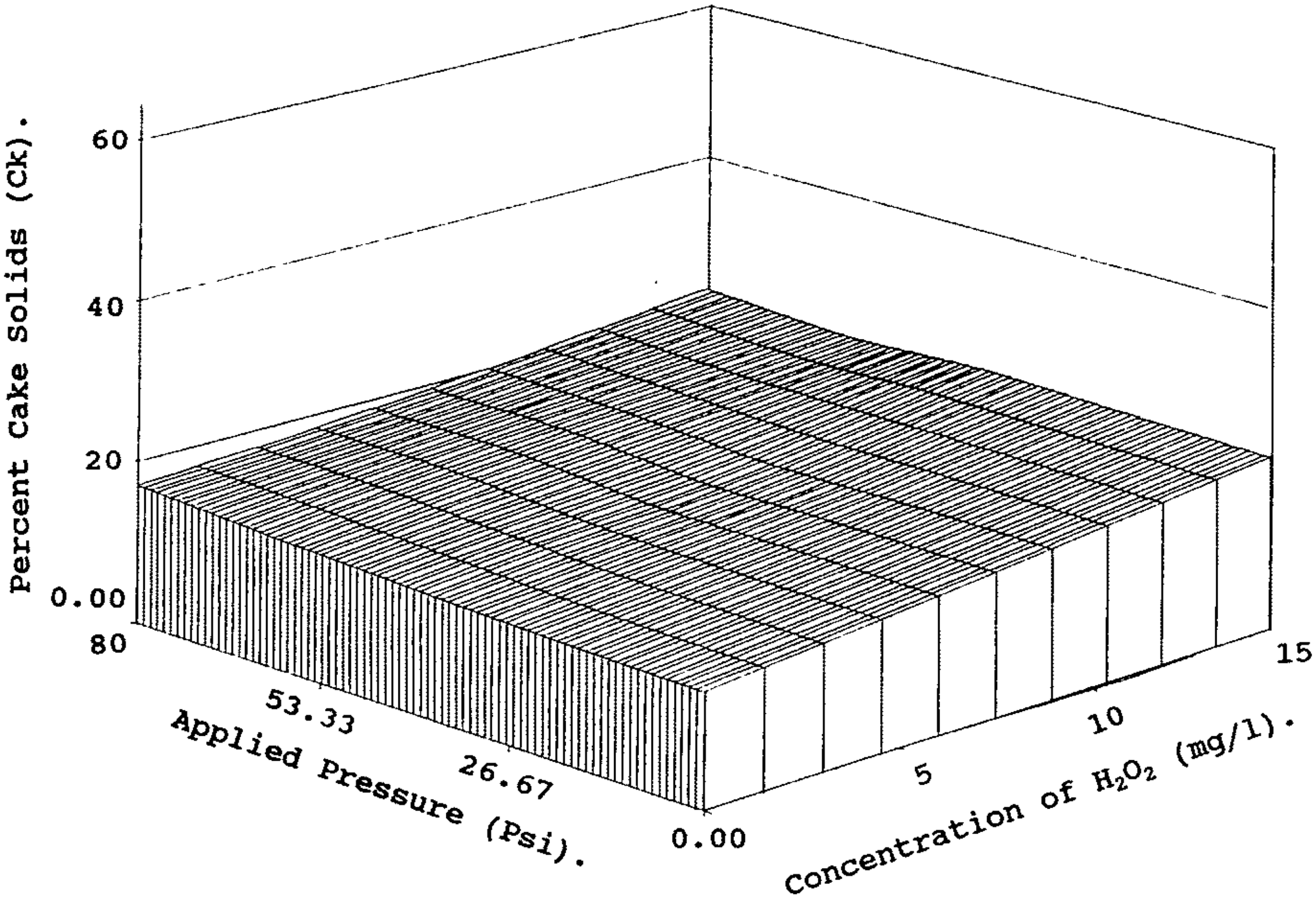
Graph 5-20 Variation of Cake Solids Concentration with Applied Pressure and Hydrogen Peroxide Concentration: Sample A (Norfolk).



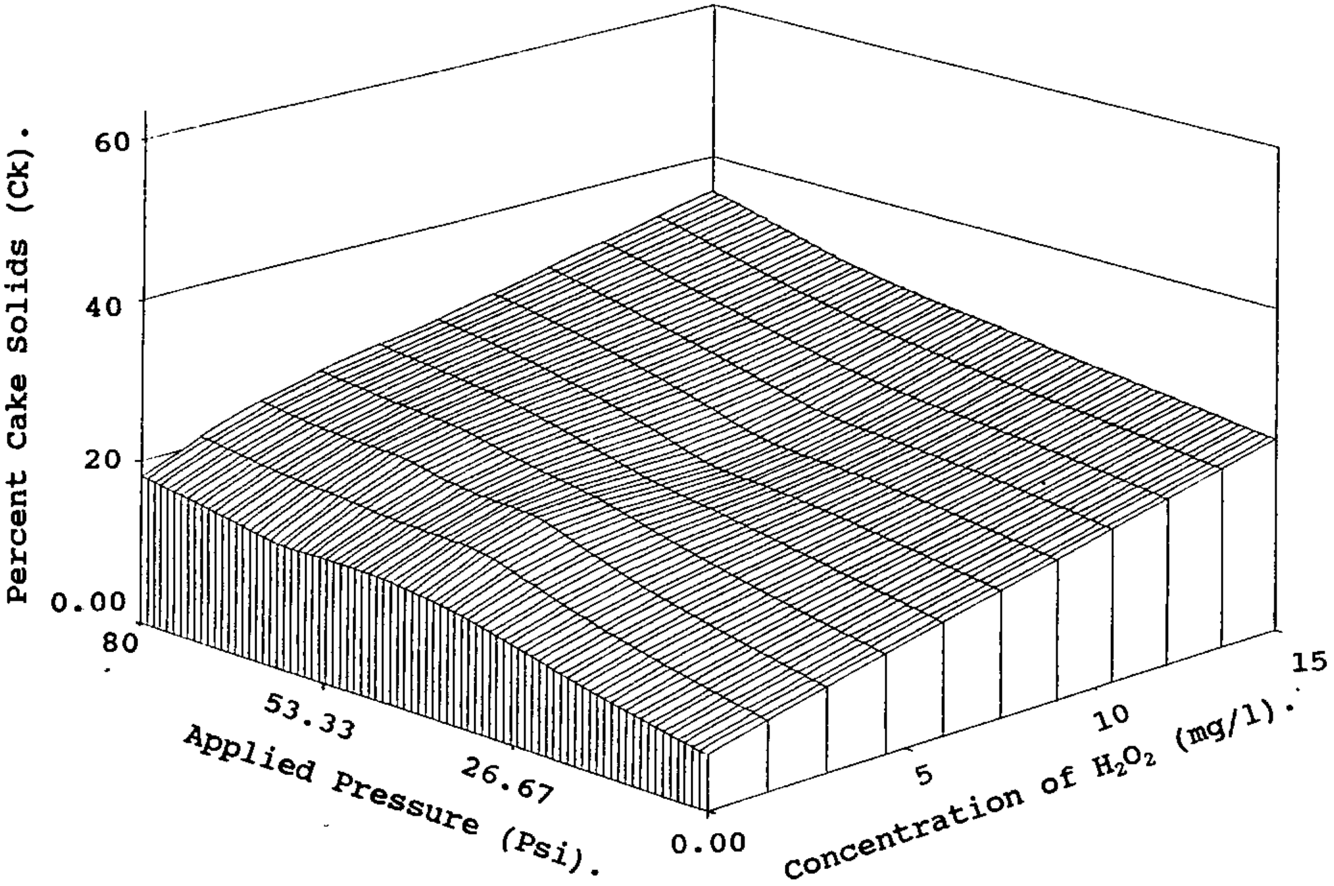
Graph 5-21 Variation of Cake Solids Concentration with Applied Pressure and Hydrogen Peroxide Concentration: Sample B (Norfolk).



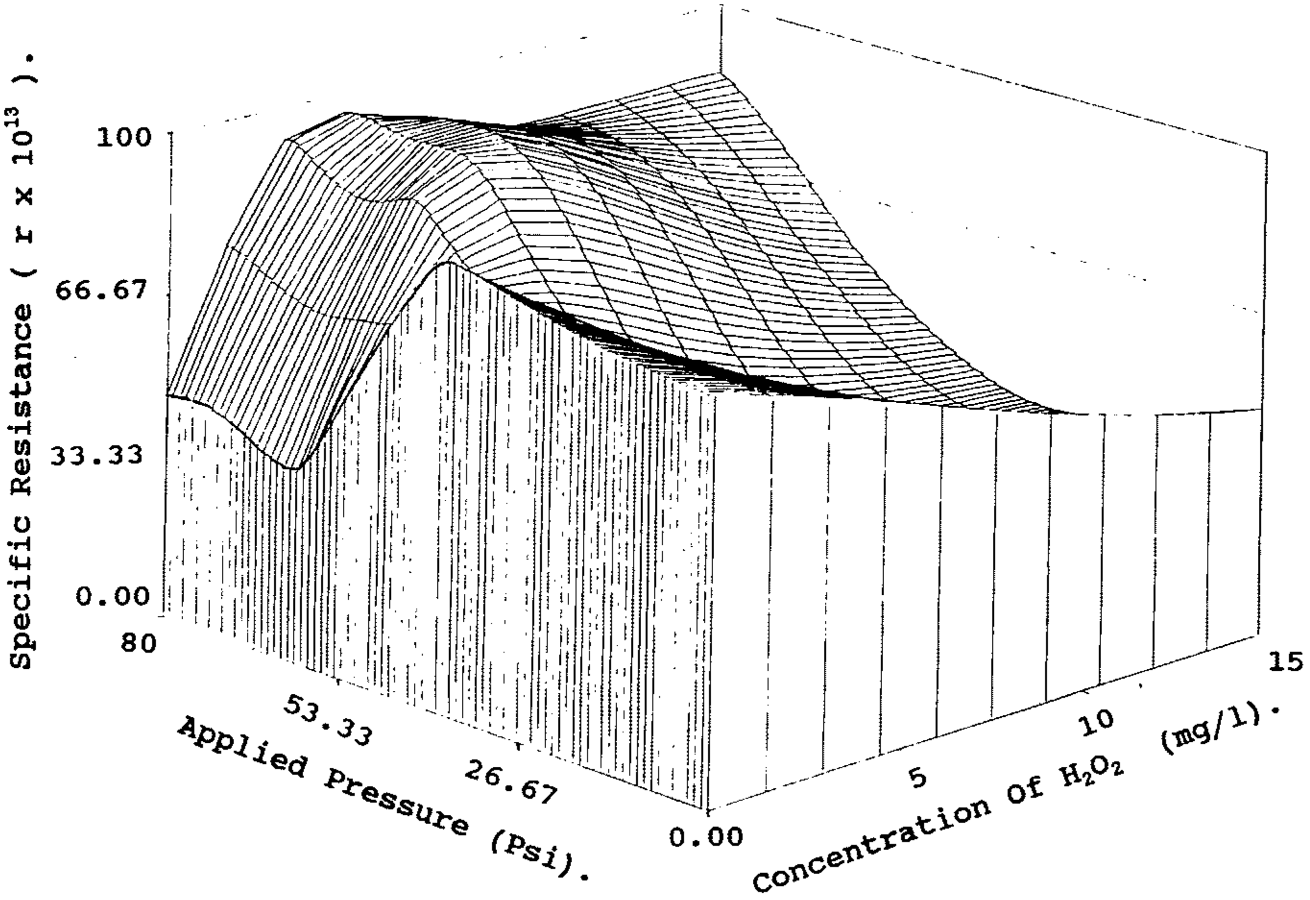
Graph 5-22 Variation of Cake Solids Concentration with Applied Pressure and Hydrogen Peroxide Concentration: Sample C (Newport News).



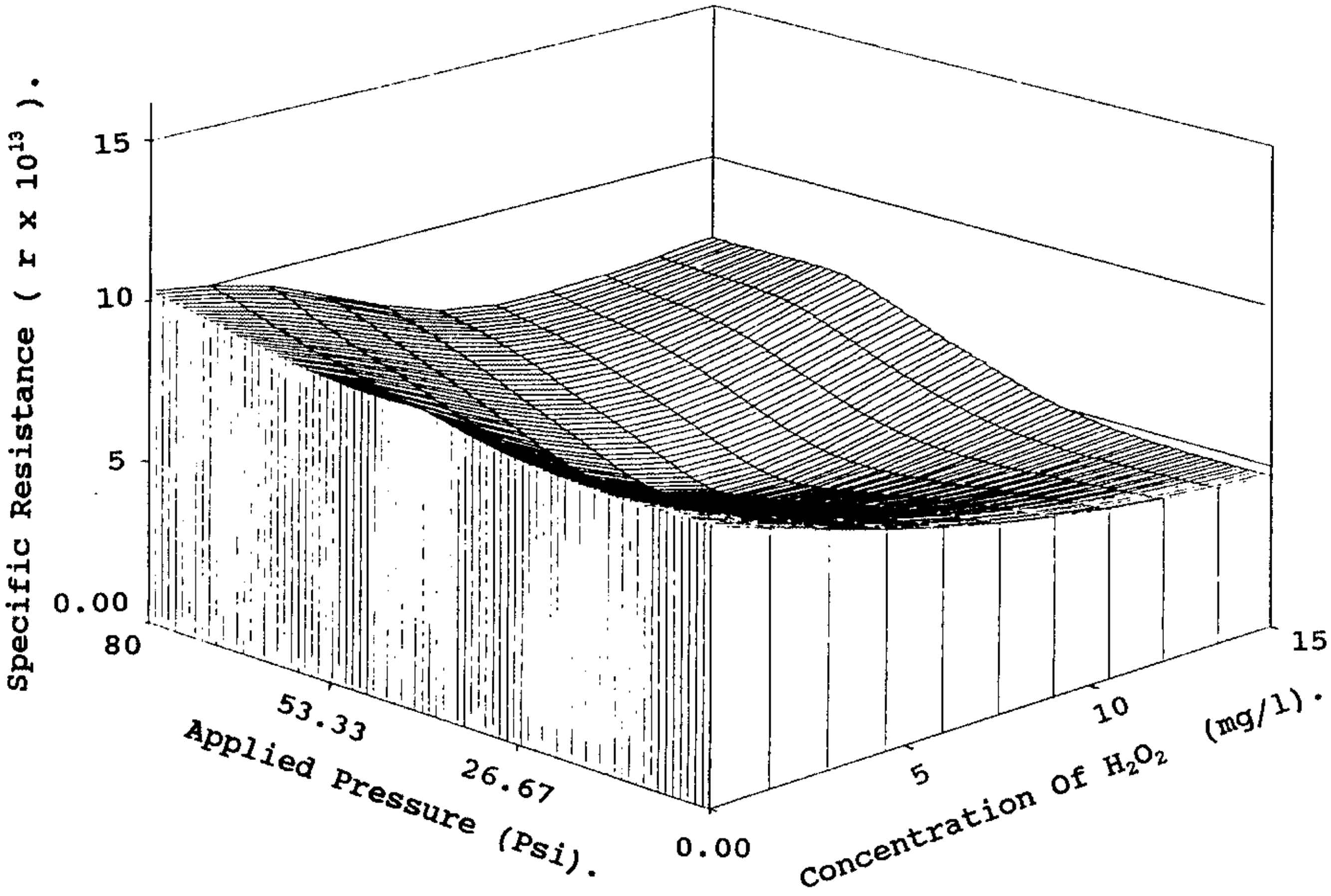
Graph 5-23 Variation of Cake Solids Concentration with Applied Pressure and Hydrogen Peroxide Concentration: Sample D (Portsmouth).



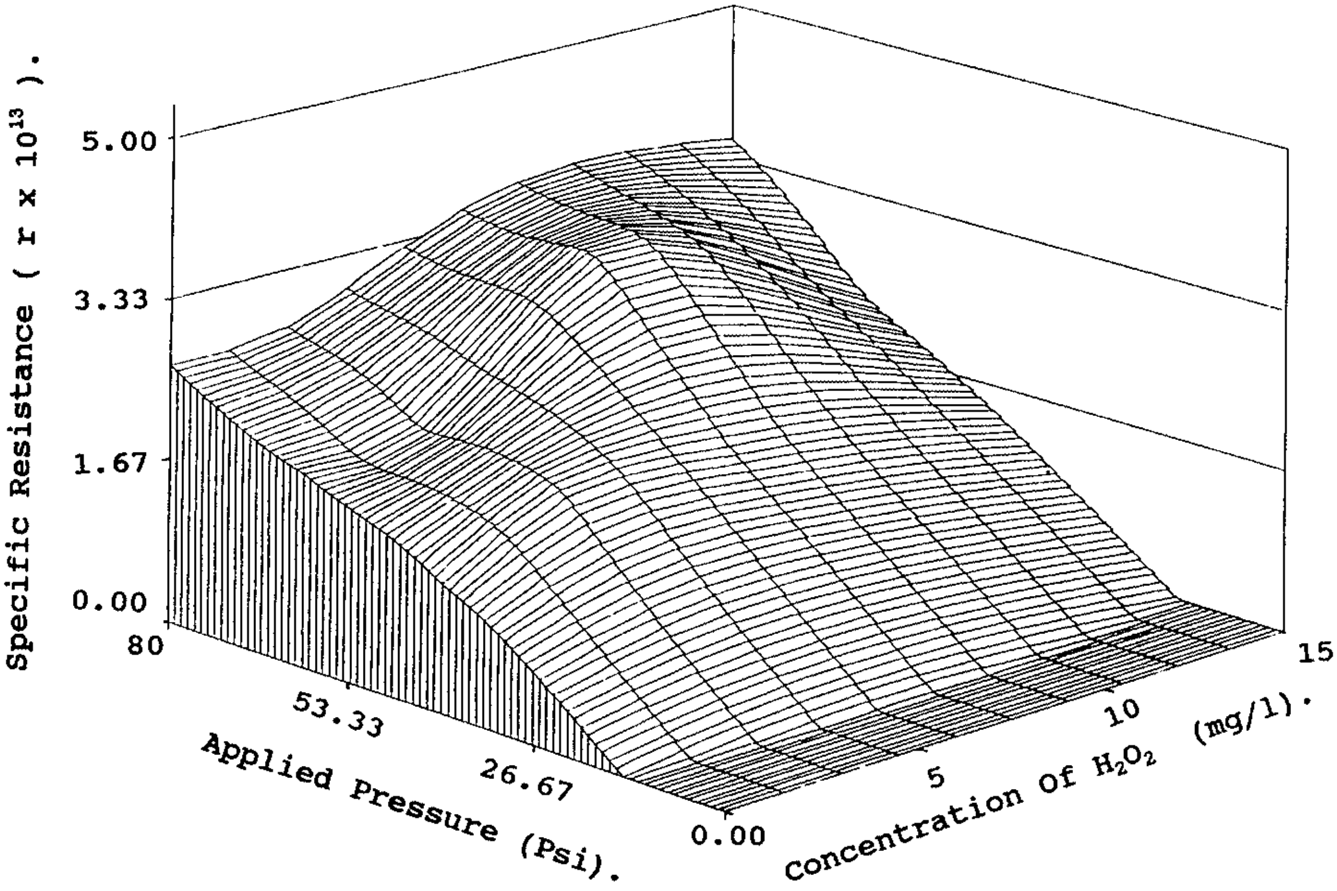
Graph 5-24 Variation of Cake Solids Concentration with Applied Pressure and Hydrogen Peroxide Concentration: Sample E (Chesapeake).



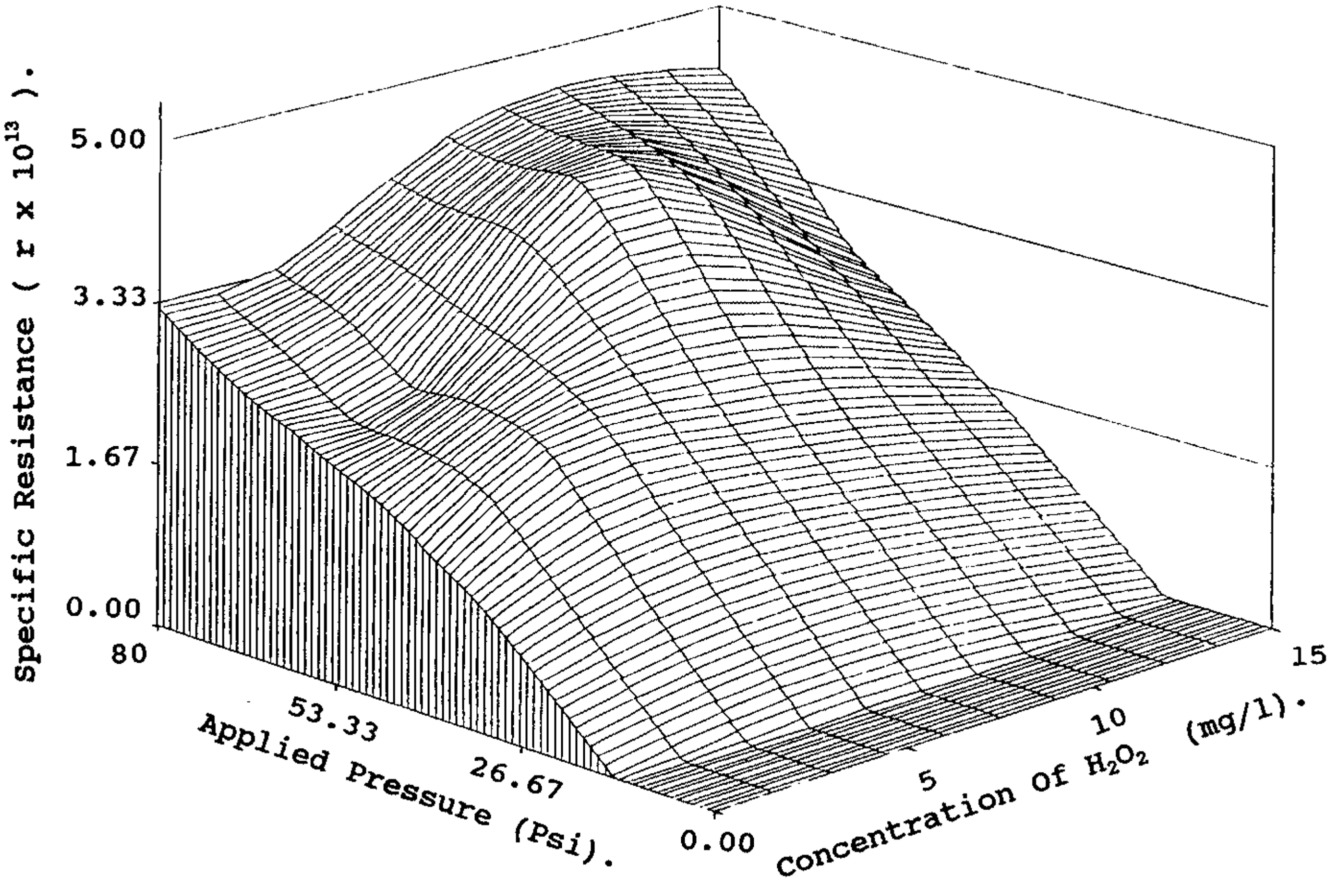
Graph 5-25 Specific Resistance as a Function of Applied Pressure and Hydrogen Peroxide Concentration: Sample A (Norfolk).



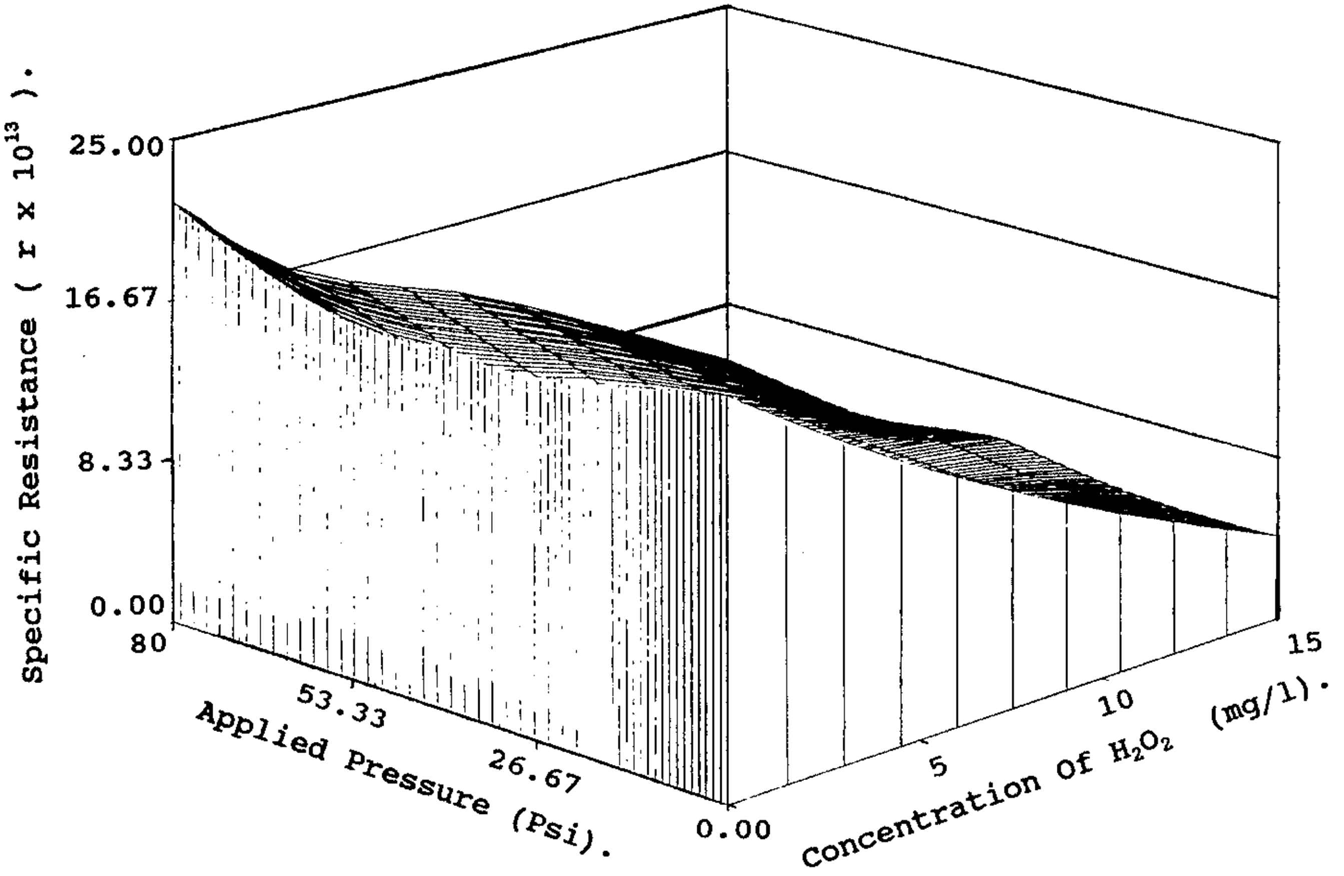
Graph 5-26 Specific Resistance as a Function of Applied Pressure and Hydrogen Peroxide Concentration: Sample B (Norfolk).



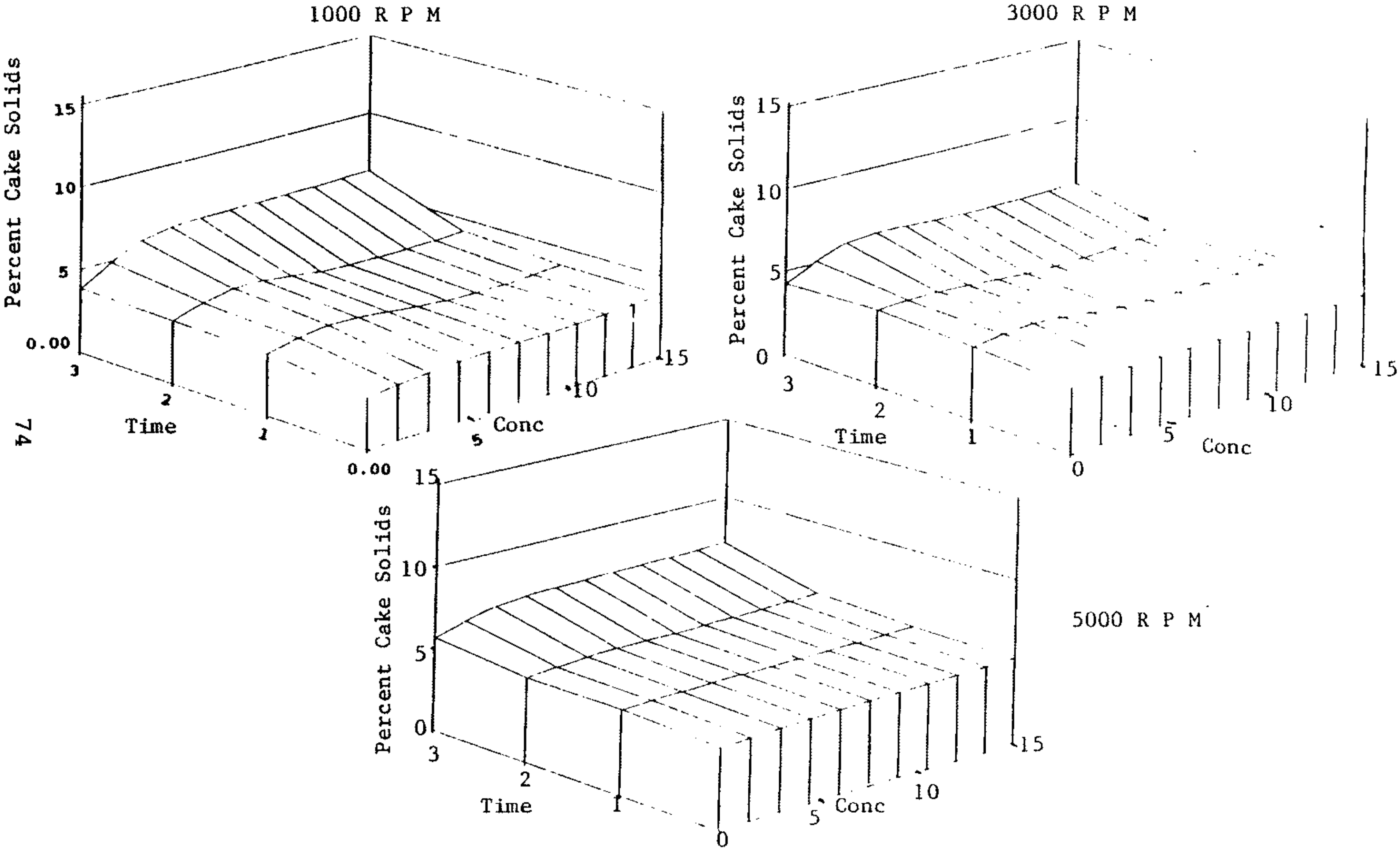
Graph 5-27 Specific Resistance as a Function of Applied Pressure and Hydrogen Peroxide Concentration: Sample C (Newport News).



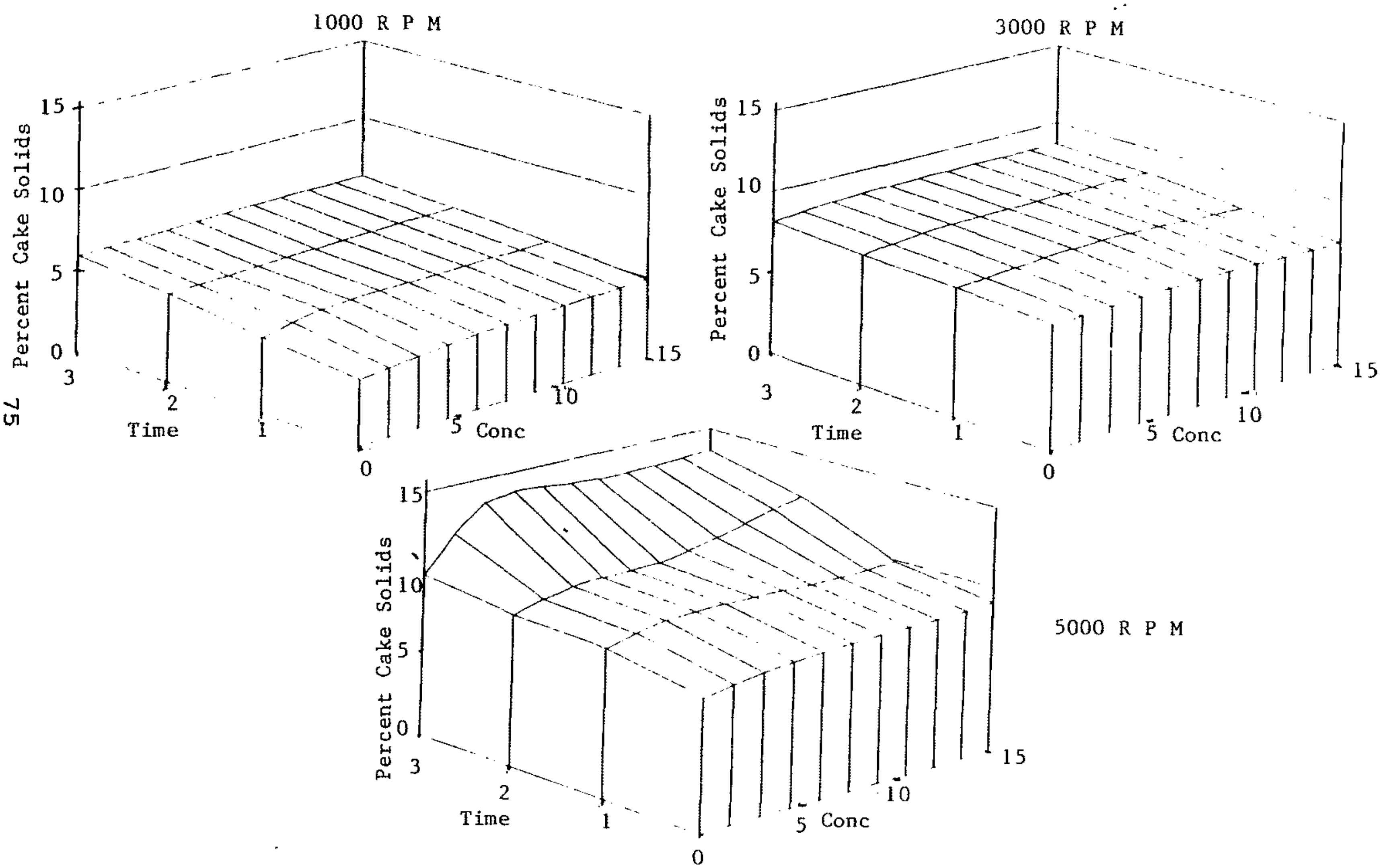
Graph 5-28 Specific Resistance as a Function of Applied Pressure and Hydrogen Peroxide Concentration: Sample D (Portsmouth).



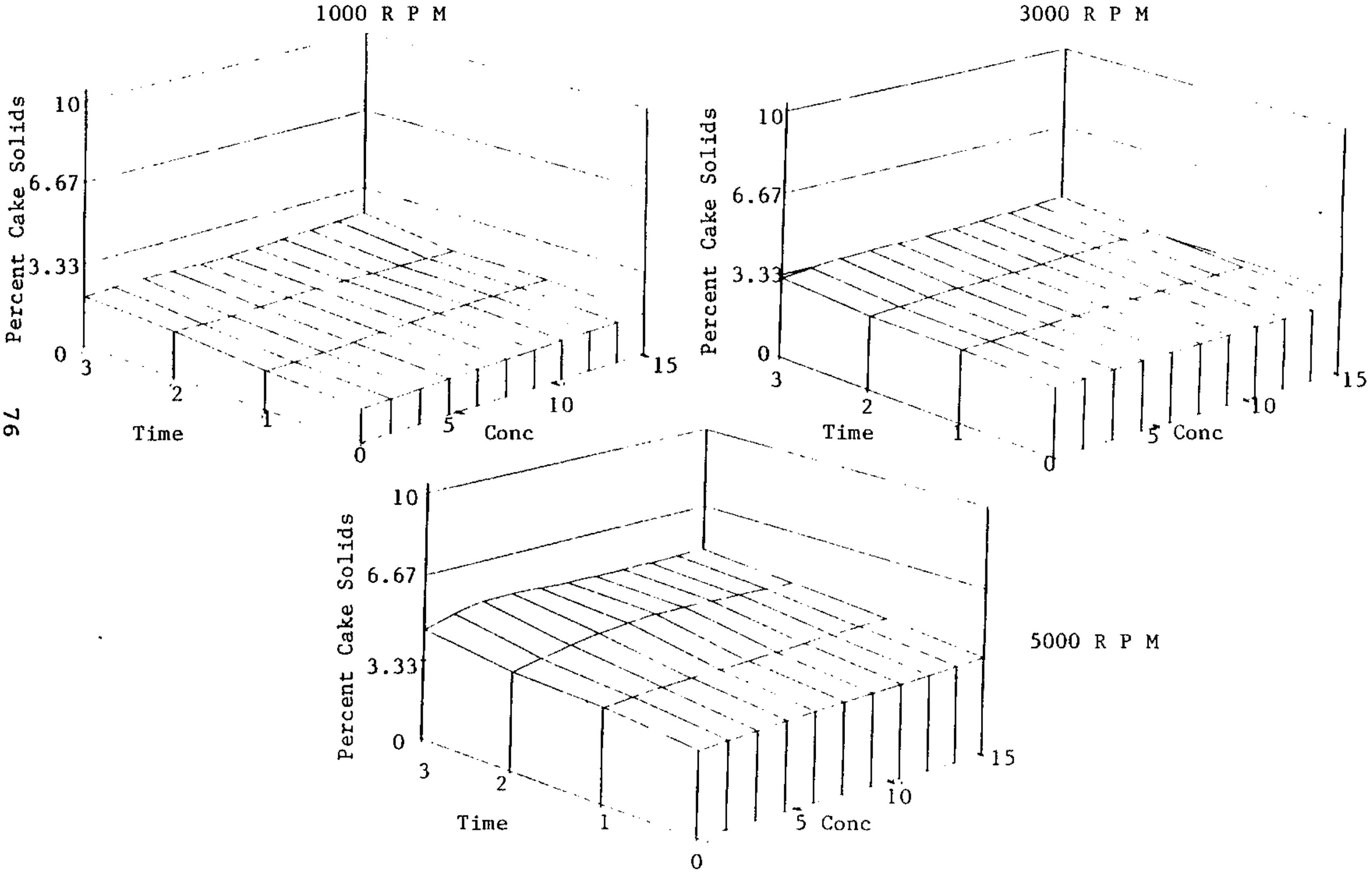
Graph 5-29 Specific Resistance as a Function of Applied Pressure and Hydrogen Peroxide Concentration: Sample E (Chesapeake).



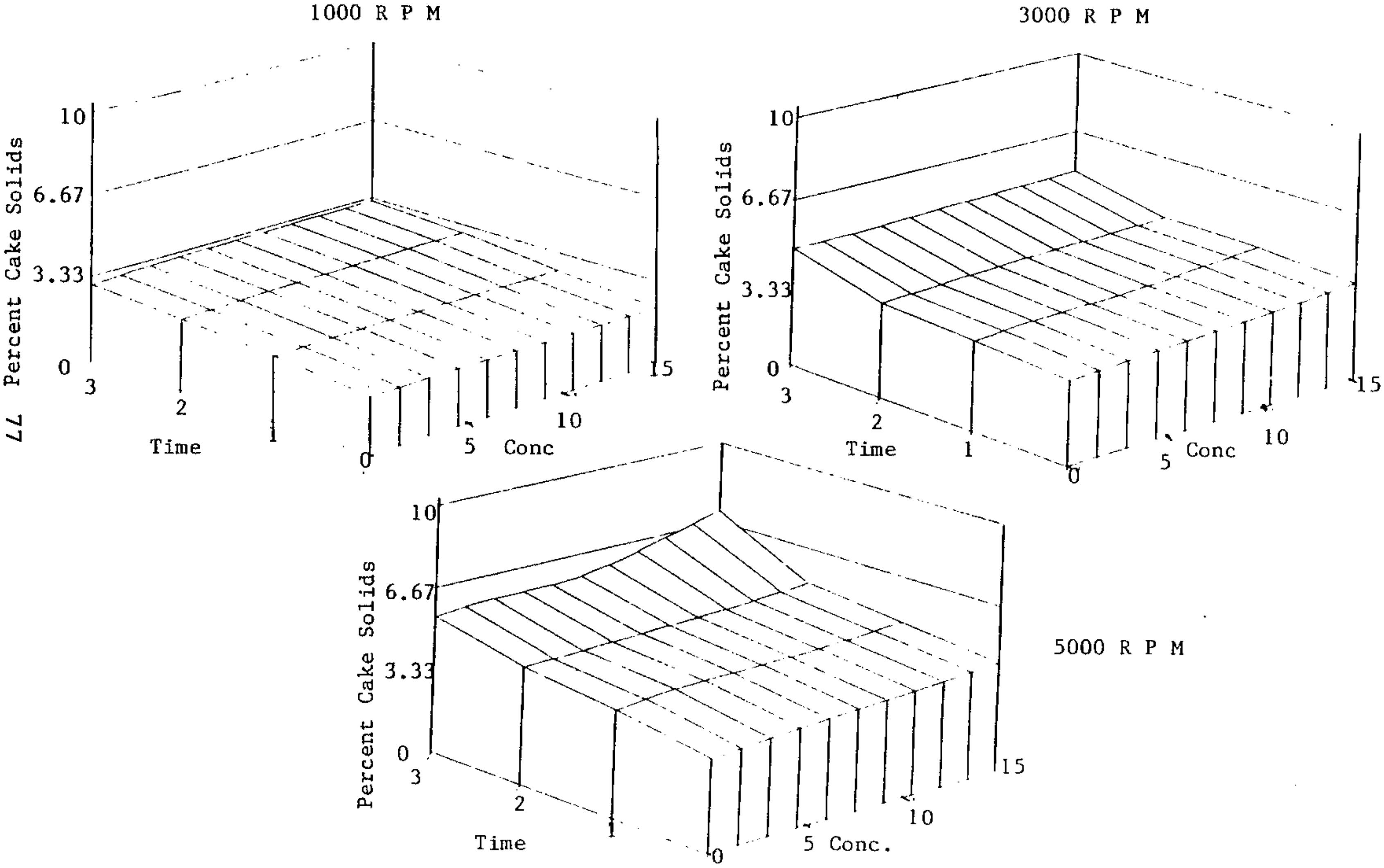
Graph 5-30 Variation of Cake Solids Concentration with Differing Speeds, Spin Time, and Hydrogen Peroxide Concentration: Sample A (Norfolk).



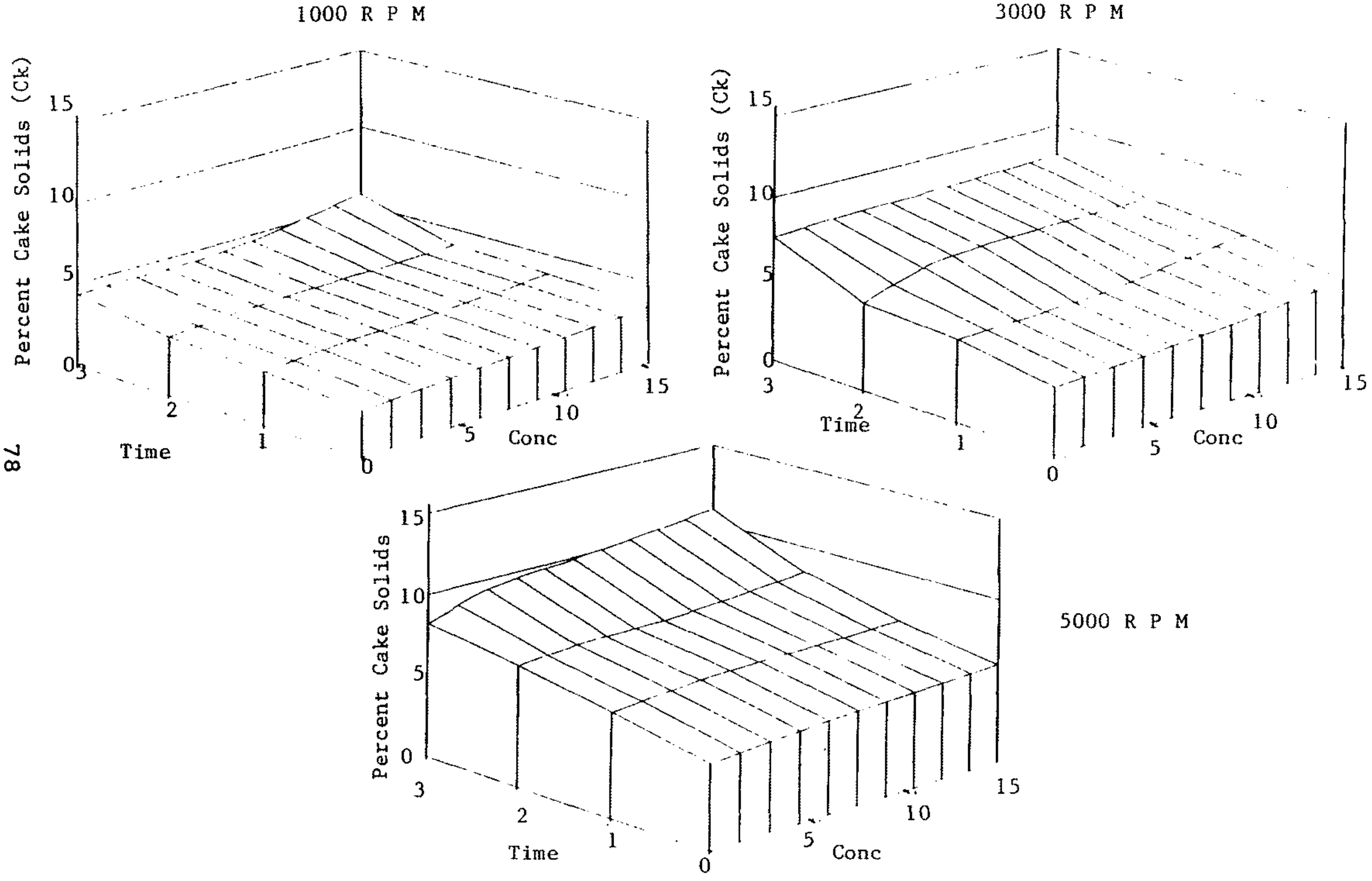
Graph 5-31 Variation of Cake Solids Concentration with Differing Speeds, Spin Time, and Hydrogen Peroxide Concentration: Sample B (Norfolk).



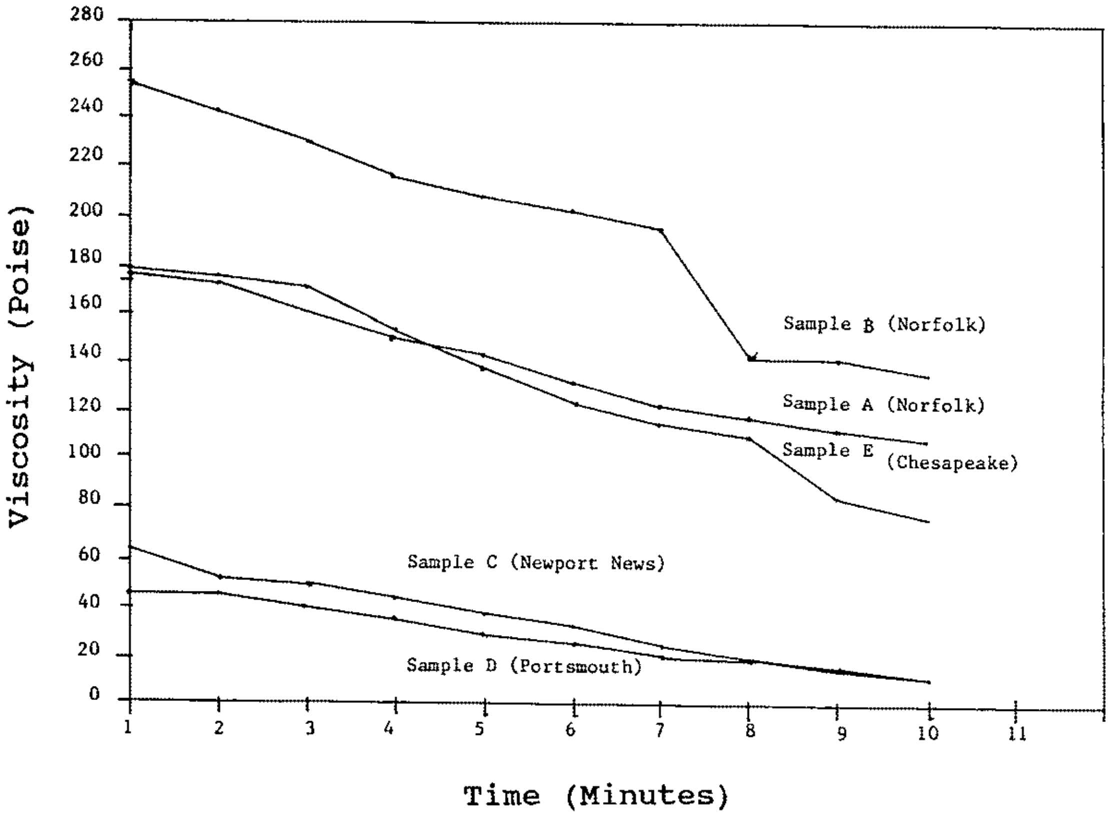
Graph 5-32 **Variation of Cake Solids Concentration with Differing Speeds, Spin Time, and Hydrogen Peroxide Concentration: Sample C (Newport news).**



Graph 5-33 Variation of Cake Solids Concentration with Differing Speeds, Spin Time, and Hydrogen Peroxide Concentration: Sample D (Portsmouth).



Graph 5-34 Variation of Cake Solids Concentration with Differing Speeds, Spin Time, and Hydrogen Peroxide Concentration: Sample E (Chesapeake).



Graph 5-35 Thixotropic Behaviour of Sludge Samples.

analysis performed on each raw sludge sample and the filtrates from different dewatering processes for the individual respectively.

5.5 Filtrate Alkalinity, Turbidity, and p^H

Tables 5-9 through 5-13 list the results of the p^H, alkalinity and turbidity measurements of the filtrates generated during the various dewatering processes, from each sample.

Sample	Aluminium Al^{3+} mg/l	Iron Fe mg/L	Manganese Mn mg/l
A (Norfolk)	17000	25000	1500
B (Norfolk)	17200	31000	1200
C (Newport News)	10000	39000	800
D (Portsmouth)	11000	28000	1300
E (Chesapeake)	13500	29200	1320

Table 5-3: Metal Analysis of Raw Sludge Samples

Sample With H_2O_2 Concentration (mg/L dose)	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	mg/L			mg/L			mg/L			mg/L		
	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn
0	18.52	1.65	0.78	8.42	0.01	2.48	18.0	1.24	2.08	18.7	5.47	2.25
2.5	4.20	1.18	4.25	4.80	0.01	1.45	5.0	0.07	1.01	-	-	-
7.5	1.46	0.30	3.22	1.53	0.07	2.87	-	-	-	2.6	5.97	1.90
15	1.28	0.02	1.26	1.28	0.01	2.36	-	-	-	2.1	5.15	0.63

Table 5-4: Metal Analysis of the filtrates Generated in Various Dewatering processes: Sample A (Norfolk)

Sample With H_2O_2 Concentration (mg/L dose)	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	mg/L			mg/L			mg/L			mg/L		
	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn
0	12.0	0.04	56.8	11.0	05.10	69.25	11.80	15.50	59.32	13.58	70.60	68.29
2.5	11.60	3.74	79.10	11.40	3.24	74.25	11.38	7.90	76.98	12.80	66.70	70.20
7.5	1.58	0.02	79.24	1.62	0.03	74.57	1.60	0.53	68.55	2.12	21.80	78.00
15	1.20	0.04	79.60	1.22	0.02	75.90	1.19	0.29	77.44	1.90	43.80	65.50

Table 5-5: Metal Analysis of the filtrates Generated in Various Dewatering processes: Sample B (Norfolk)

Sample With H_2O_2 Concentration (mg/L dose)	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	mg/L			mg/L			mg/L			mg/L		
	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn
0	10.0	0.20	15.55	-	1.85	17.05	9.98	-	-	11.52	2.66	15.02
2.5	9.7	0.01	15.30	10.3	-	-	9.50	-	-	10.10	0.06	15.44
7.5	2.1	0.04	15.80	2.2	0.01	16.42	2.0	0.05	17.55	2.8	0.02	17.55
15	1.4	0.03	17.35	1.41	15.52	11.35	1.40	-	-	1.80	0.02	20.74

Table 5-6: Metal Analysis of the filtrates Generated in Various Dewatering processes: Sample C (Newport News)

Sample With H_2O_2 Concentration (mg/L dose)	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	mg/L			mg/L			mg/L			mg/L		
	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn
0	10.62	0.32	31.90	-	-	-	-	-	-	12.68	6.60	21.22
2.5	9.83	0.44	32.20	9.81	0.01	22.50	-	-	-	10.11	8.25	42.45
7.5	4.32	0.23	32.10	4.30	0.01	29.20	-	-	-	5.01	7.70	44.05
15	1.46	0.13	38.57	1.40	0.01	40.50	-	-	-	3.16	9.46	49.70

Table 5-7: Metal Analysis of the filtrates Generated in Various Dewatering processes: Sample D (Portsmouth)

	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	mg/L			mg/L			mg/L			mg/L		
Sample With H_2O_2 Concentration (mg/L dose)	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn
0	8.91	1.30	6.34	-	-	-	-	-	-	9.54	34.20	4.5
2.5	6.36	0.02	6.47	6.39	0.01	7.40	-	-	-	7.25	46.50	7.35
7.5	5.83	0.03	6.35	5.81	0.01	9.30	-	-	-	7.60	41.50	7.57
15	3.22	0.06	6.01	3.10	0.01	9.05	3.10	0.42	9.05	5.18	46.20	8.85

Table 5-8: Metal Analysis of the filtrates Generated in Various Dewatering processes: Sample E (Chesapeake)

Sample With H_2O_2 Dose mg/L	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)
0	7.26	211.60	12.1	7.32	155.6	45	7.37	180.0	50	7.52	214.28	340
2.5	7.05	210.50	10.8	7.53	168.2	10.10	7.58	180.0	25	7.41	207.1	321
7.5	7.35	189.60	3.4	7.28	142.86	3.4	7.18	168.7	10.10	7.66	128.6	50
15	7.45	152.68	3.1	7.38	142.86	3.2	7.35	155.38	3.40	7.51	124	10.8

Table 5-9: pH, Alkalinity and Turbidity of the filtrates Generated in the Various Dewatering processes: Sample A (Norfolk)

	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
Sample With H_2O_2 Dose mg/L	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)
0	7.05	125.0	10.30	7.01	128.0	3.2	7.01	101.8	3.4	6.68	60	380
2.5	7.28	128.10	10.10	6.92	135.10	3.4	6.88	114.3	3.3	6.30	114.6	210
7.5	7.31	152.30	6.3	6.88	148.60	3.5	7.03	136.5	3.4	7.10	150.8	65
15	7.49	181.81	3.3	6.90	125.0	3.1	6.92	145.2	3.4	7.08	149.70	62

Table 5-10: pH, Alkalinity and Turbidity of the filtrates Generated in the Various Dewatering processes: Sample B (Norfolk)

Sample With H_2O_2 Dose mg/L	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)
0	7.51	153.80	10.10	6.60	100	3.4	6.88	100.2	3.3	7.08	100.60	65
2.5	7.38	148.68	4.8	6.58	115.2	3.6	6.93	120.70	3.4	7.06	89.92	3.5
7.5	7.30	161.23	3.2	6.83	156.7	3.4	6.91	148.62	3.3	7.00	83.33	3.8
15	7.14	131.58	3.1	6.78	140.83	3.1	6.95	142.60	3.3	6.91	80.35	3.1

Table 5-11: pH, Alkalinity and Turbidity of the filtrates Generated in the Various Dewatering processes: Sample C (Newport News)

Sample With H_2O_2 Dose mg/L	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)
0	7.30	108.69	18.1	7.15	112.60	5.4	7.01	110.60	6.2	6.98	118.80	65
2.5	7.36	138.60	10.8	7.01	135.70	3.4	6.95	128.80	4.1	6.88	95.24	61
7.5	7.38	152.62	5.4	6.77	148.90	3.6	6.78	142.37	3.1	6.78	129.32	51
15	7.32	142.86	3.4	6.88	129.63	3.1	6.55	128.60	3.1	6.72	132.81	50

Table 5-12: pH, Alkalinity and Turbidity of the filtrates Generated in the Various Dewatering processes: Sample D (Portsmouth)

Sample With H_2O_2 Dose mg/L	Filtrates From											
	Sand Bed			Vacuum Filtration			Pressure Filtration			Centrifuge		
	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)	pH	Alkalinity mg/L as $caco_3$	Turbidity (NTU)
0	5.7	88.24	12.6	6.03	88.10	8.10	6.08	75.12	10.10	6.15	48.88	68
2.5	6.28	80.27	10.7	6.95	81.57	3.8	6.79	70.18	4.10	6.85	30.30	62
7.5	6.71	81.48	4.3	6.82	83.33	3.5	6.80	78.23	3.5	6.78	28.63	65
15	6.86	83.33	3.5	6.90	81.00	3.5	6.65	69.63	3.5	5.41	30.78	65

Table 5-13: pH, Alkalinity and Turbidity of the filtrates Generated in the Various Dewatering processes: Sample E (Chesapeake)

CHAPTER SIX

DISCUSSION OF RESULTS

Chapter 6

Discussion of Results

6.1 Sludge Characteristics:

Basic sludge characteristics were measured. Sludge solids contents ranged from 0.78 percent minimum to 4.03 percent maximum. Alkalinities of all these sludges were found to be high, (350 - 1400 mg/L as C_aCO_3), as generally expected for water treatment plant sludges. In general, alkalinity was found to increase with increasing solids concentration, except for sludge sample A (Norfolk) (graph 5-2), which showed higher alkalinity values.

In the metal analysis (Table 5-3), all the samples were found to have higher aluminum and iron concentrations, as compared to the manganese concentrations.

Capillary Suction Time (CST):

The CST procedure used to evaluate sludge drainability was very useful for quickly determining the ability of the sludge to release water in the dewatering processes. When evaluating sludge dewatering characteristics, it is important that this test be viewed as a preliminary test to shorten the time required for more expensive dewatering tests that follow. Good CST test results do not guarantee that a sludge can be dewatered on a vacuum filter or pressure filter. Graph 5-2 establishes the possible relationship between sludge CST and initial solids concentration(Co). A definite trend could be seen between the CST and the Co of the sludge. Capillary suction time values increased with increasing C_o of the sludge, except a sludge sample from Norfolk water treatment plant (Norfolk (A)) showed higher CST values than Norfolk (B), even though its Co was lower. One possible reason may be due to the oily nature of sample A (Norfolk), which resulted in a thin film of oil on the filter paper, eventually covering the filter and probably causing the higher CST value. Also, due to the oily nature of this sample a higher volatile solids concentration was observed as compared to the other samples tested.

CST was found to decrease with increasing hydrogen peroxide dosages (Graphs 5-3 and 5-4). Sludge samples from Newport News (Co=0.95%) and Portsmouth (Co=0.78%) were found to behave similarly after the 2.5 mg/l dose of H_2O_2, giving rise to nearly constant CST values.

6.2 Dewatering Processes:

Sand Beds:

The sand bed studies on all the sludge samples illustrate a practical means of sludge dewatering in situations where sufficient land is available to construct adequate sludge drying beds. The addition of hydrogen peroxide improved the rate of gravity drainage. Sludge samples from Newport News and Portsmouth drained rapidly even with a zero mg/l hydrogen peroxide dose. However, a small dose of H_2O_2 to these sludge samples gave rise to about 95 percent drainage within 100 hours of the initiation of drainage. The drainability of sludge samples from Norfolk (sample A and B) and Chesapeake (sample E) water treatment plants, improved significantly with increasing hydrogen peroxide concentration within the 100 hour drainage time.

The sample from Newport News (sample C) showed about 98 percent drainage with a 2.5 mg/l H_2O_2 dose over a 100 hour drainage time, clearly indicating that a 2.5 mg/l dose of H_2O_2 was sufficient to dewater the sludge. In general, it was observed that samples having low Co values showed maximum drainability even with a smaller dose of hydrogen peroxide.

Buchner Funnel Test (Vacuum Filtration):

The Buchner funnel procedure gives a good indication of the relative degree of dewaterability, which could be obtained for each sludge sample and hydrogen peroxide combination. Good results on the Buchner funnel does not, however, guarantee that a particular combination of sludge and H_2O_2 dose will give similar performance on the actual vacuum filter, as the operation and the nature of the filter media is different, and the nature of the cake release is different. One suggested way to improve the correlation between test results and vacuum filter performance is to use the same vacuum filter media material in the Buchner funnel rather than the traditional filter paper.

Experimental results show that the sludge samples from Norfolk (A and B) and Chesapeake (sample E) water treatment plants gave excellent cake solids concentrations, ranging from 20 percent to about 60 percent as compared to the samples from Newport News (sample C) and Portsmouth (sample D), (15 to 25% and 12 to 25%, respectively). It is seen that there is a definite trend in the increase of cake solids concentration with increasing hydrogen peroxide dose and vacuum pressure.

The average specific resistance (r) and the blinding coefficient (β) were determined by equation,

$$\ln t = (\beta + 2) \ln V + \ln \frac{\mu \alpha c}{(\beta + 2) P A^2}$$

as described in the Appendix B.

In general, where the blinding coefficient is less than zero, the average specific resistance decreased as filtration proceeded. This effect may occur with compressible solids in the manner described by Gale [21] such that the layer close to the filter media is subjected to the greatest pressure and therefore, compresses to a greater degree. Each added layer of solids will have a specific resistance slightly less than the preceding layer and therefore, the average specific resistance drops with the final volume. All the samples tested during this experimentation exhibited this behavior, except Norfolk (sample A). The sample A (Norfolk), showed blinding (beta more than zero) giving higher values of specific resistance as filtration proceeded.

During the filtration test for Norfolk (sample A), it was observed that a thin film of oil was deposited on the filter paper. It is suspected that this thin film of oil contributed towards blinding and made it progressively more difficult to dewater, while the dewatering of all other samples improved as filtrate volume increased. To explore this further, blinding coefficients were plotted against the average specific resistance estimated from Buchner funnel data for Norfolk (sample A). Graph 6-1 shows that blinding coefficient (β) and average specific resistance (r) appear to be related. AS the average specific resistance increased to more than 1 x 10^{14} m/kg, blinding always occurred.

Sludge Compressibility Coefficient:

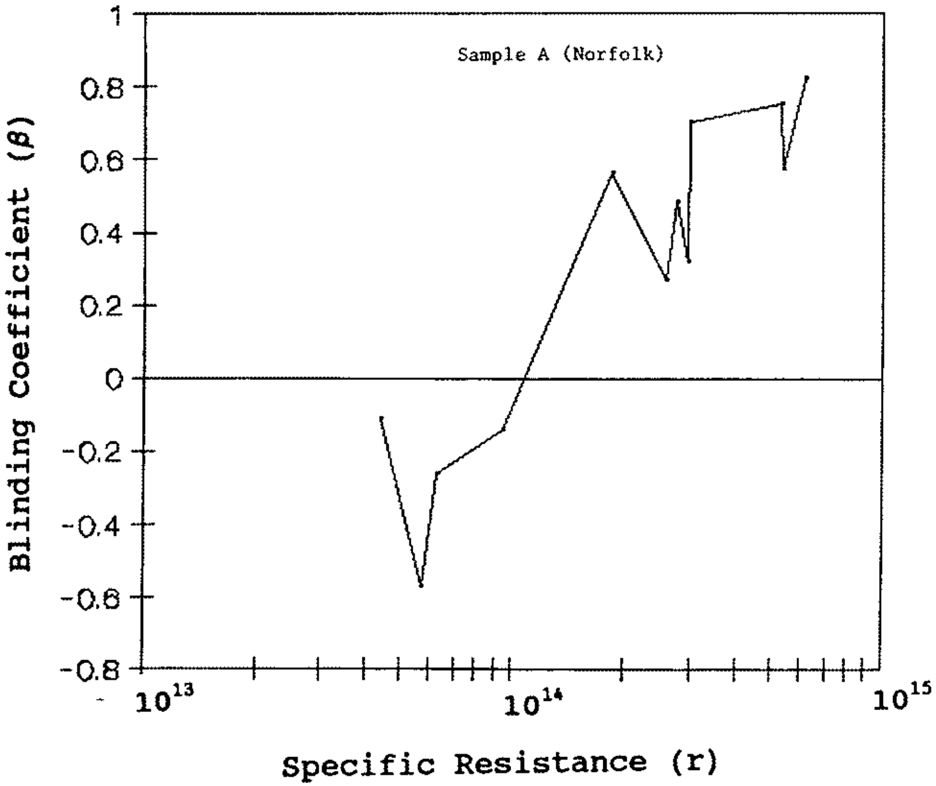
Vacuum pressure is a variable that can be controlled in the prototype, and thus it is advantageous to have an idea how specific resistance varies with pressure. In the formulation of the specific resistance equation, Carman [8] reported that the change in specific resistance with pressure was described by the equation,

$$r = r_1 P^s$$

where r_1 = Constant for a given sludge

s = Compressibility coefficient (zero for an incompressible cake)

A slope of the straight line drawn through a log-log plot of specific resistance versus vacuum pressure gave a calculated compressibility coefficient.



Graph 6-1 Variation of Blinding Coefficient With Specific Resistance: Sample A (Norfolk).

Sludge compressibility coefficients were found to decrease with an increasing hydrogen peroxide dosage, indicating lower specific resistance values for the sludge sample with increasing H_2O_2 concentrations. Table 6-1 lists the values of compressibility coefficient for each sludge sample tested.

Filter Press (Pressure Filtration):

Pressure filtration differs from vacuum filtration in that the liquid is forced through the filter medium by a positive pressure instead of by vacuum.

Graph 5-20 through 5-24 shows the trend of increasing cake solids concentration with increasing pressure and hydrogen peroxide dosage. Sludge samples A and B (Norfolk) again showed higher cake solids concentrations as compared to other three samples.

The specific resistance (r), for this test was calculated from equation 5 (Appendix B). No attempt was made to calculate the blinding coefficient (β) while calculating the specific resistance.

Graphs 5-25 through 5-29 show the variation of specific resistance with applied pressure and H_2O_2 concentration. Specific resistance for sludge samples Norfolk (sample B) and Chesapeake (sample E) decreased with increasing pressure and hydrogen peroxide dose. Surprisingly, sludge samples from Newport News and Portsmouth (sample C and D) showed increases in specific resistance with increasing pressure and H_2O_2

	H_2O_2 Dose (mg/L)			
Sludge Sample	0	2.5	7.5	15
A (Norfolk)	1.58	1.32	1.18	1.03
B (Norfolk)	1.51	1.24	1.05	0.98
C (Newport News)	1.01	0.95	0.91	0.81
D (Portsmouth)	1.01	0.98	0.87	0.80
E (Chesapeake)	1.22	1.15	1.10	1.08

Table 6-1: Sludge Compressibility Coefficient For Sludge Samples with Varying Hydrogen Peroxide Dosage.

concentration. On the other hand, in the Buchner funnel test the specific resistance for these samples was found to decrease with increasing vacuum and H_2O_2 concentration. No probable explanation was found for this behavior.

From this test it was noted that the specific resistance for sludge sample A (Norfolk), decreased beyond 7.5 mg/l H_2O_2 dose as compared to its specific resistance values obtained in the Buchner funnel test.

Centrifuge Test:

Low cake solids concentrations were obtained in this test as compared to the other dewatering processes. In general, the cake solids concentrations were found to increase slightly with increasing H_2O_2 concentration, spin time, and speed of the centrifuge. Although there was a definite trend in the increase of cake solids concentration resembling other test results, no significant benefit of hydrogen peroxide addition was observed.

The low solids concentration could be associated with the batch type of operation employed during the test, rather than a continuous mode of operation.

6.3 Filtrate Analysis:

Data from the metal analysis of the filtrates indicates that most of the Aluminum, Iron and Manganese was retained in the residues. Metal analysis showed that the manganese concentrations increased with increasing hydrogen peroxide dose. Such kind of trend was not observed with iron or aluminum. Interestingly enough, filtrates having higher concentrations of manganese showed lower values of turbidity, especially for filtrates from the sandbed, vacuum filtration, and pressure filtration studies. This may be due to the retention of finer particulates in these processes, which if not retained, would have contributed towards higher turbidity as was observed in the filtrates from the centrifuge test (Table 5-9 through 5-13).

6.4 Mathematical Model:

In order to establish an empirical relationship between the cake solids concentration (Ck), hydrogen peroxide dosage, applied pressure, and the initial solids concentration (Co) of a sludge, a multiple regression analysis was performed to relate these variables.

From the experimental data, it was noted that cake solids concentration (Ck) could be expressed as a function of the hydrogen peroxide dose, applied pressure and the Co of the sludge samples.

$$Ck = f\ (H_2O_2, Pr., Co)$$

Using a SAS [49], system program for statistical analysis, a general equation was determined. This general equation was calculated using the NLIN (A Non Linear regression) and the GLM (General Linear model) procedures. A separate empirical relationship was determined for vacuum filtration and pressure filtration tests as given below.

Vacuum Filtration Test:

$$Ck_v = 19.45 + 0.224\ Co\ [11.58\ H^{0.324} + 0.757\ P_v] \qquad (A)$$

Pressure Filtration Test:

$$Ck_p = 17.63 + 0.224\ Co\ [12.58\ H^{0.333} + 0.152\ P_p] \qquad (B)$$

where,

Ck_v = Cake solids concentration obtained in the vacuum filtration test. (percent)

Ck_p = Cake solids concentration obtained in the pressure filtration test. (percent)

Co = Initial solids concentration of the sample.

H = Hydrogen peroxide concentration (mg/l).

P_v = Vacuum pressure (inches of Hg).

P_p = Applied pressure (psi).

The observed and the calculated values of Ck for both vacuum and pressure filtration tests are tabulated in Appendix D-I and D-II respectively.

The correlation factor (R-Square) for both the equations A and B, was found to be 0.803 and 0.7711 respectively. The significance level of 0.0001 for the independent varaibles in both the models indicate that the independent variables, Pressure, H_2O_2 and C_o contribute significantly to the model.

The experimental results of this investigation clearly showed that the dewaterability of alum sludge can be greatly improved by using small dosages of hydrogen peroxide. Hydrogen peroxide enhanced filterability, drainability, and the resulting cake quality of these sludge samples.

CHAPTER SEVEN

CONCLUSIONS

Chapter 7

Conclusions

Based upon the final experiment on the four sludges, the following conclusions were reached.

1. Hydrogen peroxide generally aids in sludge dewatering, providing higher cake solids concentrations.

2. The 7.5 mg/l and 15 mg/l H_2O_2 dosages showed no significant difference for all the four sludges tested.

3. In the sand bed tests, the cake solids concentration was doubled for samples treated with 7.5 and 15 mg/l Hydrogen Peroxide concentrations over the samples treated with lower Hydrogen Peroxide concentrations.

4. Very low cake solids concentrations were obtained in the centrifugation tests (2 to 15 percent). Hydrogen peroxide addition generally showed no benefit gained.

5. In both vacuum and pressure filtration tests the Cake solids concentration was almost tripled for samples treated

with 7 mg/l and 15 mg/l H_2O_2 dosage over the samples with 0 mg/l H_2O_2 concentration (raw sludges).

6. The empirical models developed for the sludges studied represent a high level of confidence, in predicating cake solids concentrations. Hence, these models may serve a useful purpose for determining the effect of hydrogen peroxide on any particular sludge. However, the general applicability of the models need further confirmation.

7. Due to the diversity in sludge from plant to plant, a laboratory (and possibly pilot) investigation is required in order to determine the optimum hydrogen peroxide dosage and the appropriate dewatering process for any particular sludge.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Albrecht, A.E., "Disposal of Alum Sludge," Jour. AWWA, 64:46 (1972).

2. *American Water Works Association Research Foundation Report*, "*Disposal of Wastes from Water Treatment Plants*," Jour. AWWA, 61:10,541 (1969), 61:11, 619 (1969), 61:12, 681 (1969), 62:1, 63 (1970).

3. *American Water Works Association*, "*Committee Report Publication*," (1978).

4. Bishop, L.B., and Fulton, G.P., "Lagooning and Freezing for Disposal of Water Plant Sludges," Public Works, 99:94 (1968).

5. Bishop, M.M., and Cornwell, D.A., "Alum Recovery and Sand Drying Bed Studies At Durham, North Carolina," AWWA Seminar Proc., "Recent Advantages in Sludge Treatment and Disposal," no. 20190 (1985).

6. Borchardt, et al.,"*Sludge and Its Ultimate Disposal*," Ann Arbor Science Publication (1981).

7. Brosset, C.G., et al., "Studies on the Hydrolysis of Metal Ions, XI the Aluminum Ion Al^{3+}," Acta. Chem. Scand., 8:1917 (1954).

8. Carman, P.C., "Study of the Mechanism of Filtration Part II," Jour. The Soc. of Chem. Ind. (Britain), 53:1597 (1934).

9. Carman, P.C., "Fundamental Principles of Industrial Filtration," Trans. Institution of Chemical Engineers, 16:168 (1938).

10. Chen, C., and Hicks, M.G., "Hydrogen Peroxide Studies of Oxygen Demand," Jour. WPCF, 42:7, 1327 (1970).

11. Coakley, P., and Jones, B.R.S., "Vacuum Sludge Filtration," Sew. Ind. Wastes, 28 (1956).

12. Doe, P.W., "The Treatment and Disposal of Wash Water Sludge," Jour. Inst. Water Engrs., 12:409 (1958).

13. Doe, P.W., Benn, D., and Bays, L.R., "Sludge Concentration by Freezing," Water and Sewage Works, 112:401 (1965).

14. Doe, P.W., and Malmrose, P.E., "Site Tests On The Mechanical Dewatering of Alum Sludge," AWWA Seminar Proc., (1985).

15. Donard, D.A., "Sludge Dewatering and Drying On Sand Beds," EPA. 600/2-78-141 (1978).

16. Dyksen, E., and Gruninger, R.M., "Success Story Times Two," Water and Wastes Engr. (1979).

17. Edwards, J.O., "Peroxide Reaction Mechanisms," Interscience Publishers, John Wiley and Sons, NY.

18. Farrell, B. et al., "Natural Freezing for Dewatering Of Aluminum Hydroxide Sludges," Jour. AWWA, 62:787 (1970).

19. Fulton, G.P., "Disposal of Wastewater from Water Filtration Plants," Jour. AWWA, 61:322 (1969).

20. Fulton, G.P., "Recover Alum to Reduce Waste Disposal Costs," Jour. AWWA, (1974).

21. Gale, R.S., "Filtration Theory With Special Reference to Sewage Sludges," Water Pollution Control, 622 (1967).

22. Gates, C.D., and McDermott, R.F., "Characterization and Condition of Water Treatment Plant Sludges," Jour. AWWA, 60:331 (1968).

23. Glenn, R.W., et al., "Filterability of Water Treatment Plant Sludges," Jour. AWWA, (1973).

24. Haarhoff, J., and Cleasby, J.L., "Comparing Aluminum and Iron Coagulants for In-Line Filtration of Cold Water," Jour. AWWA, 168 (1988).

25. Hayden, P.L., "Aqueous Chemistry of Aluminum (III) and the Solubility and Colloidal Stability of Its Precipitates," Ph.D. Dissertation, Department of Civil Engineering, Ohio State University, (1971).

26. Hayden, P.L., and Rubin, A.J., "Systematic Investigation of the Hydrolysis and Precipitation of Aluminum (III)," Aqueous Environmental Chemistry of Metals, 371 (1974).

27. "Hazardous Waste Regulations," U.S. Environmental Protection, Federal Register 45(98):33063 (1980).

28. Hem, J.D., and Roberson, C.E., "Form and Stability of Aluminum Hydroxide Complexes in Dilute Solutions," Geological Survey Water Supply Paper, 1827-A (1967).

29. Hem, J.D., "Graphical Methods for Studies of Aqueous Aluminum Hydroxide, Fluoride and Sulfate Complexes," Geological Survey, Water Supply Paper, 1827-B (1968).

30. Hitch, B.F., et al., "The Solubility of Gibbsite (α - $Al(OH)_3$) in 1 molal NaCl As A Function Of p^H and Temperature," Oak Ridge National Laboratory, (1980).

31. Hubert, N.L., et al., "Alum Sludge Thickening and Disposal," Jour. AWWA, (1973).

32. Inhoffer, W.R., and Doe, P.W., "Design Of Washwater and Alum Sludge Disposal Facilities," Jour. Inst. Water Engrs., (1958).

33. Keller, P.J., and Cole, C.A., "A Treatment for Filamentous Bulking Using H_2O_2," Purdue Ind. Waste Conference, (1972).

34. King, P.H., et al., "Lagoon Disposal of Water Treatment Plant Wastes," Jour. San. Eng. Div., ASCE, 96:103 (1970).

35. King, P.H., et al., "Treatment of Waste Sludges From Water Purification Plants," Virginia Water Resources Research Center, Bulletin 52 (1972).

36. Knocke, W.R., and Wakeland, D.L., "Floc Property Effects On Sludge Dewatering Characteristics," Virginia Water Resources Research Center, Bulletin 133-4C (1982).

37. Knocke, W.R., and Wakeland, D.L., "Fundamental Characteristics of Water Treatment Plant Sludges," Jour. AWWA, 516 (1983).

38. Krasauskar, J.W., "Review of Sludge Disposal Practices," Jour. AWWA, 225 (1969).

39. Logsdon, G.P., and Edgerly, E.Jr., "Sludge Dewatering By Freezing," Jour. AWWA, 63:734 (1972).

40. Mahoney, P.F., and Duensing, N.J., "Precoat Vacuum Filtration and Natural Freeze Dewatering of Alum Sludge," Jour AWWA, 64:665 (1972).

41. Neubauer, A.E., "Waste Alum Sludge Treatment," Jour. AWWA, 60:819 (1968).

42. Nielsen, H.L., et al., "Alum Thickening and Disposal, Processing Water Treatment Plant Sludges," AWWA Manual 20108 Denver Colorado (1974).

43. Notebaert, et al., "A New Deduction With a Large Application to the Specific Resistance to Filtration of Sludges," Water Res., 9:667 (1975).

44. Novak, J.T., and Calkins, D.C., "Sludge Dewatering and Its Physical Properties," Jour. AWWA, 67:42 (1975).

45. Novak, J.T., et al., "The Blinding of Sludges During Filtration," Jour. WPCF, 60:206 (1988).

46. Ohio River Valley Water Sanitation Commission , "Waste Water Discharge from Water Treatment Plants," Report by Gates and Associates., (1981).

47. Palin, A.T., "Treatment and Disposal Of Alum Sludge," Proc. Soc. Water Treatment and Examination, 3:131 (1954).

48. "Safe Drinking Water Act," Public Acts of the Legislature, 399:325.1001-235.1023 (1976).

49. "SAS" System Programs, SAS Institute Inc., Cary, NC, (1985).

50. "Standard Methods for the Examination of Water and Wastewater," 14th ed. Washington, D.C.: American Public Health Assoc, (1979).

51. " 'TYSUL' W. W. Hydrogen Peroxide," Waste water Handbook, E.I.Dupont de Nemours and Co (Inc), Industrial Chemicals Department, Wilmington, DE 19898.

52. Vesilind, P.A., "Treatment and Disposal of Wastewater Sludges," Revised Ed., Ann Arbor, Mich.: Ann Arbor Science (1979).

53. Westerhoff, G.P., and Daley, M.P., "Water Treatment Plant Waste Disposal," Jour. AWWA, (1974).

54. Wilhelm, J.H., and Silberblatt, C.E., "Freeze Treatment of Alum Sludge," Jour. AWWA, 66:312 (1976).

55. Young, E.F., "Water Treatment Plant Sludge Disposal Practices in the United Kingdom," Jour. AWWA, 60:717 (1968).

APPENDICES

APPENDIX (A)

CAKE SOLIDS CONCENTRATION FOR SANDBED DRAINAGE TEST

Cake Solids Concentration (C_k) (Percent)

Sludge Sample	Hydrogen Peroxide Concentration mg/L			
	0	2.5	7.5	15
A (Norfolk)	4	10.80	15.10	19.15
B (Norfolk)	5.82	10.34	18.52	22.43
C (Newport News)	4.12	6.57	15.16	17.15
D (Portsmouth)	3.10	7.10	9.66	14.0
E (Chesapeake)	5.8	10.28	12.31	18.10

Cake Solids Concentration (C_k) Obtained
In Sand Bed Drainage Test

APPENDIX (B)

SPECIFIC RESISTANCE

SPECIFIC RESISTANCE:

Specific Resistance is defined as the resistance to fluid flow exerted by a Cake of unit weight dry solids per unit area. Historically, this term was developed through Carman's application of Darcy's law to filtration of compressible sludge under constant pressure.

The rate of water removal from sludge by filtration has been described by several Investigators (9,11) as:

$$\frac{\left(\frac{dv}{dt}\right)}{A} = \frac{P}{\mu R_T} \qquad (1)$$

where $\frac{dv}{dt}$ = change in filtrate volume with time

A = Filter area

p = Pressure drop

R_T = Total resistance to filtration

and

μ = Filtrate viscosity

Total resistance to filtration has been separated into resistance created by the deposited filter cake, R_c and resistance created by the filter media, R_m.

Equation (1) may be modified, so that, cake resistance can be expressed as ''Specific resistance" or resistance per unit of dry mass deposited per unit area, Equation (1) then becomes

$$\frac{dv}{dt} = \frac{PA}{\mu(\frac{\bar{r}cv}{A} + R_m)} \qquad (2)$$

where $\bar{r}$ = specific resistance of the sludge cake and cv/A = Mass of dry solids deposited in the cake per unit volume of filtrate

Integrating equation (2) and rearranging yields

$$t/v = \frac{\mu \bar{r} cv}{2PA^2} + \frac{R_m \mu}{PA} \qquad (3)$$

Equation (3) is used to determine the specific resistance $\bar{r}$, from a filtration test by plotting t/v versus v. Equation (3) can be expressed in the form

$$t/v = bv + a \qquad (4)$$

such that the slope of the plot b is given by

$$b = \frac{\mu \bar{r} c}{2PA^2} \qquad (5)$$

solving for $\bar{r}$

$$\bar{r} = \frac{2PA^2 b}{\mu c} \qquad (6)$$

Use of equation (6) for sludge characterization assumes a certain cake composition consistency. However, factors that may affect cake consistency, sludge particle compression, and migration of fines, may occur during the course of filtration. Where these cake changes occur, validity of equation (6) may be in question.

Notebaerl et al (43) found that for some sludges when t/v versus v is plotted to calculate the specific resistance could not be considered constant but rather varied over the filtration cycle.

They attributed an increase in $\bar{r}$ as being caused by media plugging, often referred to as blinding. Notebaerl et al (43) further showed that if the data from Buchner funnel filtration test were plotted as the log time versus the log of the filtrate volume, the slope of this line could be used to indicate the extent of media plugging.

Notebaerl et al (43), described the change in specific resistance with filtrate volume using an equation of the form

$$\bar{r} = \alpha v^{\beta} \tag{7}$$

where

α = the specific resistance value for the initial volume of filtrate and

$\bar{r}$ = average specific resistance over the entire filtered volume

β = constant characterizing 'Blinding'

If equation (7) is substituted in equation (2) and the media resistance, R_m can be neglected, the following equation is found.

$$\frac{dv}{dt} = \frac{PA^2}{\mu \alpha c v^{\beta+1}} \tag{8}$$

Integration of this equation from t = 0 and v = 0 to time t and volume v yields

$$t = \frac{\mu \alpha c}{(\beta + 2) PA^2} v^{\beta+2} \tag{9}$$

Taking logarithms of both sides.

$$\ln t = (\beta + 2)\ln v + \ln \frac{\mu\alpha c}{(\beta + 2)PA^2} v^{\beta+2} \tag{10}$$

By plotting lnt versus lnv, a straight line results with slope equal to $\beta + 2$ and intercept equal to $\frac{\mu\alpha c}{(\beta + 2)PA^2}$ for a Buchner test, values for c, μ, p and A can be determined permitting the unique determination of α and β of each filtration test.

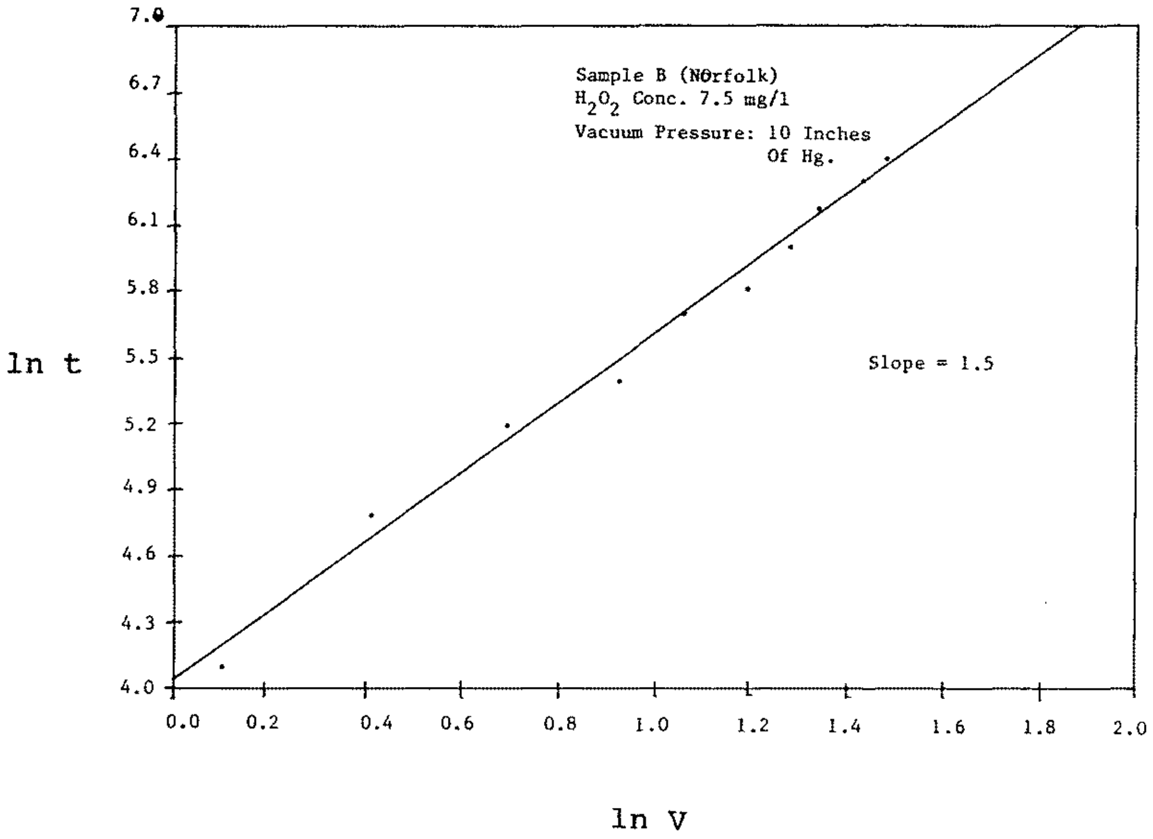
Sample B (Norfolk)

H_2O_2 Concentration: 7.5 mg/l

Vacuum Pressure: 10 inches of Hg

Min	Sec	V (ml)	ln V	ln t
0	-	-	-	-
1	60	1.1	0.10	4.09
2	120	1.50	0.41	4.78
3	180	2.0	0.69	5.19
4	240	2.50	0.92	5.40
5	300	2.90	1.06	5.70
6	360	3.30	1.19	5.80
7	420	3.60	1.28	6.0
8	480	3.80	1.34	6.17
9	840	4.20	1.43	6.30
10	600	4.40	1.48	6.40

Vacuum Filtration Test Data



Plot of ln V Versus ln t

From the graph on ln V versus ln t

Slope = $(\beta + 2) = 1.50$

Intercept = 4.11

Using equation (10) (Appendix B)

$$\text{Intercept} = \frac{\mu \alpha c}{(\beta + 2) P A^2}$$

$$\therefore \alpha = \frac{4.11 \ (\beta+2) P A^2}{\mu c}$$

$$\alpha = 9.42 \times 10^{12}$$

μ = Viscosity of water ($N\text{-}S/m^2$)
A = Filter Area (m^2)
P = Vacuum Pressure (N/m^2)
c = wt of cake deposited per volume of filtrate (kg/m^3)

From equation (7) (Appendix B)

$$\bar{r} = \alpha v^{\beta}$$

$\bar{r}$ = Average specific resistance over the entire filtered volume

$\therefore$ for the total filtered volume of 20 ml

$$\bar{r} = 9.42 \times 10^{12} \ V^{-0.5}$$

$$\bar{r} = 2.10 \times 10^{12}$$

APPENDIX (B-I)

SPECIFIC RESISTANCE AND BLINDING COEFFICIENT VALUES FOR VACUUM FILTRATION TEST

Specific Resistance $\bar{r}x10^{13}$

H_2O_2 Concentration Mg/L	Vacuum Pressure (in of Hg)		
	10	15	20
0	6.25	5.72	29.70
2.5	4.39	27.60	53.60
7.5	18.40	25.50	61.50
15	9.43	29.40	53.10

Blinding Coefficient

Vacuum Pressure (in of Hg)		
10	15	20
-0.26	-0.57	+0.70
-0.11	+0.48	+0.57
+0.56	+0.27	+0.82
-0.14	+0.32	+0.74

Sample A (Norfolk)

H_2O_2 Concentration Mg/L	Vacuum Pressure in of Hg		
	10	15	20
0	1.23	0.85	3.256
2.5	0.78	1.14	1.33
7.5	0.21	0.89	0.99
15	0.64	0.90	1.10

Vacuum Pressure in of Hg		
10	15	20
-0.66	-0.73	-0.59
-0.49	-0.43	-0.28
-0.50	-0.41	-0.31
-0.45	-0.43	-0.26

Sample B (Norfolk)

H_2O_2 Concentration Mg/L	Vacuum Pressure in of Hg		
	10	15	20
0	0.95	1.14	1.91
2.5	0.96	1.32	2.10
7.5	0.80	1.33	1.94
15	0.81	1.34	1.95

Vacuum Pressure in of Hg		
10	15	20
-0.30	-0.39	-0.24
-0.32	-0.30	-0.62
-0.07	-0.21	-0.58
-0.07	-0.21	-0.58

Sample C (Newport News)
Specific Resistance and Blinding Coefficient Values for Vacuum Filtration Test

Specific Resistance $\bar{r}x10^{13}$

H_2O_2 Concentration Mg/L	Vacuum Pressure (in of Hg)		
	10	15	20
0	1.10	1.61	2.35
2.5	1.35	2.18	2.72
7.5	1.63	2.48	2.92
15	1.47	2.28	2.37

Blinding Coefficient

Vacuum Pressure (in of Hg)		
10	15	20
-0.30	-0.39	-0.50
-0.45	-0.34	-0.25
-0.53	-0.43	-0.38
-0.53	-0.42	-0.42

Sample D (Portsmouth)

H_2O_2 Concentration Mg/L	Vacuum Pressure in of Hg		
	10	15	20
0	2.46	1.69	5.49
2.5	0.59	0.77	0.89
7.5	0.41	0.76	0.97
15	0.55	0.94	1.06

Vacuum Pressure in of Hg		
10	15	20
-0.66	-0.73	-0.60
-0.63	-0.52	-0.49
-0.74	-0.58	-0.35
-0.66	-0.57	-0.45

Sample E (Chesapeake)

Specific Resistance and Blinding Coefficient Values for Vacuum Filtration Test

APPENDIX (B-II)

SPECIFIC RESISTANCE VALUES FOR PRESSURE FILTRATION TEST

		Specific Resistance $\bar{r}$ x 10^{13}		
Sample	H_2O_2 Concentration mg/L	Applied Pressure (PSI)		
		40	60	80
A (Norfolk)	0	90.20	38.90	45.80
	2.5	72.50	83.80	89.10
	7.5	47.50	85.20	86.30
	15	36.40	56.40	85.00
B (Norfolk)	0	9.19	9.45	10.31
	2.5	6.92	8.21	9.73
	7.5	4.24	5.92	7.32
	15	5.72	7.28	7.35
C (Newport News)	0	1.31	1.97	2.65
	2.5	1.86	2.0	2.68
	7.5	1.87	3.42	3.51
	15	1.35	2.23	3.53
D (Portsmouth)	0	1.62	2.44	3.28
	2.5	2.28	2.45	3.30
	7.5	2.30	4.21	4.31
	15	1.65	2.73	4.32
E (Chesapeake)	0	18.40	18.80	21.70
	2.5	11.90	14.60	17.30
	7.5	7.32	10.50	13.0
	15	5.19	4.32	5.25

Specific Resistance Values Obtained in the Pressure Filtration Test

APPENDIX (C)

CAKE SOLIDS CONCENTRATION FOR CENTRIFUGE TEST

Sample A (Norfolk)

H_2O_2 mg/L	1000 RPM (738.47 G)			3000 RPM (2058.00 G)			5000 RPM (4028.00 G)		
	1 Min.	2 Min.	3 Min.	1 Min.	2 Min.	3 Min.	1 Min.	2 Min.	3 Min.
0	3.6	3.7	3.85	4.21	4.5	4.23	5.06	5.02	5.6
2.5	4.2	4.56	5.57	4.58	4.6	5.63	5.15	5.31	6.5
7.5	3.8	4.10	6.2	4.05	4.23	5.75	5.22	5.38	6.93
15	3.90	4.21	6.32	4.25	4.62	5.82	5.31	5.62	7.1

Sample B (Norfolk)

0	4.5	5.3	5.87	7.68	7.82	8.1	8.95	9.12	9.82
2.5	5.1	5.42	5.93	7.88	8.2	8.4	9.64	9.88	13.15
7.5	5.28	5.641	6.14	8.17	8.35	8.58	9.81	10.15	13.45
15	5.4	5.8	6.20	7.86	8.42	8.62	9.88	12.30	13.63

Sample C (Newport News)

0	1.50	1.82	1.99	2.89	2.91	3.19	3.80	3.91	4.42
2.5	1.52	1.75	2.08	2.91	3.05	3.38	3.93	4.30	4.93
7.5	1.70	1.86	2.0	2.98	3.15	3.41	4.03	4.72	4.85
15	1.8	1.79	2.26	3.07	3.35	3.62	4.23	4.54	4.83

Sample D (Portsmouth)

0	2.56	2.82	3.01	3.50	3.72	4.68	4.28	4.68	5.48
2.5	2.58	2.88	3.11	3.61	3.81	4.66	4.47	4.73	5.63
7.5	2.58	2.91	3.18	3.72	3.98	4.79	4.52	4.88	5.71
15	2.59	2.99	3.19	4.12	4.15	4.96	4.81	5.23	7.12

Sample E (Chesapeake)

0	3.2	3.51	4.38	4.91	5.22	7.52	6.32	7.28	8.15
2.5	3.4	3.73	4.39	4.96	6.28	7.68	6.55	7.54	9.22
7.5	3.45	3.85	4.44	5.13	6.81	7.81	6.82	7.63	9.86
15	3.80	3.96	5.62	6.27	6.91	8.10	6.97	8.41	10.82

Cake Solids Concentration (C_k) (Percent)
Obtained in Centrifuge Test

APPENDIX (D-I)

EXPERIMENTAL AND CALCULATED VALUES OF CAKE SOLIDS CONCENTRATION

(Vacuum Filtration Test)

Experimental

H_2O_2 Concentration Mg/L	Vacuum Pressure (in of Hg)		
	10	15	20
0	15.45	21.0	22.61
2.5	20.77	21.60	32.95
7.5	21.70	36.10	40.67
15	23.44	37.14	48.58

Calculated

Vacuum Pressure (in of Hg)		
10	15	20
24.59	27.16	29.74
35.19	37.76	40.33
39.72	42.29	44.86
43.52	46.09	48.67

Sample A (Norfolk)

Experimental

H_2O_2 Concentration Mg/L	Vacuum Pressure (in of Hg)		
	10	15	20
0	17.45	18.28	19.70
2.5	24.98	47.40	29.76
7.5	40.28	42.64	41.89
15	42.50	49.0	54.56

Calculated

Vacuum Pressure (in of Hg)		
10	15	20
26.28	29.69	33.12
40.34	43.76	47.18
46.36	49.76	53.19
51.52	54.82	58.25

Sample B (Norfolk)

Vacuum Filtration Cake Solids
(C_k) Concentration (Percent)

Experimental

H_2O_2 Concentration Mg/L	Vacuum Pressure (in of Hg)		
	10	15	20
0	15.30	16.15	18.20
2.5	17.12	18.0	19.52
7.5	19.41	20.50	20.60
15	22.10	26.57	24.80

Calculated

Vacuum Pressure (in of Hg)		
10	15	20
21.06	21.86	22.67
24.37	25.18	25.98
25.73	26.59	27.40
26.98	27.78	28.59

Sample C (Newport News)

Experimental

H_2O_2 Concentration Mg/L	Vacuum Pressure (in of Hg)		
	10	15	20
0	12.01	17.18	18.47
2.5	13.06	15.22	15.85
7.5	13.68	16.58	18.50
15	18.34	20.19	22.67

Calculated

Vacuum Pressure (in of Hg)		
10	15	20
20.77	21.43	22.09
23.49	24.15	24.81
24.65	25.31	25.98
25.63	26.29	26.95

Sample D (Portsmouth)

Vacuum Filtration Cake Solids
(C_k) Concentration (Percent)

Experimental

H_2O_2 Concentration Mg/L	Vacuum Pressure (in of Hg)		
	10	15	20
0	15.28	17.45	18.01
2.5	18.12	18.23	22.43
7.5	19.96	21.91	26.61
15	28.75	32.38	34.58

Calculated

Vacuum Pressure (in of Hg)		
10	15	20
23.28	25.19	27.11
31.16	33.08	35.00
34.54	36.45	38.37
37.37	39.28	41.20

Sample E (Chesapeake)

Vacuum Filtration Cake Solids
(C_k) Concentration (Percent)

APPENDIX (D-II)

EXPERIMENTAL AND CALCULATED VALUES OF CAKE SOLIDS CONCENTRATION

(Pressure Filtration Test)

Experimental

H_2O_2 Concentration Mg/L	Applied Pressure (PSI)		
	40	60	80
0	16.06	18.01	18.85
2.5	20.05	21.04	22.11
7.5	25.85	27.64	29.16
15	40.10	41.61	44.10

Calculated

Applied Pressure (PSI)		
40	60	80
21.77	23.84	25.91
33.38	35.45	37.52
38.52	40.59	42.66
42.87	44.94	47.01

Sample A (Norfolk)

Experimental

H_2O_2 Concentration Mg/L	Applied Pressure (PSI)		
	40	60	80
0	16.23	17.0	18.90
2.5	22.48	25.71	28.13
7.5	30.15	34.65	38.08
15	45.59	49.05	55.34

Calculated

Applied Pressure (PSI)		
40	60	80
23.12	25.86	28.60
38.51	41.26	44.00
45.32	48.06	50.81
51.09	53.83	56.58

Sample B (Norfolk)

Pressure Filtration Cake Solids
(C_k) Concentration (Percent)

Experimental

H_2O_2 Concentration Mg/L	Applied Pressure (PSI)		
	40	60	80
0	14.20	15.30	18.10
2.5	16.90	17.10	18.10
7.5	19.24	19.68	20.45
15	2.10	23.42	24.32

Calculated

Applied Pressure (PSI)		
40	60	80
18.92	19.57	20.21
22.55	23.20	23.84
24.15	24.80	25.45
25.51	26.16	26.81

Sample C (Newport News)

Experimental

H_2O_2 Concentration Mg/L	Applied Pressure (PSI)		
	40	60	80
0	15.20	16.0	17.15
2.5	17.30	17.28	17.65
7.5	17.70	19.16	19.38
15	22.28	21.64	22.71

Calculated

Applied Pressure (PSI)		
40	60	80
18.69	19.22	19.75
21.67	22.20	22.73
22.99	23.52	24.05
24.10	24.63	25.17

Sample D (Portsmouth)

Pressure Filtration Cake Solids
(C_k) Concentration (Percent)

Experimental

H_2O_2 Concentration Mg/L	Applied Pressure (PSI)		
	40	60	80
0	14.42	15.15	18.20
2.5	19.21	21.11	22.82
7.5	20.10	25.12	28.18
15	28.34	30.95	35.48

Calculated

Applied Pressure (PSI)		
40	60	80
20.70	22.24	23.78
29.34	30.88	32.42
33.16	34.70	36.23
36.39	37.93	39.47

Sample E (Chesapeake)

Pressure Filtration Cake Solids
(C_k) Concentration (Percent)