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SORPTIVE AND GEOTECHNICAL CHARACTERISTICS OF KAOLINITE

by

Chi-Yuan Shih

Thesis submitted to the Faculty of the Graduate School of the New Jersey Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Civil/Environmental Engineering.

1988

APPROVAL SHEET

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ACKNOWLEDGEMENT

The author wishes to express his gratitude and appreciation for the guidance and advice given to him by his advisor, Dr. Paul Chan, Professor, throughout this study. His constant encouragement and enthusiasm boosted the morale of the author during the difficult times. The financial support was given to him by Dr. Chan's "realease time" through the Center of Hazardous Waste Management at New Jersey Institute of Technology.

The author is also grateful to Ms. Jane Wu, Chemist, for her kind assistance, comments, and suggestions.

Futhermore, the author wishs to thank his friends who helped him during these four years at NJIT.

Last, but not least, the author wishes to dedicate this thesis to his parents and beloved wife whose sacrifices and endless encouragement gave him the necessary inspiration for the completion of ths study.

ABSTRACT

Title of Thesis: Sorptive and Geotechnical Characteristics
of Kaolinite

Chi-Yuan Shih, Master of Science in Civil/Environmental
Engineering

Thesis directed by: Dr. Paul C. Chan
Professor of Civil/Environmental
Engineering

The sorption/desorption behavior of phenol and chlorobenzene as well as their influence on geotechnical characteristics of kaolinite were studied. The results reveal that the sorption process follows closely with the Freundlich adsorption isotherm whereas the sorption/desorption ratio depends upon the characteristics of organic compounds.

A series of geotechnical properties tests was also undertaken after achieving equilibrium at different concentrations of organic compounds. It was found that the parameters such as liquid limit, plastic limit, optimum moisture content, and dry density increase with an increasing concentration of organic compounds

The relationship between the geotechnical properties and sorption behavior of soils provides the information necessary in predicting the pollutant transport in the

groundwater system. The variation of geotechnical properties due to sorption process is of paramount importance in construction engineering, such as the design of the liner in hazardous waste disposal site.

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CHAPTER 1 INTRODUCTION

In 1963, McGuinness [1] predicted that the water consumption in the United State would reach 1700 x 10^4 m^3/d by 1980 and 3360 x 10^4 m^3/d by the year 2000. However, according to the estimation of Murray [2], the use of water was over 3000 x 10^4 m^3/d in 1965. Since this estimate of water consumption in 1965 is higher than that of McGuinness, the actual present day consumption must greatly exceed the prediction of McGuinness. Today, 50% of the nation's drinking water comes from groundwater resources, while our rural areas are 95% dependent upon groundwater. Therefore, it is imperative that every possible precaution be taken to protect the purity of this resource. In the New Jersey area, the total groundwater pumpage is 1000 mgd, with almost 60% of it withdrawn from the unconsolidated Coastal Plain aquifers of southern New Jersey, while the remaining 40% is from the sand and gravel and rock aquifer of northern New Jersey [3].

Recently, many leakages were found in the hazardous waste disposal site due to the breakage of liners [4], thus contaminating the groundwater. For example, in New Jersey, the PJP landfill created a serious problem in groundwater resources [5]. Since much of the dump is uncovered and fires sometimes occurred above and below ground, volatile organics and other toxics were released. These hazardous substances have been detected in the groundwater and run-off. In

Alabama, the Cadillac landfill was constructed in 1979 over a 100-feet thick of impermeable clays. The clay liner was guaranteed by the waste site management not to leak for at least 10,000 years. Unfortunately, the EPA staff memorandum indicates that the site was leaking and creating groundwater contamination after five years of construction [6].

Most contamination is related to land disposal of industrial and municipal wastes as well as leaks and spills of petroleum and chemical products. For example, where industrial waste was disposed of in upper layers of the earth's surface in the form of landfills, such wastes may result in changes of physical, chemical, or biological processes of the in-situ soil system. When precipitation or groundwater goes through and makes contact with disposed solid wastes containing hazardous substances, the water can dissolve toxic pollutants from the wastes to become leachate. Anderson [7] has pointed out that acids can solubilize minerals in clays and change their geotechnical properties, including permeability. If design or operation is imperfect, the leachate can move out of the site and reach the groundwater or aquifer, thus having serious environmental and health effects.

As mentioned above, groundwater is the major water resource in the United States. However, much of the groundwater has been contaminated by hazardous waste from disposal sites. The development of waste management is a crucial step in solving this problem. This study is intended to provide basic data in sorption characteristics and their influence upon geotechnical properties of soils which is needed in groundwater modelling and environmental geotechnical construction.

CHAPTER 2 LITERATURE REVIEW

Clay soils have been used as liners in landfill construction because of their low permeability and sorption characteristics. However, the effects of sorption/desorption of the physical and chemical properties of soil are not well understood at this time. Recently, much effort has been expanded towards the understanding of sorption behavior for organic polluants.

Mackay and Cherry [8] have pointed out that sorption and retardation can be used to determine the movement and concentration of contaminants in groundwater system. Freeze and Cherry [1] also illustrated the significance of sorption action in groundwater transportation.

Generally, based on the principle of mass transfer, the development of solute transport in groundwater can be expressed as :

(rate of mass inflow) - (rate of mass outflow)
± (rate of mass transfer through a source or sink)
± (rate of mass depletion prediction by sorption)
= rate of change of solute mass in solution (1)

The sorption, as seen in Equation (1), plays an important role in the groundwater contaminant transportation system. Most modelling of the transport of sorbing organics has followed the Freundlich isotherm

$$S = K_p * C^n \qquad (2)$$

where S = (g sorbed solute)/(g soil)

C = (g dissolved solute)/(cm^3 pore water)

n = constant.

The value of K_p (partition coefficient) depends on the nature of the soil, the solute, and to a less extent the nature of the aqueous phase. For flow through homogeneous porous media with linear sorption , the retardation factor can be expressed as :

$$R = 1 + (K_p \rho_b / n) \qquad (3)$$

where ρ_b= the bulk density of soil

n = the soil porosity

The retardation factor, R, is also expressed in the relationship between the migration velocity and physical groundwater velocity. Hence, the K_p value can affect the determination of R. Furthermore, it can affect the transportation of organic contaminants. The partitioning of solutes between liquid and solid is determined by laboratory experiment and expressed in a two-ordinate graphical form (S/M vs C) where S/M is the sorption ability. The transfer by sorption/desorption can retard the advance rate of the contaminant.

In a series of studies, Uchrin and Mangels[9], Katz[10], and Southworth and Keller[11], evaluated the sorption and desorption equilibrium for local or particular soils by organic compounds and determined that the sorption processes for these system is not completely reversable and that the resistant component of desorption should be developed from the slope of the linear isotherm - Freundlich Isotherm - of sorption.

DiToro[12] also proved that the consecutive desorption isotherm can be approximated by a straight line, at least for the first few consecutive desorption processes. The reversible component exhibits no hysteresis if the concentration of the aqueous solution concentration is changed but does not exceed the initial concentration. This means the reversible component will react and increase because of increased solution concentration.

The studies cited above show detailed investigation for the relationship between sorption and desorption by organic compounds on soils. Also, the sorption and desorption models were developed by mathematics -Freundlich equilibrium isotherm - which is helpful for this study in order to use the same analytical procedures. From the Freundlich isotherm formula, the sorption capacity and Kp can be calculated and the equilibrium isotherm shown to be linear.

The parameters that affect sorption/desorption capacity are concentration of solution, pH, surface charge, type of solution, and grain size of sorbent. There are a series of researchers, Southworth and Keller[11], Roy and Griffin[13], Anderson and Pankow[14], Fu and Luthy[15], and Hassett and Banwart[16], who have drawn the same conclusion that the concentration of organic solution is a very important parameter. In their studies, different water solubility and octanol-water partition coefficients were used to explain the relationship between sorption/desorption and the linear Frendlich isotherm. In other words, the octanol-water partition coefficient indirectly expressed the concentration of organic solution. They found the octanol-water partition coefficient increased and the sorption capacity increased too, but not indefinitely. Also, the sorption of organic partition coefficients are inversely, semi-logarithmically related to the concentration of solution used.

Balon[17], Garcia-Miragaya and Davalos[18], and Semu[19] proved that the pH of the solution can vary the sorption capacity of the soil. In their studies, the pH values were found to alter the surface charge condition of the soil, the activity of the sorbent and the surrounding environment of the sorbent. Different organic compounds have been found to have various optium pH regions. In this study, the pH value 4-5 is the better region for the sorption between organic solution and kaolinite.

The surface charge is related to the capacity of sorption/desorption and it decides the type of sorption. Felsol and Dah[20], Nir[21,22], and Stanffer and MacIntyre[23] found that organic compounds' sorption and cation in soils should be in agreement with the Freundlich isotherm models. Also, their results indicated the sorption capacity increased in a consistent order at higher surface charges. This means that different sorbents can provide for different sorption capacity requirements. Generally, organic compound sorption in soil almost always is due to Van der Waal force, hydrogen bonding and double layer phenomenon. Those experiments can provide the information to help this study to explain the mechanism of binding between soils and organic solutions - phenol and chlorobenzene.

Abdul[24] investigated the effect of grain size on the sorption equilibrium by aquifer materials. The results showed that the smaller the grain size, the better the sorption capacity. This is due to increased contact surface area and also increased contact opportunity between sorbent and solution.

Although the methods of determining index properties were documented, the variations of relationships between index properties and chemical interaction (sorption) have not been explored completely. Also, from the discussion of Grim[25], it is revealed that the index properties can be altered by the surface activities of the solid phase of the soil. The soil index properties of compressive strength, permeability, and Atterburg limit etc. were used to evaluate the feasibility of construction engineering, but were not applied to the environmental field. At a hazardous waste disposal site, the soil properties can provide significant information for making the decision on which soil is suitable as a liner, be utilized to estimate how much settlement will develop in the disposal site, and help develop the model for the dispersion of groundwater contamination. Index properties are good indicators and can be used to handle the problem of treating the hazardous waste quickly because of their ease and high reliability.

In this study, the important factors were identified and quantified around the binding characteristics and sorption properties following the Freundlich isotherm. The mechanisms of interaction, index properties, and kinetics of sorption were also studied.

CHAPTER 3 THEORETICAL CONSIDERATION

3.1. Introduction

The objectives of this study are to discuss the sorption capacity and removal ratio (desorption capacity) for organic compounds on kaolinite. Also, the connections between kaolinite and organic compounds are to be discovered.

An other purpose is to consider the physical properties of kaolinite when soaked with organic compounds. As a result of geotechnical tests including plastic limit, liquid limit, compression test, specific gravity etc., the index variation was determined to aid in the prediction of sorption capacity.

Sorption is recognized as a significant phenomenon in most natural physical, chemical, and biological processes. Sorption involves the accumulation at interface or the concentration of substances at a surface or interface. The process can occur at an interface between any two phases, such as, liquid-solid, liquid-gas, or gas-solid interfaces.

Desorption is a process in which the substances are removed from the surface or interface by extra forces. The material being concentrated or sorbed is the sorbate, and the sorbing phase is termed the sorbent.

3.2. Types of sorption

Kaolinite has a net negative charge. The negative charge is due to the flat surface that is resemble to the octahedral layer which in turn to develop a positive charge and causes the edge surface to be negatively charged. The charge on the edge surface is balanced by the ions of opposite charge which are in the acid organic solution surrounding the kaolinite particles. The phenomenon of charge balance can be referred to as the double layer. The double layer consists of the kaolinite particle negative charge and equivalent amount of ionic charge which is accumulated in liquid near the particle surface. The ions are attracted by the negative charge surface of kaolinite. Simultaneously, those ions have a tendency to diffuse back into the bulk solution when concentration is low. In Figure 1, the distribution of positive and negative ions is represented.

Basically, the Stern model presented the relationship between attraction and repulsion forces. The inner layer of Figure 1 is called the Stern layer and the outside layer, the diffuse layer. In the Stern layer, the ion concentration is greatest near the surface of kaolinite and decreases linearly further away. In the diffuse layer, the ion distribution decreases roughly exponentially with increasing distance. The Stern potential energy is the summation of attraction and repulsion potential energy. When the ion

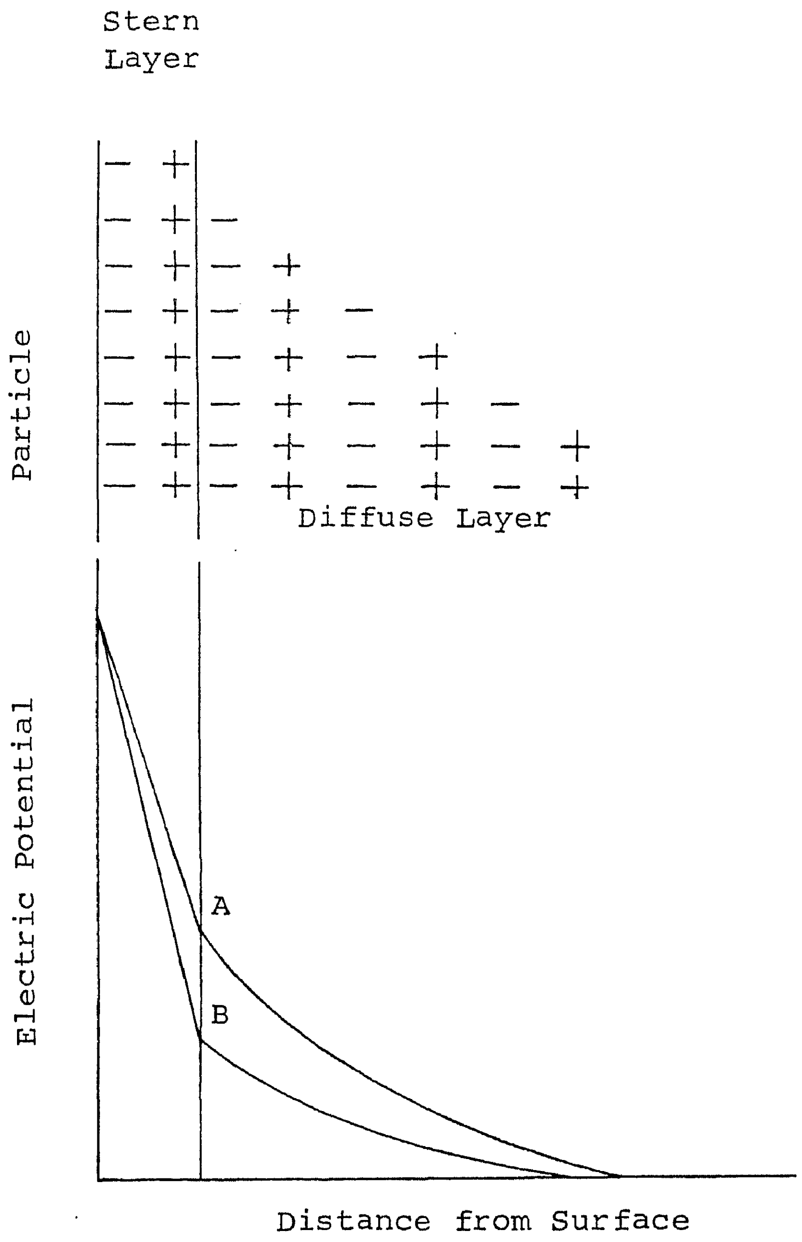


Figure 1 Stern's Model of the Potential Distribution in the Electron Double-Layer

concentration is increased, the additional ions compress the diffuse layer and go into the Stern layer from the diffuse layer. Hence the Stern potential energy will decrease. This means that the attraction force is increased and the ions quickly exceed the Stern potential energy and adhere on the kaolinite surface. There is continuous interchange between the ions within the double layer and the ions in the solution. An equilibrium condition occurs when the positive ion - net negative charge system is balanced. The opposite ion is attracted on the surface and can not penetrate the surface.

Where there are double layers of two particles with the same polarity, repulsion will take place. If the particle adheres, there must be attractive forces present which exceed the repulsion forces of the double layer. Generally, the Van der Waals force plays this role. The adsorption from Van der Waals force is termed physical adsorption.

3.3 Factors influencing sorption

The solubility of the solute in the solvent has an important effect on adsorption equilibria. The strength of the bonds between solute and solvent determines the degree of solubility. When solubility is low, solute-solvent bonds are weak and easily broken.

The relative polarity of sorbent and sorbate also is a necessary factor for sorption. A solute prefers the phase which is closest to it in polarity. The kaolinite surface is only slightly polar and prefers sorbates with low polarity. Thus, a favorable situation on kaolinite is a low polarity solute in a polar solvent such as water.

An organic compound with a simple structure, kaolinite prefers neutral species over charged species. As With many organic acids or bases in aqueous systems, the amount of adsorption decreases with increasing ionization. Since the degree of ionization of a compound in water is affected by the pH value, the adsorption of an ionized specie changes with the pH of the solution.

3.4. Sorption equilibria and the sorption isotherm

Positive sorption in a solid-liquid system results in the removal of solutes from solution. The concentration of the solute remaining in solution is in a dynamic equilibrium at the solid surface that is referred to as equilibrium condition. The equilibrium distribution ratio is determined by the sorption process. It may be a function of the concentration of the solute, the concentration and nature of competing solutes, or the nature of the solution. The preferred form for depicting this equilibrium distribution is to express the quantity q_e as a function of C at a fixed temperature. The expression of this type is termed a sorption isotherm.

3.5. Freundlich isotherm equation

The Freundlich isotherm equation is widely used in this field[10,11,12]. It can clearly indicate the relationship between sorption/desorption capacity and concentration of solution. Also, the sorption partition coefficients can be determined easily.

The Freundlich isotherm equation is shown as follows:

$$\frac{X}{M} = K_p * C^{1/n}$$

where X = amount of solute sorbed at an equilibrium state,

M = weight of sorbent (kaolinite)

C = concentration of solution remaining at an equilibrium state,

and K_p,n = experimental constant for the Freundlich sorption isotherm.

The Freundlich isotherm can be rewritten

$$\log \frac{X}{M} = \log K_p + \frac{1}{n} \log C$$

If the sorption relationship conforms to the Freundlich model, the plot of x/m vs C on log-log paper can be linearized.

Values for K_p and 1/n are calculated from regression equations as the intercept and the slope of a straight line. For all conditions, the best fit is a linear isotherm with the 1/n value near 1. K_p, the partition coefficient, is the measurement for strength of adsorption and can be used to compare the sorption of different solutions on various sorbates. Theoretically, the higher the values of K_p and 1/n are, the better the sorption capacity. However, the value of K_p is only a linear function of the concentration, whereas 1/n is an exponential function.

3.6. The correlation of chemical/geotechnical properties

There are several geotechnical properties which are useful to study when making a judgment of soil properties, namely, the Atterburg limit, compression test, and specific gravity. These parameters are important indices in this study.

3.6.1. Plastic and liquid limits

Plastic limit is the lowest moisture level and is expressed as a percentage by weight of oven dried soil which can be rolled into threads of 1/8 inch in diameter without breaking into pieces. Liquid limit is the moisture content expressed as a percentage by weight of oven dried soil at which the soil will just begin to flow when jarred slightly. Although the limit values are based on simple empirical tests, they have been found to be very useful as index properties which may be correlated by more fundamental means. When the organic contaminants are added to clay soil, they connect with kaolinite by double layer reaction and produce hydrogen or Van der Waal force binding. The suppression of hydrogen ionization can cause the replacement of

OH^- with an organic compound and form the other basic salt polymer. Then, the organic compounds are sorbed by kaolinite and the moisture content also is changed. The Atterburg limit depends on the moisture content and changes after sorption.

3.6.2. Shear strength, optimum moisture content, and dry density

Shear strength is measured by the shearing strength at maximum displacement before failure. It is usually determined under conditions of increasing load pressure. Theoretically, organic contaminants inserted into a void of clay particles would cause an increase in attracting forces depending upon the characteristics of the organic contaminants. Shear strength also relies on optimum moisture content and dry density. Lambe and Martin[18] have shown that halloysite soils have low compacted dry-density values and that maximum density is obtained with high moisture contents (optimum moisture contents). These data show that at low moisture contents the density decreases because of the interaction of cation. The organic compounds are added and sorbed by kaolinite. The resulting optimum moisture content is changed because of the exchange between the organic compound and water. The kaolinite needs more water to reach the point of optimum moisture content. Directly, the shear strength and dry density also varies.

3.6.3. Specific Gravity

Specific gravity is the ratio of the mass of a unit volume of a material at a stated temperature to the mass in air of the same volume of gas-free distilled water at a stated temperature. When the adsorption is complete, the organic compounds take over the water and are on the surface of the kaolinite. Since the boiling point of the organic compound is higher than normal room temperature, the structure of binding for organic compounds and kaolinite particles does not alter. There is no great variation in specific gravity.

CHAPTER 4 METHOD AND MATERIALS

Sorption and desorption, ultilizing phenol and chlorobenzene as organic solutions, were studied in a batch test. Since the solution flow of the batch test is neither entering nor leaving the reactor, the liquid solution is mixed completely and has more opportunity to contact with soil particles. The tendency of sorption and desorption can thus be presented easily.

4.1. Soil Sample

4.1.1. Structure of the kaolinite

The sample used, Standard Air floated Kaolinite, is from the Georgia Kaolinite Company, Inc. The chemical representation of a kaolinite layer is $(Si_2O_5)Al_2(OH)_4$ implying layers of $n(Si_2O_5)^{2-}$ linked to $(Al_2(OH)_4)^{2+}$ units which are based on an hexagonal silica network.

These layers have little net negative charge, which is due to the edge surface which may require a positive charge. The opposite charge which is from the solution is joined together with the negative charge on the kaolinite surface. Interaction between the sorbent surfaces and the solute can vary from the weak Vander Waal's force up to the strong electron-static interaction such as hydrogen bonding.

4.1.2. Geotechnical Properties

The measurement of geotechnical properties[26,27,28] was done following the American Society for Testing and Materials' (ASTM) standards. The results are given in Table 1.

4.1.3. Chemical Properties

The chemical properties of the sample kaolinite was furnished by Georgia Kaolinite Company Inc. and are given in Table 2.

4.1.4. Solute Characteristics

Phenol and chlorobenzene[29] were selected for examination because of their univeral presence in industrial waste and their ease of extraction and measurement. Also, phenol and chlorobenzene are the 52nd and 14th priority pollutants rsepectively of the Toxic Pollutant List included in P.L.500 under part 307(a) which concerns toxic material[30].

4.1.4.(a) Phenol

Phenol is a compound that has a hydroxyl group attached directly to an aromatic nucleus. The structure of phenol is as below:

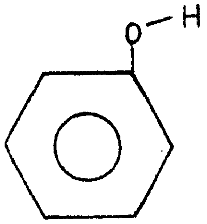


Table 1. Geotechnical properties for kaolinite.

Item of geotechnical property	experimental data
moisture content	1.39%
liquid limit	43.80%
plastic limit	22.30%
pH in distilled water	5.10
pH in $CoCl_2$ solution	4.83
specific gravity	2.58
dry density	1.61 g/cm^3
stress	63.5 psi
grain size	
a) average diameter	240 um
b) geometric standard	1.46

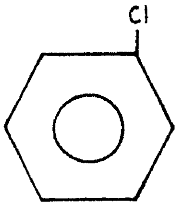
Table. 2. Chemical properties for kaolinite.

Item of chemical property	content(%)
SiO_2 (combine)	45.1
Al_2O_3 (combine)	38.1
TiO_2	1.4
Fe_2O_3	0.6
Na_2O	0.3
MgO	0.2
K_2O	0.1
CaO	trace

Pure phenol is a colorless solid or liquid. It boils at 180 °C which is much higher than room temperature. The physical properties are described in Table 3. Since phenol is hydrophilic compound, it is easy to form hydrogen bonding on the kaolinite surface.

4.1.4.(b) Chlorobenzene

The compound in which a chlorine atom has replaced a hydrogen atom in benzene is known as chlorobenzene. A formula is written with one group at the top carbon atom of the hexagon as below



The double bonding is included to indicate that the ring is aromatic.

Chlorobenzene is liquid at room temperature, and boils at 132°C. The physical properties are described as Table 3.

Phenol and chlorobenzene, although represented by a simple chemical formula C_6H_5OH and C_6H_5Cl, are in reality highly complex entities. The presence of those ions in solution plays an important role in aligning the dipoles of the C_6H_5-O-H and C_6H_5-Cl molecules. Also, they readily ionize and in some circumstances behave as a grouping dissociated into phenoxide and chlorobenzene oxidized ions, $(C_6H_5\text{-O-})^-$ and $(C_6H_5)^+$, and hydrogen ions and chlorine ions, (H^+) and (Cl^-). This behavior is responsible for acidic properties of solutions and for the colloidal characteristics of suspensions. These statements apply to phenol and chlorobenzene which do not contain strongly electron-attracting groups in the nucleus.

Table 3. Physical properties of phenol and chlorobenzene

Item	phenol	chlorobenzene
toxicity sp.	5 ppm, skin, 8 hrs. TWA.	78 ppm, skin, 8 hrs. TWA.
boiling point (1atm)	182 °C	132 °C
vapor pressure @ 25 °C, mm of Hg	0.35	11.8
vapor density (air = 1)	3.24	3.90
solubility in water (%)	6	0.049
sp. Gr. (water = 1)	1.07	1.11
molecular weight	94.11	112.56
dipole moment (debyes)	1.45	1.69

4.2. Procedure

4.2.1. The geotechnical properties of soil after sorption

This study was done to compare the geotechnical properties of kaolinite before and after sorption. A Soil sample was sorbed with phenol and chlorobenzene with different concentrations over 24 hours and then the test was done following the ASTM standards.

4.2.2. The sorption-desorption batch test

The batch technique was used to evaluate the equilibrium of sorption and desorption. The sorption equilibrium studies were conducted in several 50 ml teflon-lined screw cap test tubes, each of which was dispensed with 40 ml aqueous phenol solution at six different concentrations; the weight of clay was 4 grams. The test tubes were shaken in a Junior Orbit Shaker (Lab-Line Instrument, Inc.) with 250 oscillations/min and withdrawn at specific time intervals for analysis. One tube was left empty to serve as a blank. The results are given in Table 4 and 5 for phenol and chlorobenzene respectively. The effect of time on sorption is shown in Figure 2 and 3 for phenol and chlorobenzene respectively. It was found that the time required for reaching equilibrium in kaolinite clay was less than 2 hours. Therefore the provision of 3 hours for a reaction period was sufficient to ensure that an equilibrium state was attained. The temperature for the equilibrium study was maintained at $23 \pm 1^{o}C$.

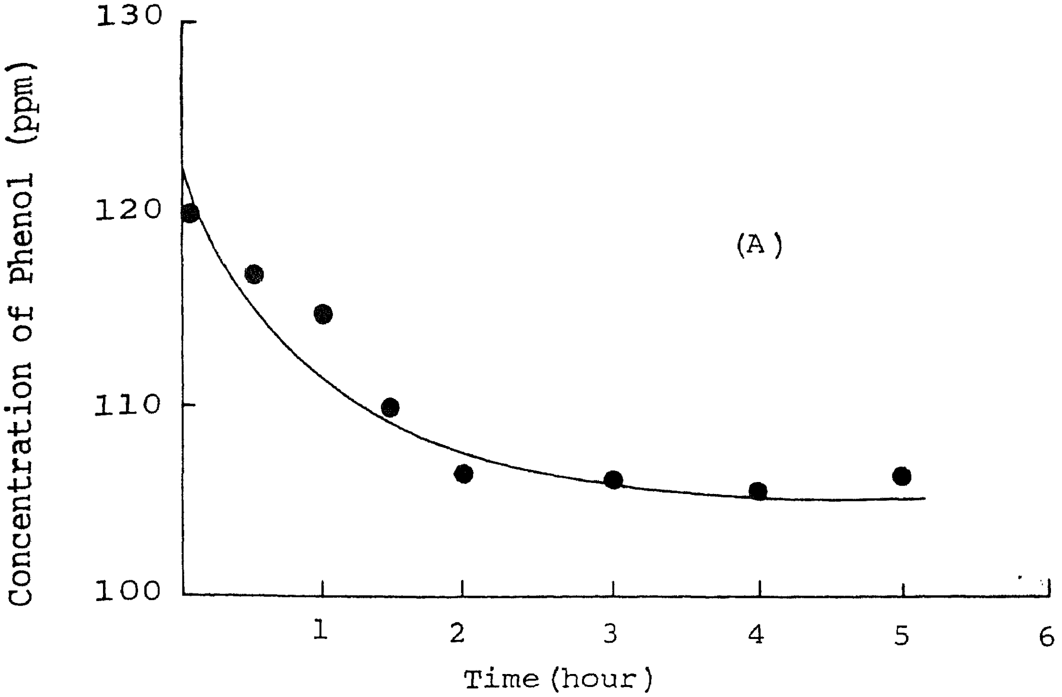
Once the shaking was completed, a 20 ml sample from the supernatant was removed and centrifuged to settle the soil and get a clear solution. Then 1 ul of clear solution was injected into a gas chromatograph to test for the residual concentration of the organic compound. The difference between the amount of organic compound in the supernatant and the amount initially present in the solution

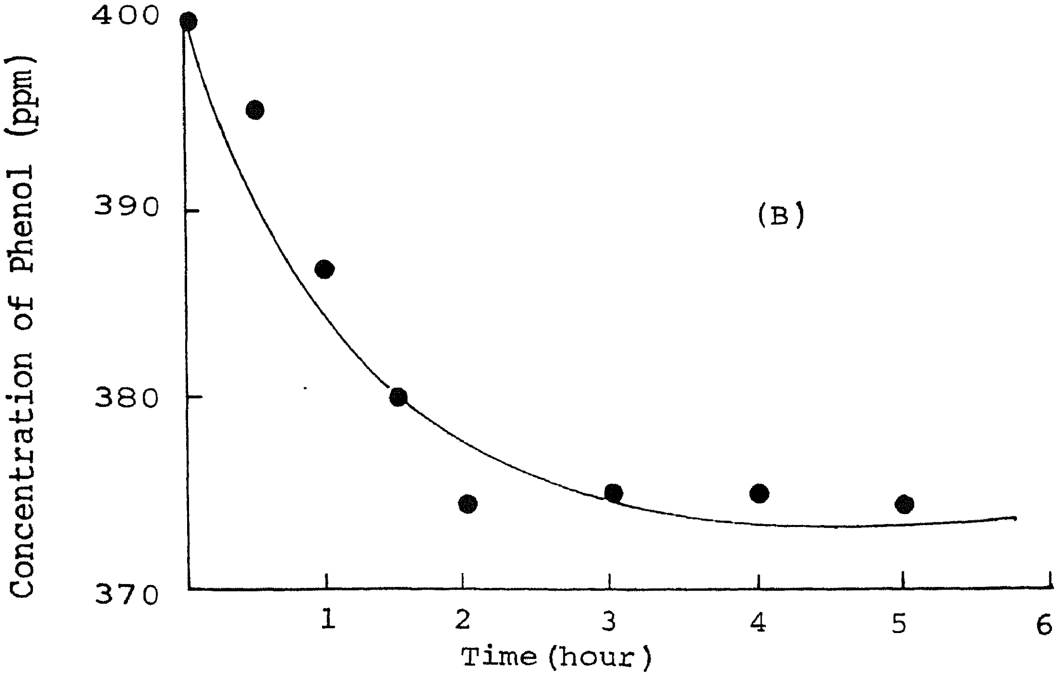
Table. 4. Time effect on sorption with phenol by kaolinite.

Initial conc. Time(min)	120	405	635	815
5	120	400	628	782
30	117	395	620	774
60	115	387	611	768
90	110	380	604	766
120	107	374	593	765
180	107	375	592	762
240	106	375	597	764
300	107	374	591	763

Table 5. Time effect on sorption with chlorobenzene by kaolinite

Initial conc. Time(min)	100	153	200	256
5	98	151	196	250
30	97	149	193	244
60	96	147	190	240
90	95	146	188	237
120	96	145	186	237
180	97	144	186	235
240	96	144	185	234
300	96	145	184	234


(A)
Concentration of Phenol (ppm)
130
120
110
100
Time (hour)
1
2
3
4
5
6


(B)
Concentration of Phenol (ppm)
400
390
380
370
Time (hour)
1
2
3
4
5
6

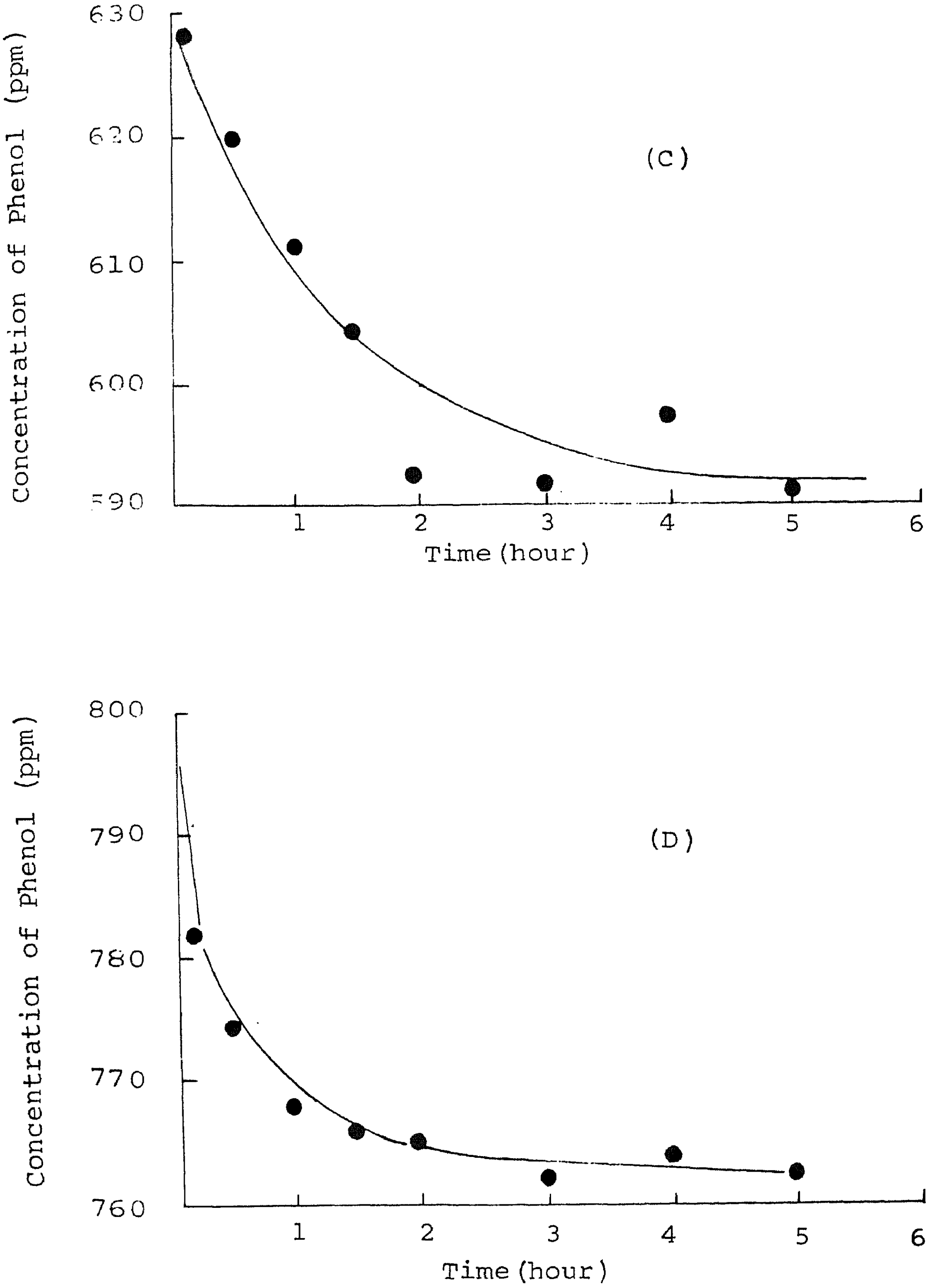
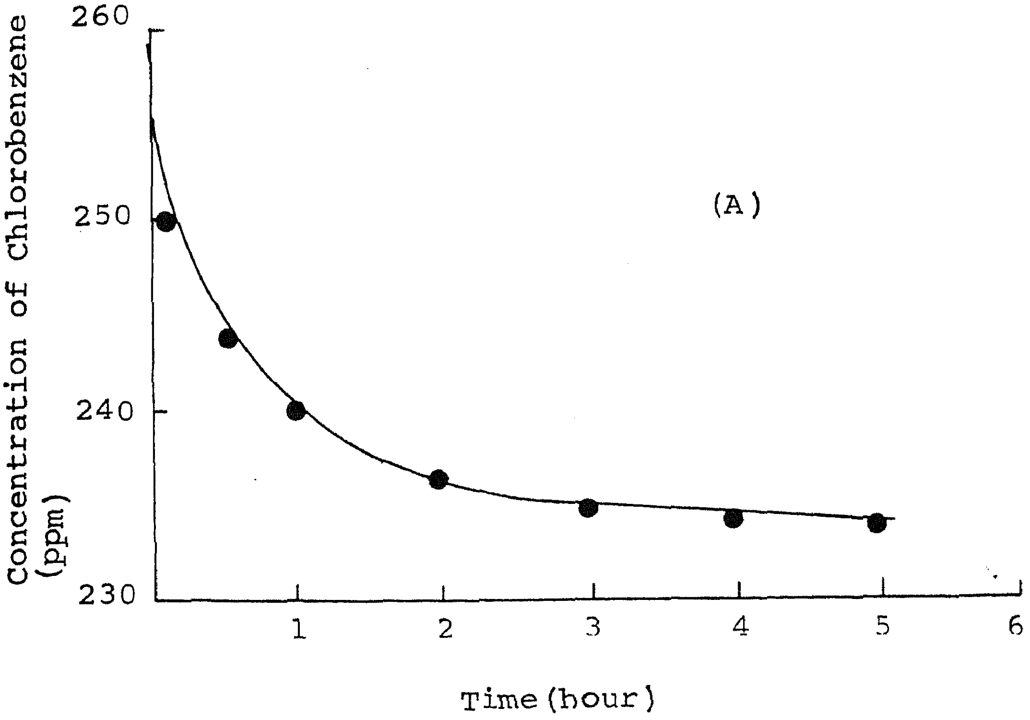
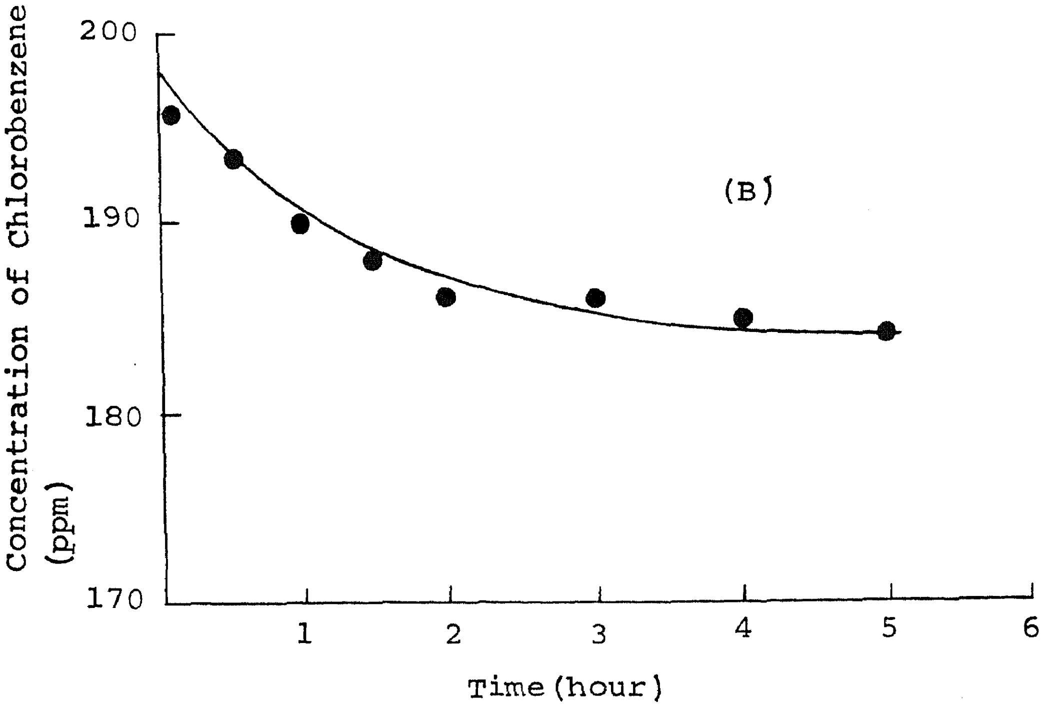


FIGURE 2 Effect of time on sorption of phenol with kaolinite


(A)
Concentration of Chlorobenzene (ppm)
260
250
240
230
1
2
3
4
5
6
Time (hour)


(B)
Concentration of Chlorobenzene (ppm)
200
190
180
170
1
2
3
4
5
6
Time (hour)

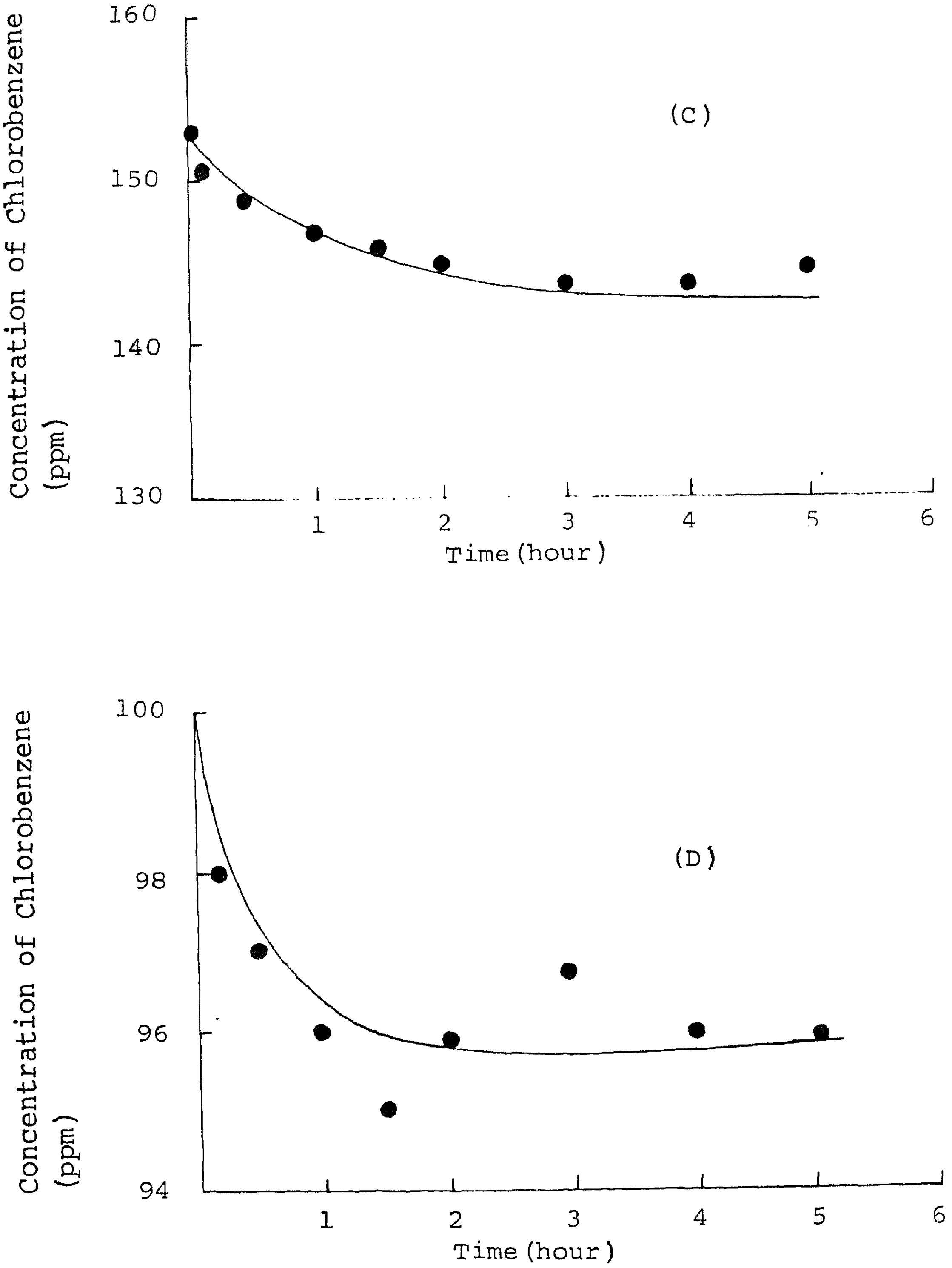


FIGURE 3 Effect of time on sorption of chlorobenzene with kaolinite

was taken as the amount of organic compound sorbed by the kaolinite. Then 20 ml of organic free distilled water was added to the tube and shaken in the same manner as the sorption study for desorption tests.

4.3. Chemical analysis

The study was performed on a Varian 3700 Gas Chromatograph equipped with two packed columns (1% s.p.-1240 for phenol and 10% s.p.-2100 for chlorobenzene, DA.100/120 supelcoport, from Supelco Inc.), flame ionization detector system, Perkin Elmer 024 recorder, and Varian CDS 111 recorder. Table. 6. lists the instrumental conditions employed[31].

The standard curve was plotted by injecting the standard solution which was prepared before the chemical analysis. According to the area under the peak in the recorder of the G.C., the standard curve, area vs concentration of the phenol and chlorobenzene solution, were plotted for phenol and chlorobenzene respectively as a straight line as shown in Figures 4 and 5. The corresponding concentration of a sample was found once the area under the peak in the recorder of the G.C. was known.

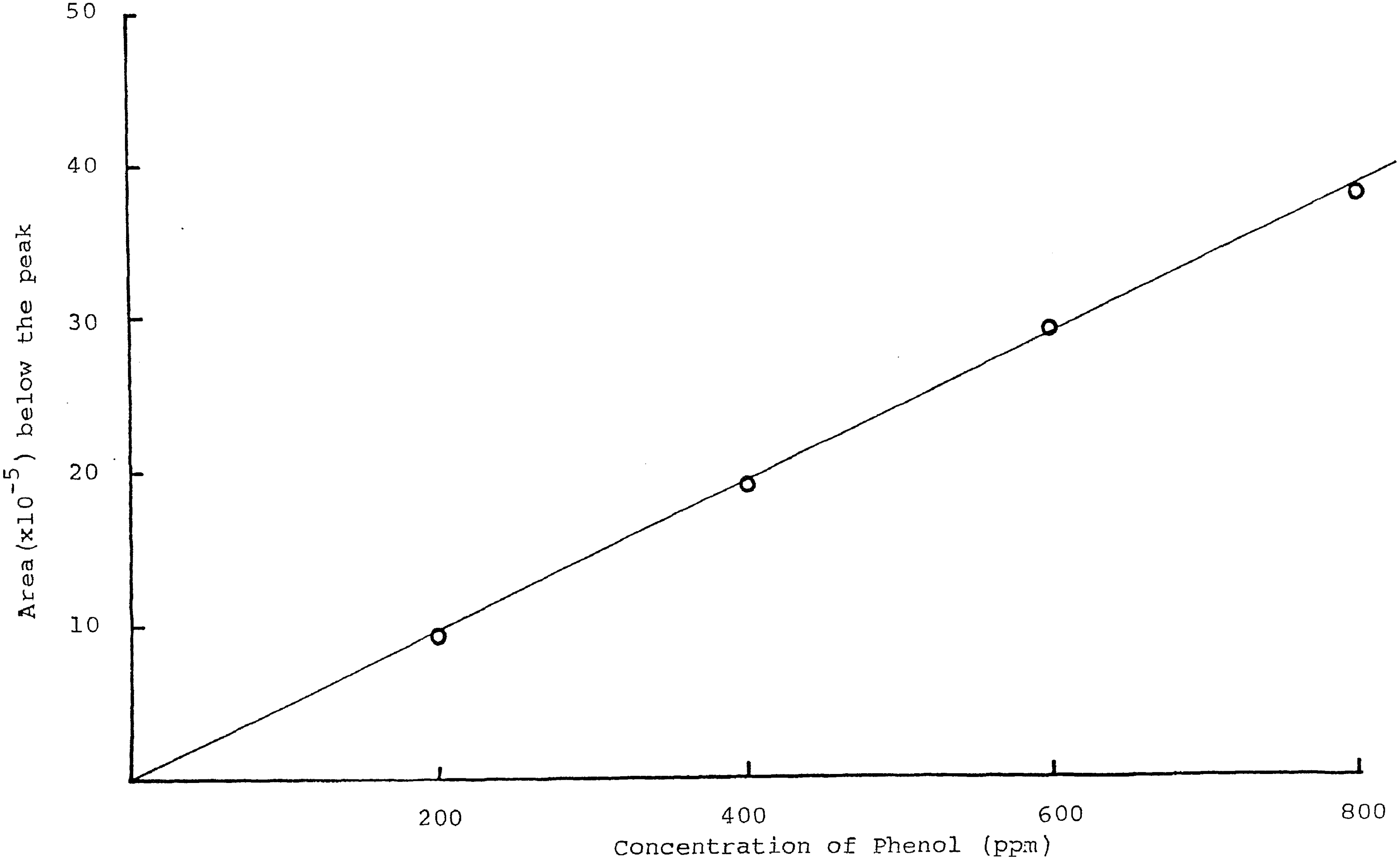


FIGURE 4 Standard curve for phenol in G.C.

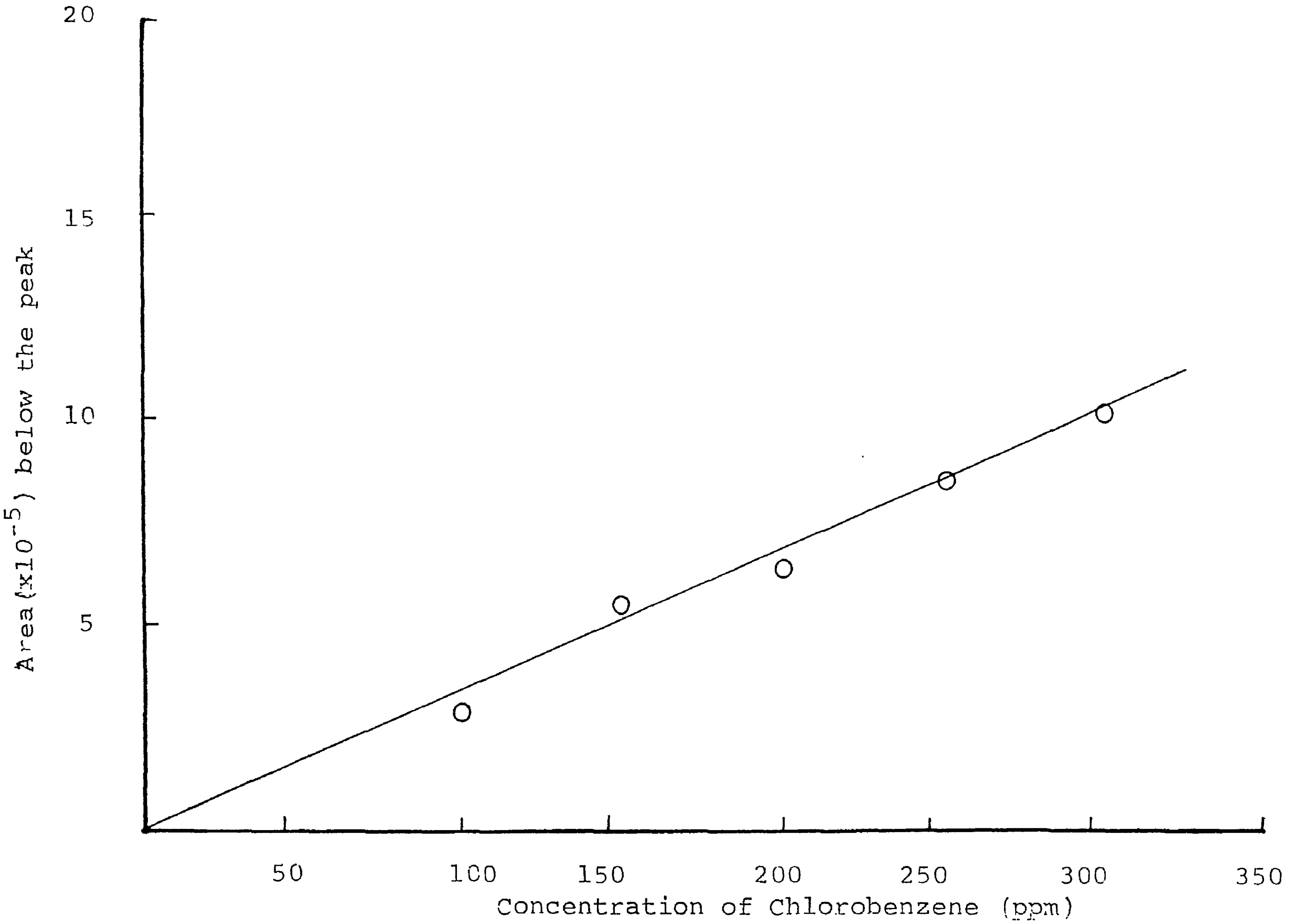


Figure 5 Standard curve for chlorobenzene in G.C.

Table 6. The Gas Chromatograph operation condition for measurement of phenol and chlorobenzene.

Item	Instrument Conditions	
	phenol	chlorobenzene
chromatograph	Varian 3700 gas chromatorgraph	Varian 3700 gas chromatorgraph
columns	1% s.p-1240, DA 100/120 supelcoport	10% s.p-2100, DA 100/120 supelcoport
linear velocity	30 cm^3/min at 50°C	20 cm^3/min at 50°C
carrier gas	nitrogen 99.99% at 60 psi	nitrogen 99.99% at 60 psi
Detector temperature	220°C	200°C
column temperature	50°C for 5 min; 20°C/min to 180°C; 180°C for 5 min.	50°C for 3min; 20°C/min to 150°C; 150°C for 5 min.
detector	FID 30 cm^3/min for nitrogen Auxiliary gas hydrogen 30 cm^3/min air 300 cm^3/min	FID 20 cm^3/min for nitrogen Auxiliary gas hydrogen 30 cm^3/min air 300 cm^3/min

CHAPTER 5 RESULTS AND DISCUSSION

In this chapter, the sorption/desorption phenomenon and the variation of geotechnical properties with phenol and chlorobenzene are presented. Furthermore, the correlation between chemicals and kaolinite can be explained in this study.

5.1. Sorption/desorption of kaolinite with phenol

There is a development of weak bonds between the basal oxygen atoms of the kaolinite plane and the upper hydroxyl group of organic compounds. This layer of kaolinite contains oxygens linked with adjacent silicons which makes the edge surface that will show negative tendency. Since the phenol can offer a higher positive ion (H^+) concentration on the near surface of kaolinite, an interchange between H^+ and negative double layers of kaolinite will occur. When the positive-negative system is balanced, the phenol molecules are attracted on the kaolinite surface but not into the surface.

The sorption isotherm for phenol is shown in Figure 6, which was fitted to the data in Table 7. Equation 3, based on a study of the sorption of phenol by kaolinite, describes the relationship between C and X/M. It was obtained using the least square method as shown below and Table 8.

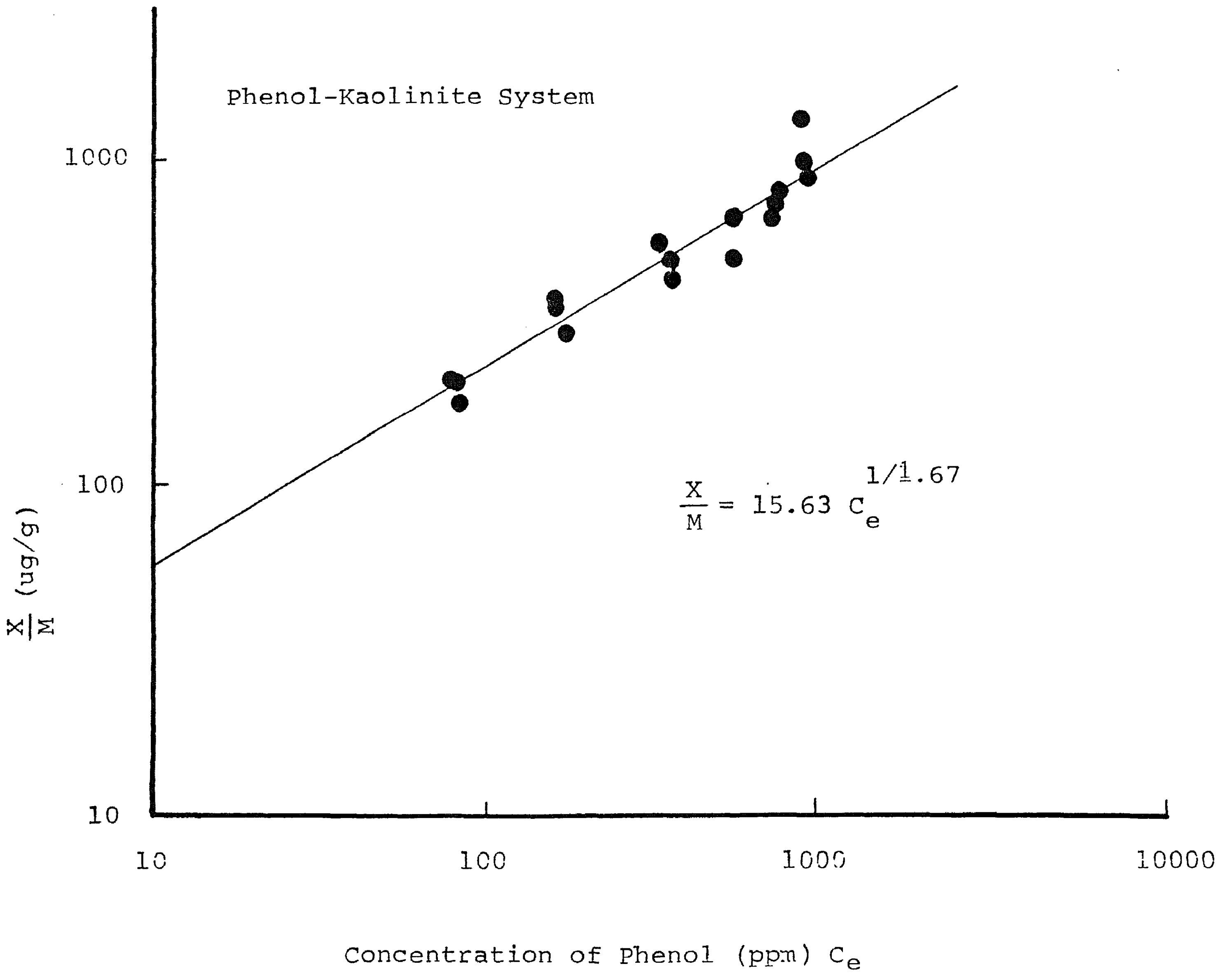


FIGURE 6 Freundlich sorption isotherm for phenol

Table 7. Sorption of phenol by kaolinite.

Set 1

Initial conc. (ppm)	conc.(ppm) after adsorption	X (ppm)	$\frac{X}{M}$(ug/g)	Log $\frac{X}{M}$	Log C
1000	865	135	1350	3.13	2.94
800	750	82	820	2.92	2.88
600	532	68	680	2.83	2.73
400	356	44	440	2.64	2.55
200	170	30	300	2.48	2.23
100	78	22	220	2.34	1.89

Set 2

1000	898	102	1020	3.01	2.95
800	734	66	660	2.82	2.86
600	550	50	500	2.70	2.74
400	349	51	510	2.71	2.54
200	160	40	400	2.60	2.20
100	82	18	180	2.26	1.91

Set 3

1000	905	95	950	2.98	2.96
800	725	75	750	2.88	2.86
600	535	65	650	2.81	2.73
400	343	57	570	2.76	2.52
200	162	38	380	2.58	2.21
100	78	22	220	2.34	1.89

because $$\text{Log}\ \frac{X}{M} = \text{Log}\ K + \frac{1}{n}\ \text{Log}\ C$$

then $$\text{Log}\ K = \frac{\sum\text{Log}(X/M) * \sum(\text{Log}C)^2 - \sum\text{Log}C * (\sum\text{Log}C * \text{Log}(X/M))}{N * \sum(\text{Log}C)^2 - (\sum(\text{Log}C))^2}$$

$$= \frac{(48.83 * 117.5892) - (45.52 * 124.9715)}{(18 * 117.5892) - (45.52)^2}$$

$$= 1.1941$$

therefore $K = 15.6315$

$$\frac{1}{n} = \frac{N * \sum((\text{Log}C) * (\text{Log}(X/M)) - (\sum\text{Log}C * \sum\text{Log}(X/M))}{N * \sum(\text{Log}C)^2 - (\sum(\text{Log}C))^2}$$

$$= \frac{(18 * 124.9715) - (45.52 * 48.83)}{(18 * 117.5892) - (45.52)^2}$$

$$= 0.6005$$

therefore $n = 1.665$

The Freundlich isotherm formula for kaolinite with phenol is

$$\frac{X}{M} = 15.6315 * Ce^{1/1.665} \qquad (3)$$

The intercept of the fitted linear isotherm, corresponding to what is commonly called the distribution coefficient, was computed to be 15.6315.

Desorption is rapid but non-reversible at the concentration tested here. Because of the higher polarity of water, the water molecules replaced the phenol on the kaolinite surface after five consecutive washings by

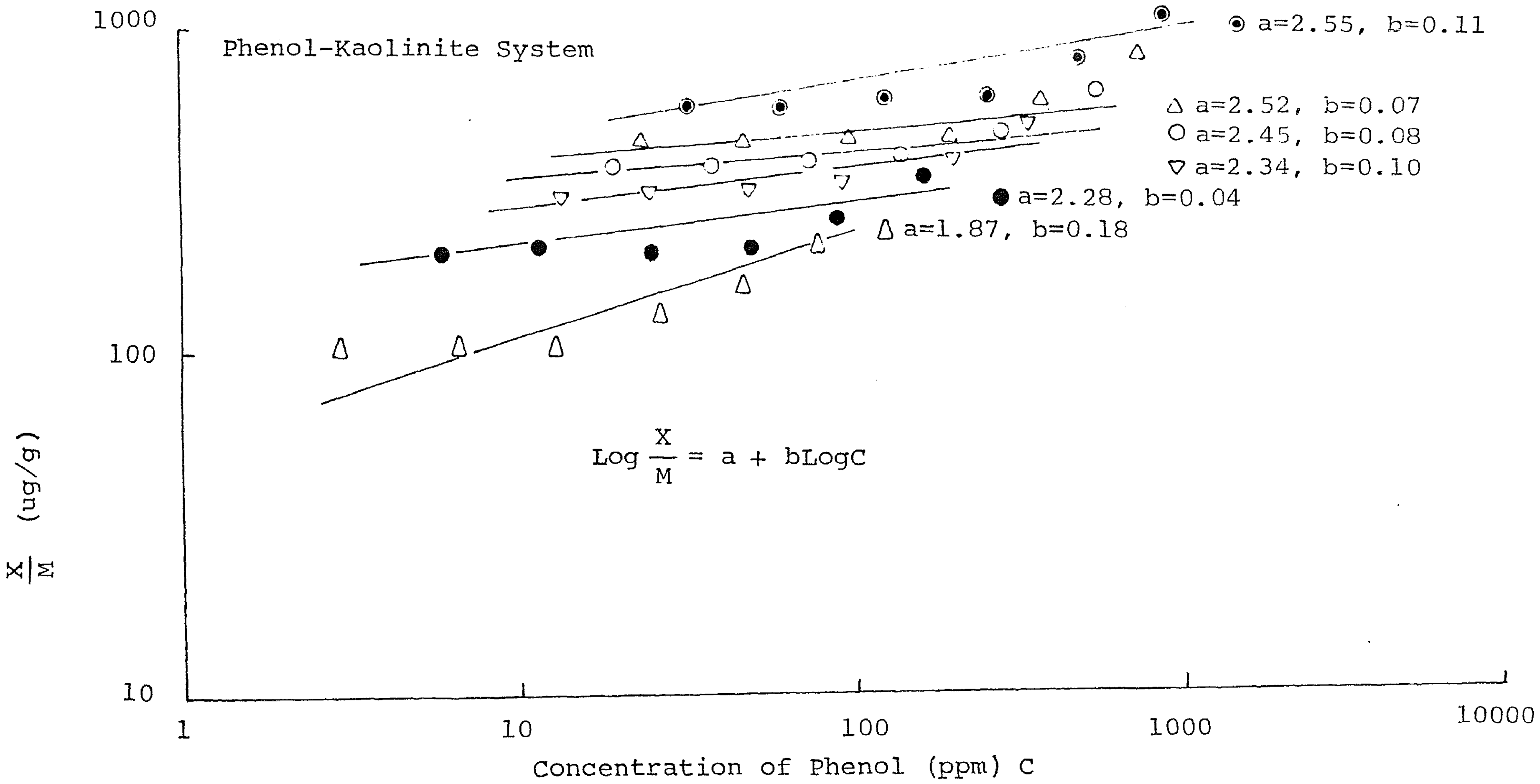


Figure 7 Desorption Isotherm of Phenol

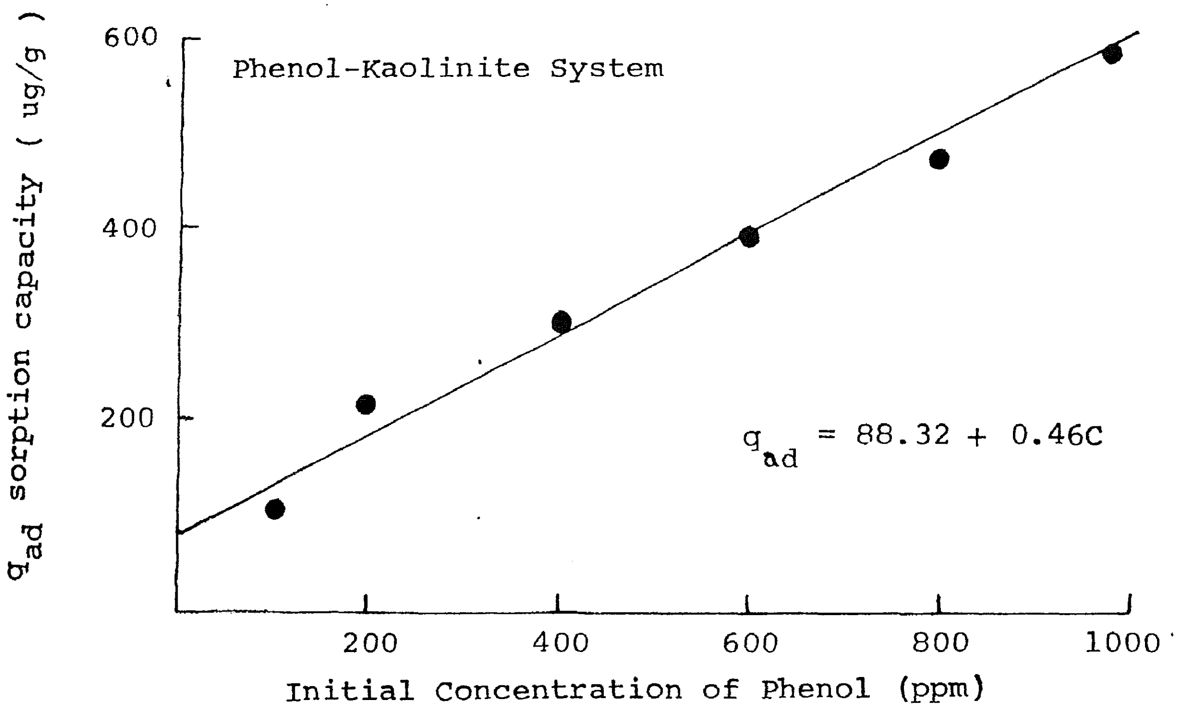


Figure 8 Effect of sorption capacity with initial phenol concentration

distilled water. Results of desorption analysis, shown in Table 9 and Figure 7, give evidence to a pronounced degree of hysteresis, and suggest that the sorption and desorption processes are not completely reversible. From Figure 8, it is found that there exists a relationship between the initial concentration of phenol and the sorption capacity (q_{ad}) after desorption and this relationship is given below:

$$q_{ad} = 88.32 + 0.46C \tag{4}$$

This result also shows that irreversible processes were found in this experiment.

Table 8 Coefficient of Freundlich isotherm for kaolinite with phenol

Log C	Log $\frac{X}{M}$	$(\text{Log C})^2$	(Log C)(Log $\frac{X}{M}$)
2.94	3.13	8.6436	9.2022
2.88	2.92	8.2656	8.3806
2.73	2.83	7.4529	7.7259
2.55	2.64	6.5025	6.7320
2.23	2.48	4.9729	5.5304
1.89	2.34	3.5721	4.4226
2.95	3.01	8.7025	8.8795
2.80	2.86	7.8400	8.0080
2.74	2.70	7.5076	7.3925
2.54	2.71	6.4516	6.8834
2.20	2.60	4.8400	5.7200
1.91	2.26	3.6481	4.3166
2.96	2.98	8.7616	8.8119
2.86	2.88	8.1796	8.2225
2.73	2.81	8.4420	7.6739
2.52	2.76	6.3504	6.9451
2.21	2.58	4.8841	5.7018
1.89	2.34	3.5721	4.4226
45.52	48.83	117.5892	124.9715

Table 9. Desorption of phenol with kaolinite

initial conc. (ppm)	conc.(ppm) after desorption	desorption capacity (ug/g)	$\frac{X}{M}$ (ug/g)	Log $\frac{X}{M}$	Log C
set 1 (1st washing)					
494	528	340	767	2.885	2.723
388	408	200	543	2.735	2.611
292	306	140	470	2.672	2.486
183	195	120	387	2.588	2.290
94	105	110	250	2.398	2.021
43	48	50	157	2.196	1.633
set 2 (2nd washing)					
264	282	180	587	2.769	2.450
204	214	100	443	2.646	2.330
153	161	80	390	2.591	2.207
97	103	60	327	2.515	2.013
52	57	50	200	2.301	1.756
21	24	30	127	2.104	1.380
set 3 (3rd washing)					
141	142	10	577	2.761	2.152
107	108	10	433	2.636	2.033
80	81	10	380	2.580	1.908
51	53	20	307	2.487	1.724
23	23	0	200	2.301	1.362
12	13	10	117	2.068	1.114
set 4 (4th washing)					
71	73	20	557	2.746	1.836
54	54	0	433	2.637	1.732
40	41	10	370	2.568	1.613
21	22	10	297	2.473	1.342
11	10	-10	210	2.322	1.079
6	7	1	97	1.987	0.778
set 5 (5th dilution and desorption)					
36	37	10	547	2.738	1.568
27	27	0	433	2.637	1.431
20	20	0	370	2.568	1.301
11	12	10	287	2.458	1.079
5	5	0	210	2.322	0.670
3	3	0	97	1.987	0.477

5.2. Geotechnical properties of kaolinite with phenol

5.2.1. Plastic and Liquid Limit

When water is added to dry kaolinite, each particle is covered with a film of sorbed water. The sorbed water film will be affected by additional dipolar compounds. These increases can be explained to be a result of the suppression of hydrogen ionization from kaolinite OH^- group. When the phenol molecules are close to the kaolinite molecules, the double layer reaction would have the effect of supressing hydrogen separation at low pH. This might remove the hydroxyl ion from the system to form water. The hydroxyl ion might be replaced by the additional phenol forming a basic salt polymer. Then, the kaolinite needs more water to reach the optimum moisture content. The results of replacement are to enhance water sorption and cause a corresponding increase in liquid limit. According to the data on liquid limit, the curve dropped down and elevated again after a phenol concentration of 1000 ppm. This phenomenon have been caused by the dispersion of the soil but we are not quite sure. Since 1000ppm is too high to occur in groundwater contaminants, the discussion is based on the contraction below 1000ppm. Phenol which is weakly sorbed causes a lower increase in liquid limit from 43.8% in distilled water to 51% in 1000 ppm concentration of phenol as shown in Figure 9 and Appendix B. The relationship between liquid limit and concentration of phenol can be given by equation (5)

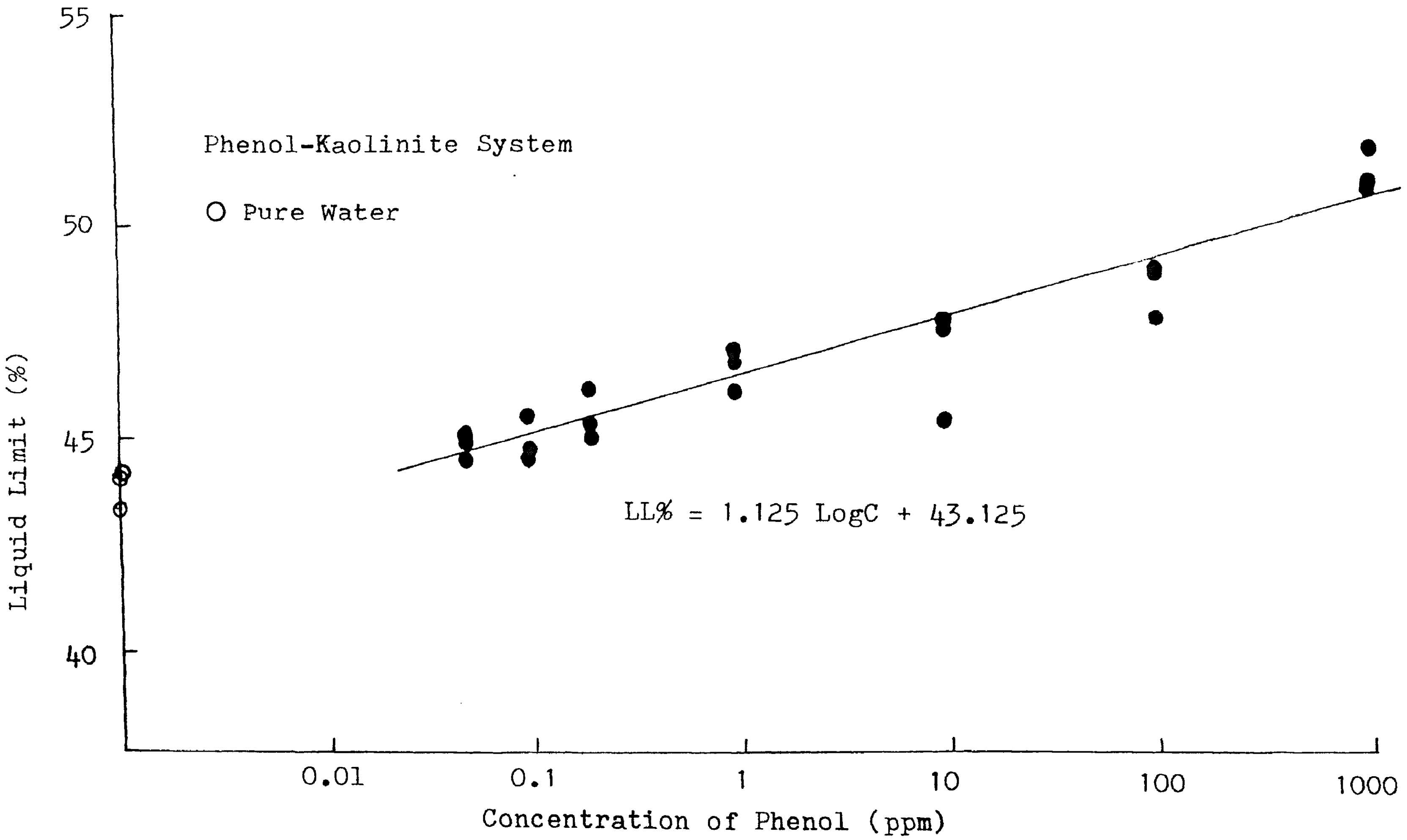


Figure 9 Effect of phenol concentrations vs liquid limit

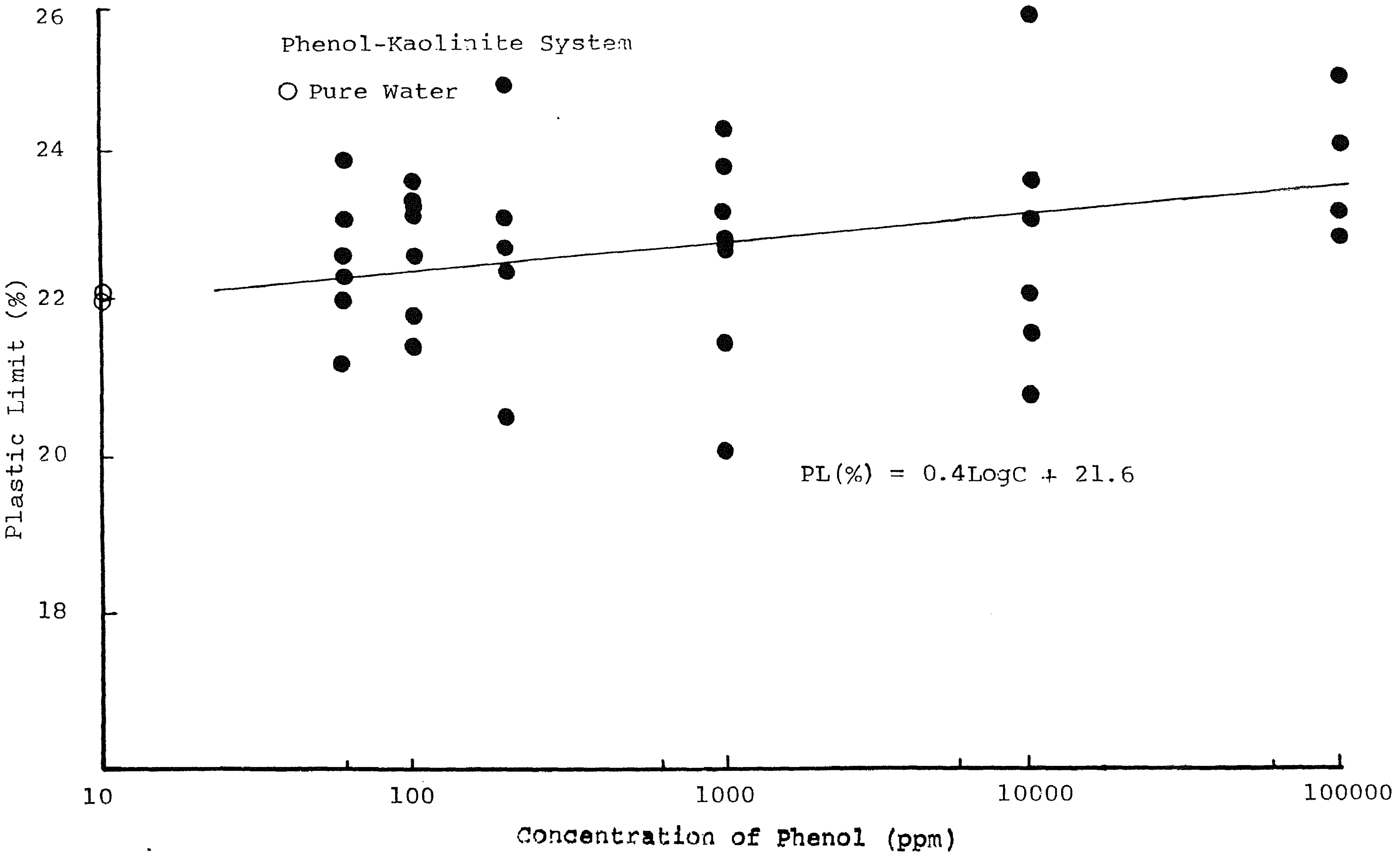


Figure 10 Effect of phenol concentrations vs plastic limit

$$L.L.(\%) = 1.125*\log C + 43.125 \qquad (5)$$

For the same reason, the plastic limit has a lower increase with respect to increasing concentration of phenol from 22.3% in the distilled water to 23.6% in 100 ppm concentration of phenol as shown in Figure 10 and Appendix C. The relationship between plastic limit and concentration of phenol also can be given by equation (6)

$$P.L.(\%) = 0.4*\log C + 21.6 \qquad (6)$$

5.2.2. Optimum Water Content, Dry Density, and Shear Strength

Upon the addition of more water, water films get thicker and permit soil particles to slide over each other very easily. After a relatively high degree of saturation is reached, the water occupies space which could be filled with soil particles and/or entrapped air. There is an optimum water content and dry density which can be expected. Also, as the additional water tends to increase the degree of soil particles' flocculation, the shear strength will also be increased.

From the quantification of these parameters, the optimum water content was found to vary from 20.7% to 21.5% with phenol concentrations between 0.01 ppm and 100 ppm. Also, the dry density was altered from 1.59 g/cm^3 to 1.64 g/cm^3. In terms of the shear stress strength, there was a little variation from 56 psi to 59 psi, but it was not stable. This increase was cause by the same reasons that affect the plastic and liquid limit increases. The additional water increase the flocculation of soil particles which in turn causes the soil molecules to rearrange. Consequently, an increased force needed to act against the other forces from out of the system. The shear strength of kaolinite-phenol system was increased by increasing phenol concentration.

5.2.3. Specific Gravity

From the data shown in Appendix D, the specific gravity does not have a large variation because there is little destruction in the soil particles' surface structure. The specific gravity is not good enough to be the indicator in this test.

5.3. Sorption/Desorption of kaolinite with chlorobenzene

Chlorobenzene is a polar compound and can be separated into $C_6H_5^+$ and Cl^-. It is difficult to share the electrons which were filled on the surface of the kaolinite particles. For the particles to adhere, the attractive forces presents must exceed the repulsion force of the double layer. The Van der Waal force plays the main role for interaction between chlorobenzene molecules and kaolinite particles. Since the Van der Waal force is strictly weak, the water molecule can displace the chlorobenzene by washing with distilled water. This desorption can occur easily and quickly. The sorption isotherm for chlorobenzene is shown in Figure 11, which was

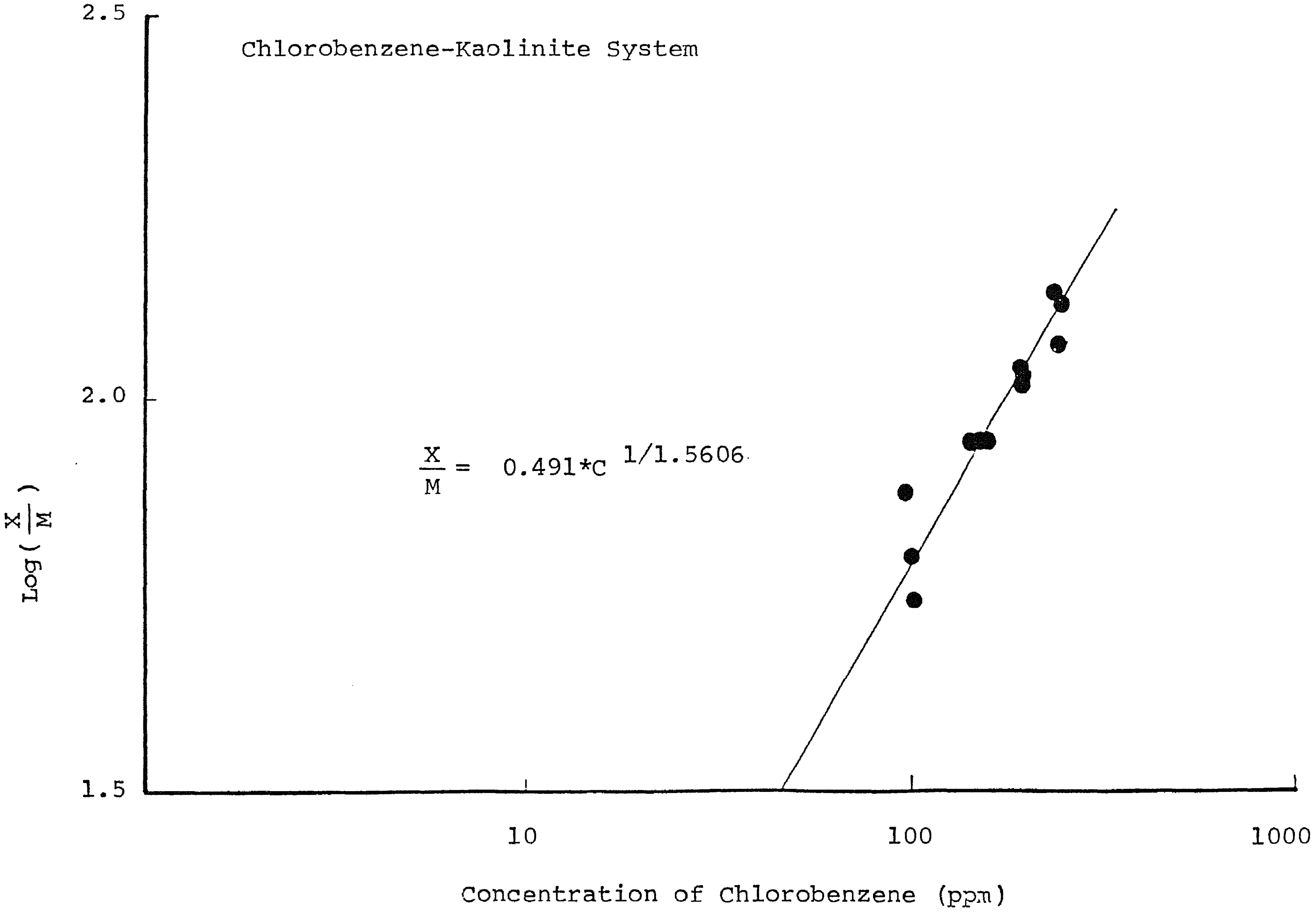


FIGURE 11 Freundlich Isotherm for Chlorobenzene

fitted to the data in Table 11. The Freundlich isotherm formula of kaolinite with chlorobenzene is shown as equation (7).

Equation 7, based on a study of the sorption of chlorobenzene by kaolinite, describes the relationship between C and X/M. It was calculated using the least square method as shown below and Table 11.

$$\text{LogK} = \frac{(23.41 * 57.9772) - (26.32 * 51.934)}{(12 * 57.9772) - (26.32)^2}$$

$$= -0.309$$

therefore $K = 0.4910$

$$\frac{1}{n} = \frac{(12 * 51.734) - (26.32 * 23.41)}{(12 * 57.9772) - (26.32)^2}$$

$$= 0.6408$$

therefore $n = 1.5606$

The Freundlich isotherm formula for kaolinite with chlorobenzene is as follows:

$$\frac{X}{M} = 0.4910 * C^{1/1.5606} \qquad (7)$$

The slope of the fitted linear isotherm, was computed to be 1.5606.

Table 10. Sorption of chlorobenzene by kaolinite

Set 1

Initial conc.	conc.(ppm) after adsorption	X (ppm)	$\frac{X}{M}$ (ug/g)	Log $\frac{X}{M}$	Log C
250	231	19	190	2.28	2.36
198	186	12	120	2.08	2.27
151	143	8	80	1.90	2.16
100	96	4	40	1.60	1.98

Set 2

250	236	14	140	2.15	2.37
198	187	11	110	2.04	2.27
151	143	8	80	1.90	2.16
100	97	3	30	1.48	1.99

Set 3

250	232	18	180	2.26	3.37
199	185	14	140	2.15	2.27
150	142	8	80	1.90	2.15
99	93	6	60	1.78	1.97

Table 11. Coefficient of Freundlich isotherm for kaolinite with chlorobenzene.

Log C	Log $\frac{X}{M}$	$(\text{Log C})^2$	(Log C)(Log $\frac{X}{M}$)
2.36	2.28	5.5696	5.3808
2.37	2.15	5.6169	5.0955
2.37	2.26	5.6169	5.3562
2.27	2.02	5.1529	4.5854
2.27	2.04	5.1529	4.6308
2.27	2.15	5.1529	4.8805
2.16	1.90	4.6656	4.1040
2.16	1.85	4.6656	3.9960
2.15	1.90	4.6225	4.0850
1.98	1.60	3.9204	3.1680
1.99	1.48	3.9601	2.9452
1.97	1.78	3.8809	3.5066
26.32	23.41	57.9772	51.7340

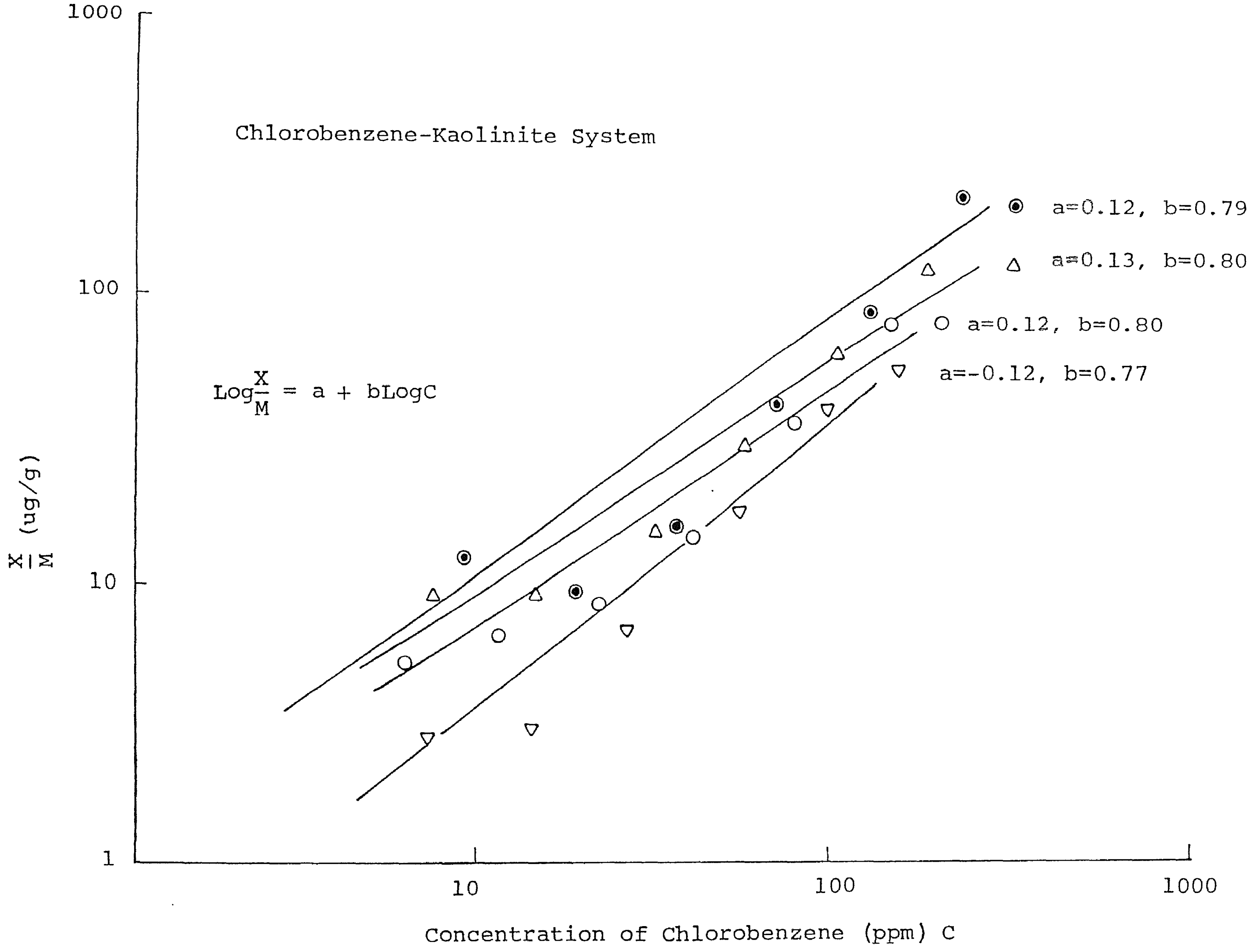


Figure 12 Desorption Isotherm for Chlorobenzene

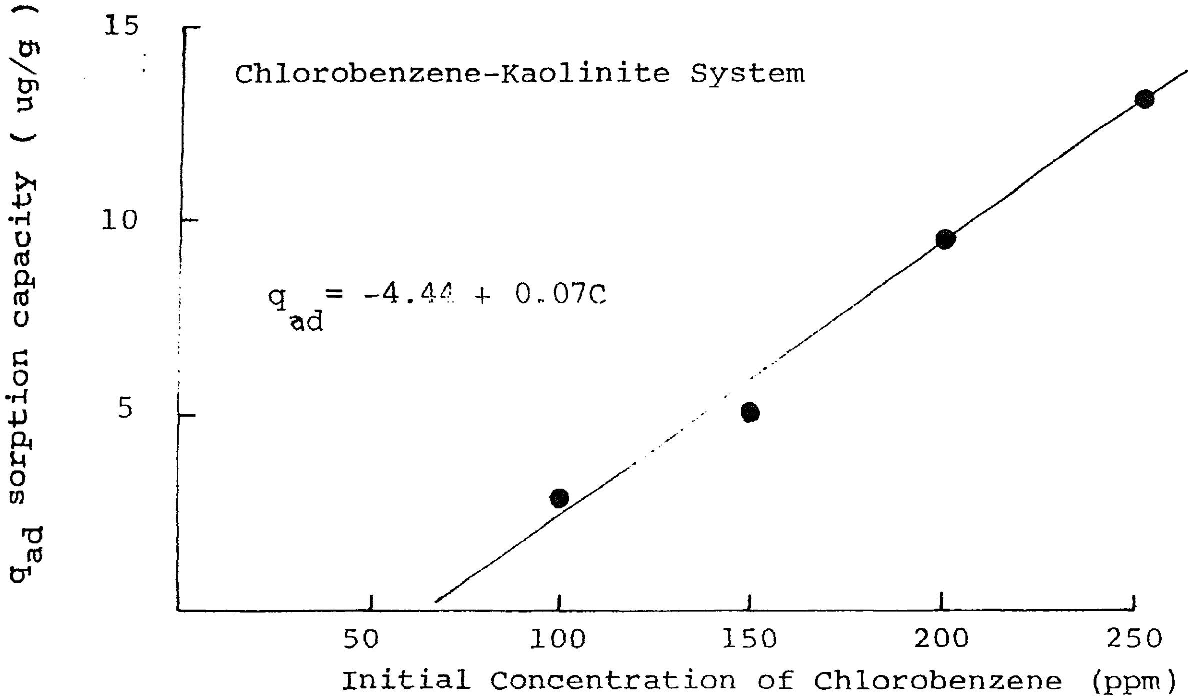


Figure 13 Effect of sorption capacity with initial chlorobenzene concentration

The results of the desorption analysis, shown in Table 12 and Figure 12, indicate that a degree of hysteresis was found and that the sorption and desorption processes are almost completely reversible. Because the physical sorption force is too weak and the washing process can destroy this force, the reserve rate of desorption is more than 92%.

In Figure 13, the relationship between the initial concentration of chlorobenzene and the q_{ad} after desorption is given and the relationship is as follows:

$$q_{ad} = -4.44 + 0.07C \qquad (8)$$

The q_{ad} was increased when the initial concentration was increased.

5.4 Geotechnical Properties of kaolinite with chlorobenzene

5.4.1. Plastic and Liquid Limit

The sorbed water film can be affected by the addition of dipolar compound like chlorobenzene. Because the chlorobenzene replaced the water on the surface of the soil particles, the water sorption was enhanced, and an increase in liquid limit occurred. In this test, chlorobenzene caused a gradual increase in liquid limit from 43.2% in 50 ppb chlorobenzene to 47.5% in 100 ppm chlorobenzene as shown in Figure 14 and Appendix B. The relationship between liquid limit and concentration of chlorobenzene is given below:

$$\text{L.L.}(\%) = 1.172 * \text{Log } C + 45.04 \qquad (9)$$

Table 12. Desorption of chlorobenzene by kaolinite

Set 1 (1st washing)

initial conc. (ppm)	conc.(ppm) after desorption	desorption capacity (ug/g)	$\frac{X}{M}$(ug/g)	Log $\frac{X}{M}$	Log C
116.5	125.1	86	84	1.924	2.097
93.0	98.8	58	65	1.813	1.995
71.7	75.0	33	44	1.643	1.875
47.8	49.8	20	23	1.362	1.697

Set 2 (2nd washing)

62.6	67.1	45	39	1.591	1.829
49.4	52.4	32	33	1.519	1.719
37.5	39.5	20	24	1.380	1.597
24.9	26.3	14	9	0.954	1.420

Set 3 (3rd wasing)

33.7	36.1	24	15	1.176	1.558
26.2	28.0	18	15	1.176	1.447
19.8	20.8	10	14	1.146	1.318
13.2	13.8	6	3	0.477	1.140

Set 4 (4th washing)

18.1	18.8	7	8	0.903	1.274
14.0	14.6	6	9	0.954	1.164
10.4	10.7	3	11	1.041	1.029
6.9	6.9	0	3	0.477	0.839

Set 5 (5th washing)

9.4	8.9	-5	13	1.114	0.949
7.3	7.3	0	9	0.954	0.863
5.4	6.0	6	5	0.699	0.778
3.5	3.5	0	3	0.477	0.544

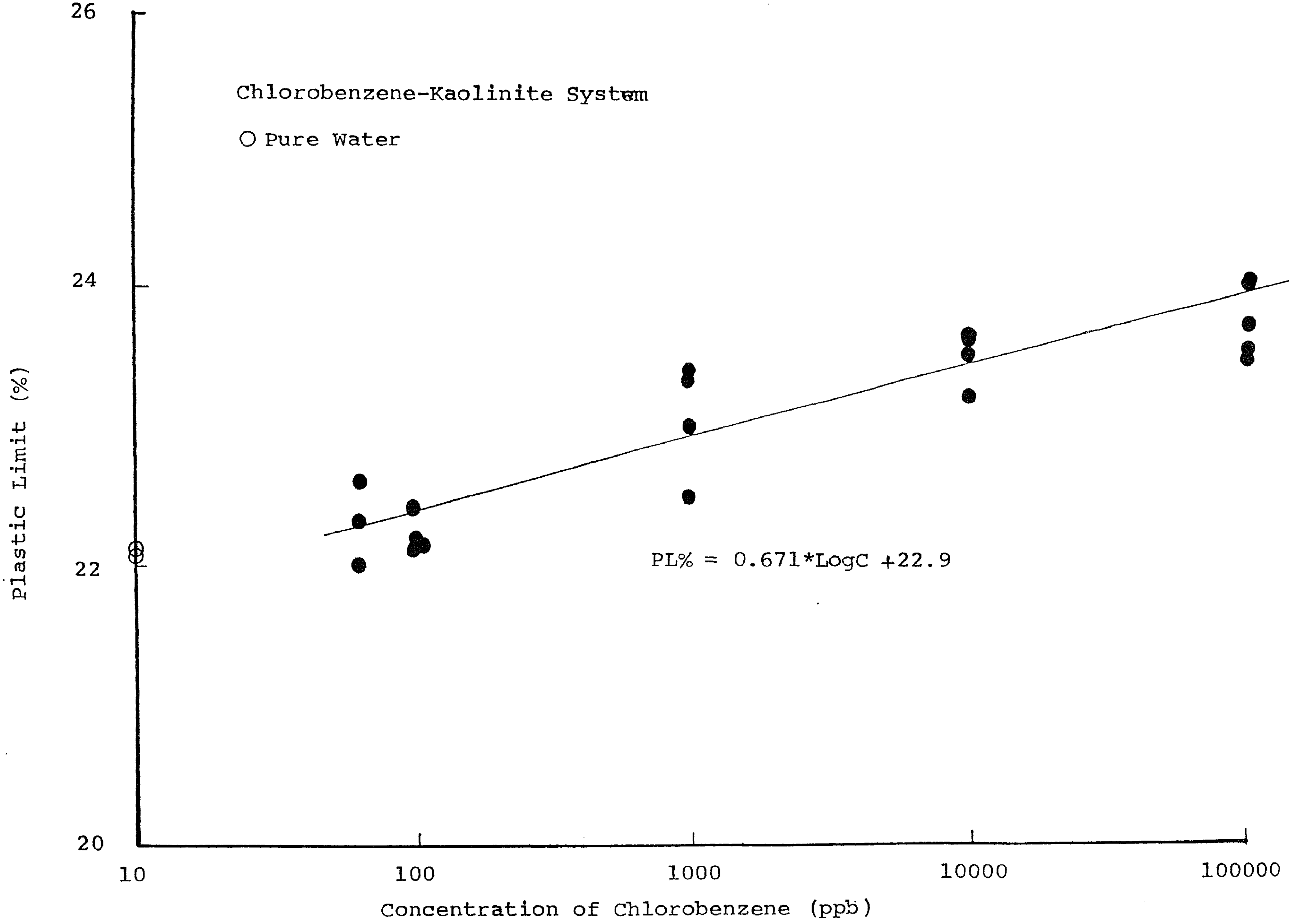


Figure 15 Effect of chlorobenzene concentration vs plastic limit

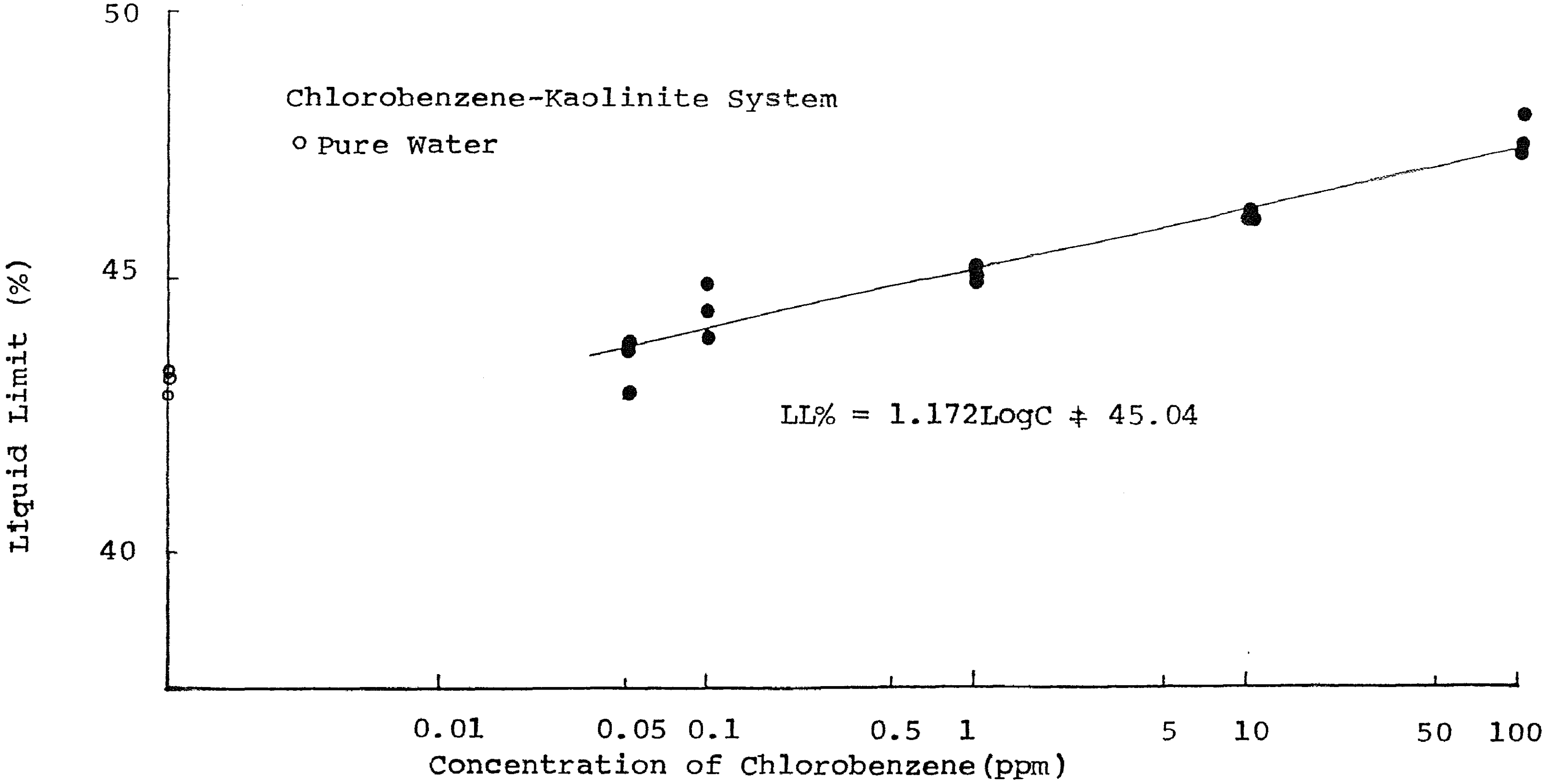


Figure 14 Effect of chlorobenzene concentration vs liquid limit

For the same reason, the plastic limit has a gradual increase with respect to the increasing concentration of chlorobenzene from 22.1% in 50 ppb chlorobenzene to 23.6% in 100 ppm chlorobenzene as the Figure 15 and Appendix C. The relatinship between plastic limit and concentration of chlorobenzene can be given by equation(10)

$$\text{P.L.} = 0.671 * \text{Log C} + 22.9 \qquad (10)$$

5.4.2. Optimum Water Content, Shear Strength, and Dry Density

For the same reason as discussed in section 5.2.2., the optimum water content and dry density have a tendency to increase with increasing concentration of chlorobenzene. The optimum water content and dry density varied respectively from 21.8%, 1.65 g/cm^3 in 0.1 ppm chlorobenzene solution to 23.0%, 1.68 g/cm^3 in 100 ppm chlorobenzene solution. The shear strength also changed slightly from 59 psi to 60 psi.

5.4.3. Specific Gravity

In this study, the chlorobenzene was found to have no significant affect on the values of specific gravity. It was found not to be a good indicator.

5.5. Discussion

The isotherm for phenol is shown in Figure 6. Similar isotherms were obtained for chlorobenzene. The variable slopes obtained for different organic solution-kaolinite system indicate that sorption in soil is a complex phenomenon including different types of sorption such as Van der Waal force or hydrogen bonding.

According to Freeze and Cherry[1], the data of K values lie in the range from near zero to 1000 or greater. Actually, experiments by DiToro and Horzempa[12] (K=0.21-2.6), Uchrin and Katz[10] (K=19-165), and Means,Hassett[16] (K=71-1155) etc. obtained values of K which also are in the range as Cherry and Freeze. In this study, the K values are 15.63 for phenol and 0.491 for chlorobenzene which are within the range found by the investigators given above. Hence, the data of this study is reasonable. From these data, it can be pointed out that the K value depends on the properties of compounds being sorbed and on the properties of the sorbent.

By comparing the K values for phenol (15.63) and for chlorobenzene (0.491), it is found that the sorption capacity for phenol is larger than that of chlorobenzene because of the force of connection between the chemical and kaolinite. The forces between chlorobenzene and kaolinite are weak. Conversely, the desorption ratio for chlorobenzene (92%) is larger than that for phenol (50%).

Figures 2 and 3 indicate that the sorption process should be faster in the first 2-3 hours. It can be concluded that the type of sorption must follow the Freundlich isotherm theory and is referred to as the L Class by Giles[32]. The interaction between organic compound and kaolinite particles was very weak. From the results of this study, the K value of phenol (15.63) and chlorobenzene (0.491) also provided clues to low sorption capacity. The two concepts as discussed above actually are reciprocal and complementary and prove that the discussion of section 5.1 and 5.3 are reasonable.

Based on experimental consecutive desorption studies for phenol and chlorobenzene on kaolinite, the phenol and chlorobenzene concentration from the initial few desorption tests are above the sorption isotherm. It indicated that a part of the organic compounds are not sorbed even at low concentrations and also found that the relationships between sorption and desorption are irreversible for phenol and almost completely irreversible for chlorobenzene. In general, increasing sorption or decreasing desorption followed the order phenol > chlorobenzene because of the different type of interaction between organic compound and kaolinite particles. This relationship as evidenced by Ward and Holly [33], Bowman and Sans [34] also agree with the results of other organic compound-sorbent systems.

From Figures 7 and 12, the similiar slopes of desorption isotherm can be obtained. It was concluded that the slopes were normalized to the initial sorption isotherm for each consecutive desorption experiment. Also, the desorption isotherm did not pass through the origin which implied that desorption process can not be completion and hystersis is apparent. Similar results are reported by other investigators, Uchrin and Mangel[9], Abdul[24], and Ditoro[12]. Hence, The results for desorption test are considered reasonable.

According to the discussion above , there are two concepts which can be proved. First, the rapid equilibration for organic compounds and kaolinite system is consistent with the physical type of sorption mechanism. Physical sorption occurs as fast as the phenol and chlorobenzene reaches the kaolinite surface. Thus, phenol or chlorobenzene sorption in kaolinite is due to Van der Waal force or hydrogen bonding. Therefore, the assumption for interaction in this study is correct. Second, there is a great difference in the type of interaction force which creates the differing degree for desorption in organic compound-kaolinite systems. The reversible capacities (desorption) vary from 92% for chlorobenzene to 50% for phenol because the Van der Waal force was less than hydrogen bonding. The kaolinite surface can hold the phenol molecule tightly, but not the chlorobenzene.

Green[35] reported the following values: liquid limit (32-50%), plastic limit (31-38%), optimum moisture content (16-31%), and dry density (1.36-1.58 g/cm^3). In this study, the parameters for phenol (liquid limit 43.6-51%, plastic limit 22.3-23.6%, optimum moisture content 20.7-21.5%, and dry density 1.59-1.64 g/cm^3) and for chlorobenzene (liquid limit 43.2-47.5%, plastic limit 22.1-23.6%, optimum moisture content 21.8-23.0%, and dry density 1.65-1.68 g/cm^3) are similar to those obtained by Green.

It can be estimated that the chemical-sorption may create great differences because the force of chemical bonding is higher than that of the physical-sorption and sometimes bonding can occur into the soil structure. Future study should focus on the polar organic compounds with polar sorbent systems.

5.6 Applications

1. In groundwater system, the geotechnical properties of soil with organic contaminants such as phenol or chlorobenzene can provide valuable information to develop transport models of groundwater contamination. It can also be used to predict the distribution of contaminants. From the results of geotechnical properties and chemical analysis, the Atterburg limits and unconfined compression test can be used to predict the level of contamination for some compounds under some pre-selected conditions. According to the range of contamination, the partition coefficient can be taken from the Freundlich isotherm which was determined by sorption test in this study. Then, the retardation value can be estimated by equation (2), Consequently the relationship between migration

velocity and actual physical groundwater velocity can be determined.

2. In a hazardous disposal site, the liner still is an important factor for the protection of the aquifer. By following the tests used in this study, the geotechnical properties found can provide the information needed by construction engineers in the results of this study shold be helpful in assessing of liner integrity; thus it could be used to evaluate the efficiency of the liner as a groundwater protection measure.

3. In the field of geotechnical engineering, clay material is also a significant factor in the design of foundations. As the contaminants go through the clay layer, they will interact with the soil and subsequently alter its geotechnical properties. As a result, it will affect the safety of the structure. The methodology undertaking in this study should shed light on the foundation design.

4. The desorption capacity obtained in this study provides the suitability of the clean-up process using the consecutive washings.

CHAPTER 6 CONCLUSION

Based on the experimental results, the following conclusions can be drawn:

1. The sorption process follows the Freundlich isotherm and the subsequent washings determine the reversibility of sorption (desorption).
2. Both plastic and liquid limits were found to increase with increasing concentrations of organic contaminants .
3. The geotechnical properties plays an important role in groundwater transportation systems and geotechnical engineering design. The inflence of the sorption process upon the geotechnical properties must be taken into account for a satisfactory design.
4. Futher studies of the sorption characteristics of different contaminants for correlating with basic geotechnical properies of soils should be taken.

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APPENDIX A

MOISTURE CONTENT OF KAOLINITE

wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	moisture content (%)
42.14	41.61	0.53	37.73	1.40
44.16	43.68	0.58	39.80	1.45
39.46	38.95	0.51	35.07	1.45
41.05	40.52	0.47	37.17	1.27

Average moisture content = 1.39%

* the weight of container = 3.88g

APPENDIX B

PART A LIQUID LIMIT FOR PHENOL

1) no phenol

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
38	18.92	13.79	5.13	12.47	41.1
30	19.21	13.95	5.26	12.63	41.6
26	17.38	12.54	4.74	11.22	43.2
22	18.52	13.29	5.23	11.97	43.7
16	19.31	13.70	5.61	12.38	45.3
40	19.87	14.30	5.57	12.98	42.9
34	23.01	16.36	6.65	15.04	44.2
23	19.88	14.12	5.76	12.80	45.0
23	15.59	11.23	4.36	9.91	44.0
21	17.98	12.83	5.15	12.85	44.7
35	18.52	13.48	5.04	12.16	41.5
33	16.22	11.81	4.41	10.49	42.0
29	14.81	10.77	4.04	9.45	42.8
27	16.43	11.83	4.60	10.51	43.8
25	15.40	11.06	4.34	9.47	44.6
15	16.25	11.60	4.65	10.28	45.2

2) 50 ug/l phenol

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
30	26.70	19.16	7.54	17.84	42.3
24	20.96	14.83	6.13	13.51	45.4
22	24.10	17.03	7.07	15.71	45.0
15	21.53	14.82	6.71	13.50	49.7
34	18.24	13.14	5.10	11.82	43.1
28	19.14	13.68	5.46	12.36	44.2
26	19.26	13.68	5.58	12.36	45.1
22	17.78	12.59	5.19	11.27	46.0
19	18.81	13.24	5.57	11.92	46.7
31	20.12	14.35	5.77	13.03	44.3
28	19.84	14.11	5.73	12.79	44.8
23	16.35	11.66	4.69	10.34	45.4
18	18.79	13.18	5.61	11.86	47.3
15	17.53	12.24	5.29	10.92	48.5

3) 100 ug/l phenol

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
30	25.73	18.33	7.40	16.93	43.71
29	22.70	16.31	6.39	14.91	42.85
24	26.07	18.60	7.47	17.20	43.43
17	26.99	18.71	8.28	17.29	47.89
13	26.13	17.92	8.21	16.52	49.70
9	27.96	18.78	9.18	17.38	52.82
30	16.80	12.13	4.67	10.81	43.2
28	16.95	12.30	4.65	10.98	42.4
27	19.30	13.85	5.45	12.53	43.5
25	17.19	12.32	4.87	11.00	44.3
22	20.27	14.25	6.02	12.93	46.6
16	19.78	13.60	6.18	12.28	50.0
35	17.82	12.84	4.98	11.52	43.2
33	16.54	11.97	4.57	10.65	42.9
28	20.32	14.52	5.80	13.20	44.0
26	21.49	15.30	6.19	13.98	44.3
23	17.38	12.31	5.07	10.99	46.2
20	18.45	12.93	5.52	11.61	47.5

4) 200ug/l phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
36	13.75	9.89	3.86	8.56	45.1
27	15.27	10.93	4.34	9.60	45.2
26	15.89	11.39	4.50	10.06	44.7
22	13.99	9.90	4.09	8.57	47.7
20	15.79	10.92	4.87	9.59	50.7
11	14.92	10.35	4.57	9.02	50.6
34	16.84	12.12	4.72	10.80	43.7
28	17.88	12.80	5.08	11.48	44.3
24	19.70	13.91	5.79	12.59	46.0
18	15.85	11.23	4.62	9.91	46.7
16	19.90	13.88	6.02	12.56	47.6
36	17.41	12.53	4.88	11.21	43.6
30	17.71	12.64	5.07	11.32	44.8
20	17.08	12.14	4.94	10.82	45.7
16	21.99	15.42	6.57	14.10	46.6
13	18.73	13.16	5.57	11.84	47.0

5) 1ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
33	17.83	12.75	5.08	11.43	44.5
28	17.54	12.35	5.19	11.03	47.1
24	18.94	13.24	5.70	11.92	47.8
22	23.14	15.89	7.25	14.57	49.8
17	19.32	13.28	6.04	11.96	50.5
35	15.83	19.44	4.39	10.11	43.4
28	17.32	12.27	5.05	10.94	46.2
22	18.79	13.13	5.66	11.80	47.9
15	19.10	13.30	5.80	11.97	48.5
36	15.65	11.15	4.50	9.83	45.8
30	19.35	13.71	5.64	12.39	45.5
24	21.58	15.17	6.41	13.85	46.3
19	21.69	14.96	6.73	13.64	49.4
14	16.55	11.41	5.14	10.09	51.0

6) 10 ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
36	19.93	14.42	5.51	13.10	42.1
29	21.52	15.24	6.28	13.92	45.1
26	21.77	15.39	6.38	14.07	45.3
23	22.62	16.05	6.57	14.73	44.6
20	22.60	15.86	6.74	14.54	46.4
14	19.77	13.55	6.22	12.23	50.9
43	17.53	12.51	5.02	11.19	44.9
25	20.09	14.02	6.09	12.70	48.0
20	15.68	10.86	4.82	9.54	50.5
19	17.96	12.30	5.66	10.98	51.6
36	18.24	12.93	5.31	11.61	45.8
30	19.18	13.53	5.65	12.21	46.3
27	17.23	12.13	5.10	10.81	47.2
23	18.14	12.65	5.49	11.33	48.5
19	18.45	12.82	5.63	11.50	49.0

7) 100 ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
32	18.25	12.93	5.32	11.61	45.8
29	18.82	13.23	5.59	11.91	47.0
23	19.38	13.48	6.00	12.16	48.5
17	16.35	11.39	4.96	10.07	49.2
15	17.23	11.85	5.38	10.53	51.1
32	19.25	13.58	5.67	12.26	46.2
26	19.77	13.81	5.96	12.49	47.7
24	18.42	12.92	5.50	11.60	47.4
19	17.33	12.06	5.27	10.74	49.1
15	15.43	10.67	4.76	9.35	50.9
35	17.76	12.51	5.25	10.78	48.7
27	18.72	12.96	5.76	11.64	49.5
19	20.55	14.30	6.25	12.98	48.2
11	17.46	11.93	5.53	10.61	52.1

8) 1000 ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
30	11.25	7.94	3.31	6.62	50.0
26	13.85	9.64	4.21	8.32	50.6
24	12.54	8.74	3.60	7.42	51.2
22	10.34	7.27	3.07	5.95	51.6
18	12.72	8.76	3.96	7.44	53.2
36	12.54	8.90	3.64	7.58	48.1
30	13.25	9.33	3.92	8.01	49.0
26	14.78	10.28	4.50	8.96	50.3
22	11.24	7.85	3.39	6.53	51.9
19	11.35	7.83	3.52	6.51	54.1
34	10.46	7.42	3.04	6.10	49.8
28	16.27	10.53	5.74	10.21	50.8
24	10.02	7.06	2.96	5.74	51.6
20	11.57	8.05	3.52	6.73	52.3

9) 2000 ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
33	12.00	8.69	3.31	7.37	44.9
31	12.37	8.81	3.56	7.49	47.5
21	13.54	9.43	4.11	8.11	50.7
13	16.38	11.00	5.38	9.68	55.6
36	13.56	9.85	3.71	8.53	43.5
30	14.28	10.32	3.96	9.00	44.0
26	12.38	8.85	3.53	7.53	46.8
22	17.25	11.80	5.45	10.48	52.0
16	15.11	10.21	4.90	8.89	55.2
35	15.22	10.89	4.33	9.57	45.3
30	18.74	13.18	5.56	11.86	46.9
26	16.15	11.36	4.79	10.04	47.7
20	17.17	11.92	5.25	10.60	49.5
17	14.95	10.28	4.67	8.96	52.2

10) 4000 ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
44	11.50	8.29	3.21	6.97	44.1
36	13.02	9.40	3.62	8.08	44.8
35	12.93	9.18	3.75	7.68	47.7
23	13.29	9.24	4.05	7.92	51.1
17	12.54	8.78	3.76	7.46	50.4
34	12.35	8.90	3.45	7.58	45.5
28	18.74	13.25	5.49	11.93	46.0
22	15.26	10.76	4.50	9.44	47.6
18	14.50	10.17	4.33	8.85	49.0
16	16.64	11.57	5.07	10.25	49.5
35	17.87	12.80	5.07	11.48	44.1
32	15.26	10.98	4.28	9.66	44.3
26	18.20	12.80	5.40	11.48	47.0
22	16.25	11.42	4.83	10.10	47.8
18	16.78	11.61	5.17	10.29	50.2

11) 5000 ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
39	12.53	9.02	3.51	7.70	45.6
32	14.73	10.44	4.29	9.12	47.1
23	14.57	10.22	4.35	8.90	48.8
20	13.35	9.42	3.93	8.10	48.5
34	13.72	9.83	3.89	8.51	45.7
31	12.21	8.73	3.48	7.41	47.0
26	17.28	12.14	5.14	10.82	47.5
22	16.07	11.26	4.81	9.89	48.6
21	15.24	10.73	4.51	9.41	48.0
34	15.27	10.86	4.41	9.54	46.2
28	16.15	11.42	4.73	10.10	46.8
26	15.89	11.18	4.71	9.86	47.7
21	16.25	11.35	4.90	10.03	48.9
18	16.36	11.41	4.95	10.09	49.0

12) 10000 ppm phenol

no. of blow	wt. of container + soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
32	12.78	9.02	7.70	3.76	48.8
30	15.45	10.77	9.45	4.68	49.5
24	14.67	10.15	8.83	4.52	51.2
20	13.93	9.63	8.31	4.30	51.7
36	11.87	8.55	7.23	3.32	45.9
27	13.25	9.13	7.81	4.12	52.8
26	13.00	9.16	7.84	3.84	49.0
21	10.96	7.57	6.25	3.39	54.2
15	12.07	8.20	6.88	3.87	56.3
36	13.72	9.73	8.41	3.99	47.4
33	12.21	8.69	7.37	3.52	47.8
28	17.11	11.87	10.55	5.24	49.7
26	16.07	11.14	9.82	4.93	50.4
22	16.07	10.99	9.67	5.08	52.5

PART B LIQUID LIMIT FOR CHLOROBENZENE

1) 50 ug/l chlorobenzene

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
37	8.26	6.23	2.03	4.91	41.3
29	12.54	10.70	3.84	9.38	41.0
26	12.88	9.33	3.55	8.01	44.3
21	18.12	12.83	5.29	11.51	46.0
13	13.13	9.36	3.77	8.04	46.9
31	13.54	9.87	3.67	8.55	42.9
29	12.92	9.55	3.37	8.23	40.9
23	11.79	8.62	3.17	7.30	43.4
22	13.48	9.79	3.69	8.47	43.6
18	12.56	9.15	3.41	7.83	43.6
29	11.78	8.63	3.15	7.31	43.1
25	12.67	9.25	3.42	7.93	43.1
20	14.56	10.45	4.11	9.13	45.0
18	13.57	9.68	3.89	8.36	46.5

2) 100 ug/l chlorobenzene

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
36	10.37	7.73	2.64	6.41	41.2
30	9.95	7.40	2.55	6.08	41.9
26	14.17	10.20	3.97	8.88	44.7
22	10.66	7.80	2.86	6.48	44.1
18	12.13	8.65	3.48	7.33	47.5
30	11.44	8.33	3.11	7.01	44.4
26	9.61	7.12	2.49	5.80	42.9
24	11.23	8.18	3.05	6.86	44.5
20	11.01	8.05	2.96	6.73	44.0
18	13.18	9.52	3.66	8.20	44.6
36	12.56	9.25	3.31	7.93	41.7
26	11.74	8.52	3.22	7.20	44.7
22	10.75	7.79	2.96	6.47	45.7
17	11.19	8.07	3.12	6.75	46.2

3) 1ppm chlorobenzene

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
42	11.78	8.66	3.12	7.34	42.5
33	13.44	9.76	3.68	8.44	43.6
26	14.08	10.17	3.91	8.85	44.2
24	11.42	8.30	3.12	6.98	44.7
20	11.96	8.58	3.38	7.26	46.6
45	12.10	8.96	3.14	7.64	41.1
32	9.28	6.90	2.38	5.58	42.7
29	12.45	9.03	3.42	7.71	44.4
25	13.19	9.55	3.64	8.23	44.2
20	10.60	7.60	3.00	6.28	47.8
32	15.48	11.18	4.30	9.86	43.6
28	13.25	9.59	3.66	8.27	44.3
24	14.35	10.28	4.07	8.96	45.4
20	10.47	7.55	2.92	6.23	46.8

4) 10 ppm chlorobenzene

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
33	11.93	8.68	3.25	7.36	44.2
25	12.57	9.06	3.51	7.74	45.3
23	13.96	9.94	4.02	8.62	46.6
17	14.59	10.23	4.36	8.91	48.9
38	11.08	8.15	2.93	6.83	42.9
30	11.65	8.51	3.14	7.19	43.7
24	15.78	11.26	4.52	9.94	45.6
23	12.51	8.89	3.62	7.57	47.8
18	11.99	8.47	3.52	7.15	49.2
35	11.25	8.35	2.90	7.03	41.3
30	10.38	7.70	2.68	6.38	42.1
26	14.92	10.65	4.27	9.33	45.7
20	13.74	9.75	3.99	8.43	47.4
16	11.89	8.36	3.53	7.04	50.1

5) 100 ppm chlorobenzene

no. of blow	wt. of container + soil	wt.of container +dry soil	wt.of water	wt.of dry soil	water content (%)
32	11.32	8.25	3.07	6.93	44.3
29	10.10	7.35	2.75	6.03	45.6
27	10.37	7.52	2.85	6.20	46.0
21	12.94	9.09	3.85	7.77	49.6
33	11.90	8.58	3.32	7.26	45.7
28	10.17	7.34	2.83	6.02	47.0
24	11.85	8.49	3.36	7.17	46.9
19	10.23	7.32	2.91	6.00	48.5
28	14.44	10.22	4.22	8.90	47.4
25	11.63	8.30	3.33	6.97	47.7
23	14.27	10.04	4.23	8.72	48.5
17	14.73	10.27	4.46	8.95	49.8

APPENDIX C

PART A PLASTIC LIMIT FOR PHENOL

1) no phenol

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
4.13	3.63	0.50	2.31	21.7
4.01	3.55	0.46	2.23	20.6
4.62	3.97	0.65	2.65	24.5
4.68	4.05	0.63	2.73	23.1
3.94	3.48	0.46	2.16	21.4
4.37	3.82	0.65	2.50	22.2

2) 50 ug/l phenol

4.23	3.68	0.55	2.36	23.1
3.98	3.50	0.48	2.18	22.3
4.15	3.66	0.49	2.34	21.2
4.32	3.74	0.58	2.42	23.9
4.95	4.28	0.67	2.96	22.6
4.24	3.71	0.53	2.18	22.0

3) 100ug/l phenol

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
3.04	2.71	0.33	1.39	23.6
3.13	2.83	0.30	1.51	21.8
3.24	2.83	0.41	1.51	26.9
3.78	3.32	0.46	2.00	23.1
3.85	3.37	0.48	2.05	23.2
3.57	3.17	0.40	1.85	21.4
3.45	3.05	0.40	1.73	23.3
3.42	3.03	0.39	1.71	22.6

4) 200ug/l phenol

3.56	3.20	0.36	1.88	19.2
4.67	4.05	0.62	2.73	22.7
4.09	3.57	0.52	2.25	23.1
4.23	3.65	0.58	2.33	24.9
3.82	3.38	2.44	2.06	21.5
3.95	3.47	0.48	2.15	22.4

5) 1ppm phenol

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
4.72	4.08	0.64	2.76	23.2
4.15	3.63	0.52	2.31	22.7
3.89	3.46	0.43	2.14	20.1
4.86	4.18	0.68	2.86	23.8
4.23	3.69	0.54	2.37	22.8
3.92	3.46	0.46	2.14	21.5
5.92	5.02	0.90	3.70	24.3

6) 10ppm phenol

4.64	4.04	0.60	2.72	22.1
4.32	3.76	0.56	2.44	23.1
4.58	4.00	0.58	2.68	21.6
4.15	3.57	0.58	2.25	25.8
4.02	3.51	0.51	2.19	23.6
4.51	3.96	0.55	2.64	20.8

7) 100ppm phenol

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
4.12	3.58	0.54	2.26	24.1
4.43	3.85	0.58	2.53	22.9
3.79	3.33	0.46	2.01	23.2
4.57	3.92	0.65	2.60	25.0

PART B PLASTIC LIMIT FOR CHLOROBENZENE

1) 50 ug/l chlorobenzene

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
3.84	3.38	0.46	2.06	22.3
4.21	3.67	0.54	2.35	23.0
4.65	4.05	0.60	2.73	22.0
4.96	4.29	0.67	2.97	22.6
5.18	4.50	0.68	3.18	21.4
4.59	4.02	0.57	2.70	21.1

2) 100 ug/l chlorobenzene

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
5.19	4.49	0.70	3.17	22.1
5.48	4.72	0.76	3.40	22.4
6.00	5.15	0.85	3.83	22.2
5.63	4.85	0.78	3.53	22.1
5.38	4.62	0.76	3.30	23.0

3) 1 ppm chlorobenzene

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
5.73	4.89	0.84	3.57	23.5
4.94	4.28	0.66	2.96	22.3
5.22	4.48	0.74	3.16	23.4
6.04	5.17	0.87	3.85	22.1

4) 10 ppm chlorobenzene

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
4.63	3.99	0.64	2.67	24.0
4.99	4.28	0.71	2.96	24.0
6.57	5.57	1.00	4.25	23.5
6.09	5.22	0.87	3.90	22.3

5) 100 ppm chlorobenzene

wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
5.24	4.99	0.75	3.17	23.7
7.06	5.95	1.11	4.27	26.0
5.64	4.84	0.80	3.52	22.7
6.05	5.20	0.85	3.88	21.9
5.84	4.98	0.86	3.66	23.5
6.75	5.71	1.04	4.39	23.7

APPENDIX D

SPECIFIC GRAVITY

a) For pure soil

Temperature of solution = 30 C

wt. of soil + water + pryrex = 683.18 g

wt. of beaber = 302.97 g

wt. of water + pryrex at 30 C = 667.6 g

wt. of dry soil + beaker = 328.36 g

wt. of dry soil = 25.29 g

Specific Gravity

$$= \frac{0.9974 * 25.39}{25.39-683.18+667.6} = 2.58$$

b) For phenol

phenol conc. (ppm)	wt. of water	wt. of container	wt. of container +dry soil	specific gravity
0.1	699.31	191.63	240.85	2.59
0.2	698.24	188.83	237.59	2.55
1	696.22	223.78	268.07	2.58
10	697.76	287.92	333.49	2.62
100	699.81	302.91	352.46	2.60

c) For chlorobenzene

chlorobenzene (ppm)	wt. of water	wt. of container	wt. of container +dry soil	specific gravity
0.05	699.61	289.00	338.72	2.58
0.1	699.38	289.00	338.55	2.57
1	699.58	289.00	338.76	2.58
10	699.67	289.00	338.90	2.58
100	699.33	289.00	338.24	2.59

* wt. of water + pryrex at 25 C = 669.05

* density of water at 25 C = 0.997077

APPENDIX E

HYDROMETER TEST

elapsed time (min)	actural reading	collec-tion	hydro-meter read	T *1	L *2	K *3	D *4	P *5
0.5	49.0	3.5	45.5	22	8.30	0.01393	0.05700	99.4
1	49.0	3.5	45.5	22	8.30	0.01393	0.04000	99.4
2	48.5	3.5	45.0	22	8.35	0.01393	0.02800	98.3
5	48.0	3.5	44.5	22	8.40	0.01393	0.01800	98.3
10	48.0	3.5	44.5	22	8.40	0.01393	0.01300	98.3
20	47.0	3.5	43.5	22	8.60	0.01393	0.00910	95.0
38	46.4	2.5	42.9	24	8.72	0.01382	0.00660	93.7
68	45.0	2.5	42.5	24	8.90	0.01382	0.00500	92.8
435	40.0	2.5	37.5	24	9.70	0.01382	0.00210	81.9
1973	35.0	3.5	31.5	22	10.60	0.01393	0.00100	68.8
2798	29.0	3.0	25.5	23	11.50	0.01377	0.00088	55.3
4273	25.0	3.0	22.0	23	12.20	0.01377	0.00073	47.7
8588	18.0	2.5	15.5	24	13.30	0.01382	0.00054	33.9
32690	16.4	3.5	12.9	22	14.17	0.01393	0.00029	28.1

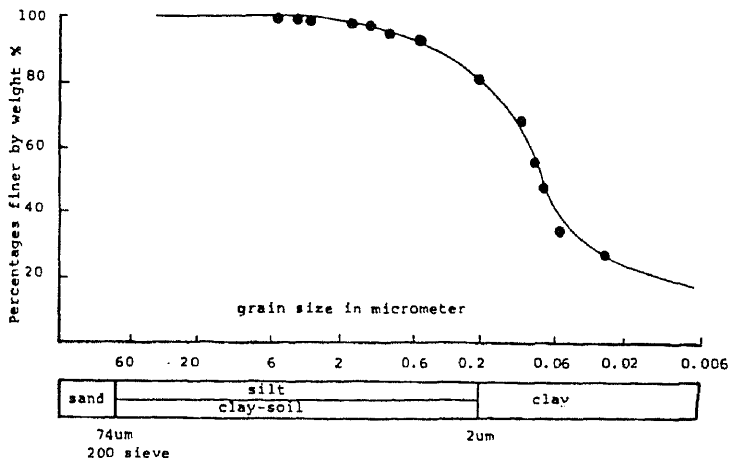
*1 T = Temperature (C)

*2 L = effective depth of hydrometer (cm)

*3 K = coefficient of hydrometer

*4 D = diameter of soil particle (mm)

*5 P = soil in suspension (% of soil finer)



APPENDIX F

pH VALUE FOR KAOLINITE

a) For phenol

phenol conc. (ppm)	set 1	set 2	set 3
0	5.10	5.00	5.20
0.1	4.60	4.40	4.45
0.2	4.60	4.60	4.50
0.5	4.40	4.45	4.45
1	4.50	4.45	4.50
10	4.60	4.60	4.45
100	4.45	4.40	4.40
1000	4.40	4.35	4.35

b) For chlorobenzene

chlorobenzene conc. (ppm)	set 1	set 2	set 3
200	4.80	4.85	4.80
100	4.84	4.82	4.85
10	4.87	4.85	4.84
1	4.89	4.87	4.86
0.5	5.00	4.90	4.85
0.1	4.95	4.92	4.93
0.05	4.95	4.95	4.95
0.01	4.98	4.97	5.00

* The pH meter is Corning Scientific Instruments (Model 7)

APPENDIX G

PART A OPTIMUM MOISTURE CONTENT AND DRY DENSITY FOR PHENOL

1) no phenol

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	81.10	70.00	10.10	66.10	15.27
2	67.80	61.03	6.77	57.13	11.85
3	100.70	82.90	17.80	79.00	22.53
4	104.20	84.43	19.77	80.43	24.58
5	91.20	74.43	16.77	70.53	23.77
6	95.90	71.53	24.47	67.73	36.12
7	114.82	90.94	23.89	79.47	30.06
8	82.35	70.40	11.95	69.07	17.30

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	29.8	100.30	70.50	1.363	1.18
2	31.5	105.20	73.70	1.425	1.27
3	32.4	131.70	99.30	1.920	1.57
4	27.6	132.10	104.50	2.020	1.62
5	31.5	120.30	88.80	1.717	1.39
6	31.6	124.10	92.50	1.788	1.31
7	31.2	131.34	100.15	1.936	1.49
8	31.2	112.37	81.18	1.569	1.34

2) 200 ug/l phenol

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	54.15	47.00	7.15	45.68	15.7
2	69.95	59.24	10.71	59.92	17.9
3	67.64	57.14	10.50	55.82	18.8
4	100.69	83.38	17.31	82.06	21.1
5	48.08	45.07	2.97	43.95	6.8
6	52.37	46.76	5.61	45.44	12.4
7	102.12	80.56	21.56	79.24	27.1
8	71.79	60.61	11.12	59.35	18.7
9	92.22	76.49	15.73	75.17	20.9

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	31.28	111.65	80.37	1.555	1.34
2	27.81	119.87	92.06	1.781	1.51
3	27.81	118.43	90.62	1.753	1.48
4	28.44	128.62	100.18	1.938	1.60
5	28.44	102.52	74.08	1.433	1.34
6	28.44	107.92	79.48	1.537	1.37
7	28.44	129.55	101.11	1.956	1.54
8	28.44	118.93	90.49	1.750	1.47
9	28.44	119.57	91.13	1.767	1.44

3) 10 ppm phenol

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	65.16	55.52	9.64	54.17	17.80
2	65.38	55.57	9.81	54.22	18.10
3	45.95	41.08	4.87	39.73	12.26
4	104.39	83.91	20.48	86.56	23.60
5	97.82	82.10	15.72	80.75	19.47
6	96.69	73.91	22.78	72.59	31.40
7	102.90	83.19	19.71	81.87	24.10

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	28.44	116.72	88.28	1.708	1.45
2	28.44	118.17	89.73	1.736	1.47
3	28.44	108.75	80.31	1.553	1.38
4	28.44	131.86	103.42	2.000	1.60
5	28.44	122.92	94.48	1.828	1.53
6	28.44	124.17	95.73	1.852	1.41
7	28.44	130.21	101.77	1.969	1.59

4) 100 ppm

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	93.53	68.26	25.27	66.94	37.8
2	49.83	43.77	6.06	42.45	14.3
3	53.12	48.62	4.50	47.30	9.5
4	66.53	58.87	7.66	57.55	13.3
5	66.74	55.16	11.58	53.84	21.5
6	100.06	78.22	21.84	76.90	28.4
7	96.37	78.86	17.51	77.54	22.6
8	77.44	54.03	23.41	52.71	44.4
9	94.40	77.50	16.90	76.18	22.2

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	28.44	121.81	93.37	1.806	1.31
2	28.44	110.41	81.97	1.586	1.39
3	28.44	104.00	75.56	1.462	1.34
4	28.44	114.96	86.52	1.674	1.48
5	28.44	131.42	102.98	1.993	1.64
6	28.44	127.73	99.29	1.921	1.50
7	28.44	129.18	100.74	1.949	1.59
8	28.44	115.34	86.90	1.681	1.16
9	28.44	130.12	101.68	1.967	1.61

5) 1000 ppm phanol

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	179.04	158.32	20.72	89.72	23.1
2	175.37	155.53	19.84	87.72	22.6
3	179.32	159.06	20.26	88.38	22.9
4	181.82	156.16	25.66	86.38	29.71

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	28.44	138.88	88.72	1.734	1.41
2	28.44	136.00	87.72	1.696	1.38
3	28.44	137.08	88.38	1.709	1.38
4	28.44	140.48	86.78	1.678	1.29

PART B OPTIMUM MOISTURE CONTENT AND DRY DENSITY FOR CHLOROBENZENE

1) 0.1 ppm chlorobenzene

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	164.93	150.50	14.43	80.82	17.85
2	187.17	158.29	28.88	94.57	30.54
3	177.99	152.52	19.47	89.32	21.80
4	183.77	161.05	22.72	91.75	24.76
5	171.76	154.64	17.12	85.10	20.12

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	31.2	122.04	90.84	1.756	1.49
2	31.2	131.14	99.94	1.932	1.48
3	31.2	135.18	103.98	2.010	1.65
4	31.2	133.83	102.63	1.984	1.59
5	31.2	128.76	97.56	1.886	1.57

2) 1 ppm chlorobenzene

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	174.13	156.38	17.75	86.70	20.47
2	174.48	156.95	17.53	87.75	19.98
3	180.08	160.12	19.96	90.82	21.98
4	185.85	163.41	22.44	93.87	23.91

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	31.2	125.44	94.24	1.818	1.64
2	31.2	126.27	95.07	1.702	1.53
3	31.2	135.95	104.75	2.205	1.66
4	31.2	136.08	104.88	1.818	1.64

3) 10 ppm chlorobenzene

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	167.00	152.46	14.54	82.92	17.54
2	182.09	161.04	21.05	91.84	22.92
3	174.43	157.49	16.94	87.81	19.30
4	182.13	160.19	22.21	91.61	24.40
5	175.16	148.93	26.23	85.40	30.80

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	31.2	123.32	92.12	1.781	1.45
2	31.2	132.93	101.73	1.967	1.68
3	31.2	126.02	94.82	1.833	1.54
4	31.2	132.97	101.77	1.967	1.58
5	31.2	132.49	101.29	1.958	1.49

4) 100 ppm chlorobenzene

no.	wt. of container +wet soil	wt. of container +dry soil	wt. of water	wt. of dry soil	water content (%)
1	184.84	161.63	23.21	91.95	25.24
2	150.92	140.72	10.20	77.00	13.25
3	152.95	139.42	13.53	70.22	19.27
4	173.33	155.51	17.82	86.21	20.67
5	178.95	158.70	20.25	89.16	22.71

no.	wt. of cylinder	wt. of cylinder +soil	wt. of soil	r_w (g/cm^3)	r_d (g/cm^3)
1	28.44	130.80	102.36	1.979	1.58
2	28.44	122.16	93.72	1.812	1.60
3	28.44	130.61	102.17	1.975	1.67
4	28.44	133.49	105.05	2.031	1.68
5	28.44	131.27	102.83	1.988	1.62

SAMPLE # P-0-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	70.0	0.020	0.0072	0.9928	1.155	18.462
40	128.0	0.040	0.0144	0.9856	1.163	33.515
60	173.0	0.060	0.0215	0.9785	1.172	44.968
80	210.0	0.080	0.0287	0.9713	1.181	54.185
100	230.0	0.100	0.0359	0.9641	1.189	58.907
120	250.0	0.120	0.0431	0.9569	1.198	63.553
140	242.0	0.140	0.0502	0.9498	1.207	61.058

SAMPLE # P-0-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	54.0	0.020	0.0072	0.9928	1.155	14.242
40	104.0	0.040	0.0144	0.9856	1.163	27.231
60	125.0	0.060	0.0215	0.9785	1.172	32.491
80	147.0	0.080	0.0287	0.9713	1.181	37.929
100	158.0	0.100	0.0359	0.9641	1.189	40.467
120	162.0	0.120	0.0431	0.9569	1.198	41.182
140	162.0	0.140	0.0502	0.9498	1.207	40.873
160	146.0	0.160	0.0574	0.9426	1.217	36.558

SAMPLE # P-0-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	32.0	0.020	0.0072	0.9928	1.155	8.440
40	54.0	0.040	0.0144	0.9856	1.163	14.139
60	78.0	0.060	0.0215	0.9785	1.172	20.275
80	86.0	0.080	0.0287	0.9713	1.181	22.190
100	94.0	0.100	0.0359	0.9641	1.189	24.075
120	94.0	0.120	0.0431	0.9569	1.198	23.896

SAMPLE # P-0-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	60.0	0.020	0.0072	0.9928	1.155	15.825
40	148.0	0.040	0.0144	0.9856	1.163	38.752
60	184.0	0.060	0.0215	0.9785	1.172	47.827
80	208.0	0.080	0.0287	0.9713	1.181	53.669
100	220.0	0.100	0.0359	0.9641	1.189	56.346
120	227.0	0.120	0.0431	0.9569	1.198	57.706
140	233.0	0.140	0.0502	0.9498	1.207	58.787
160	236.0	0.160	0.0574	0.9426	1.217	59.094
180	231.0	0.180	0.0646	0.9354	1.226	57.402
210	200.0	0.210	0.0753	0.9247	1.240	49.127

SAMPLE # P-0-5

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	9.0	0.020	0.0072	0.9928	1.155	2.374
40	15.0	0.040	0.0144	0.9856	1.163	3.928
60	22.0	0.060	0.0215	0.9785	1.172	5.718
100	29.0	0.100	0.0359	0.9641	1.189	7.427
140	35.0	0.140	0.0502	0.9498	1.207	8.831
180	40.0	0.180	0.0646	0.9354	1.226	9.940
240	49.0	0.240	0.0861	0.9139	1.255	11.896
280	55.0	0.280	0.1005	0.8995	1.275	13.143
320	60.0	0.320	0.1148	0.8852	1.295	14.109
390	69.0	0.390	0.1399	0.8601	1.333	15.765
600	100.0	0.600	0.2153	0.7847	1.461	20.847

SAMPLE # P-0-6

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	4.0	0.020	0.0072	0.9928	1.155	1.055
40	6.0	0.040	0.0144	0.9856	1.163	1.571
60	9.0	0.060	0.0215	0.9785	1.172	2.339
80	11.0	0.080	0.0287	0.9713	1.181	2.838
100	14.0	0.100	0.0359	0.9641	1.189	3.586
140	18.0	0.140	0.0502	0.9498	1.207	4.541
180	23.0	0.180	0.0646	0.9354	1.226	5.715
220	28.0	0.220	0.0789	0.9211	1.245	6.851
280	33.0	0.280	0.1005	0.8995	1.275	7.886
320	37.0	0.320	0.1148	0.8852	1.295	8.701
380	42.0	0.380	0.1363	0.8637	1.328	9.636
460	52.0	0.460	0.1650	0.8350	1.373	11.534

SAMPLE # P-0.2-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	22.0	0.010	0.0036	0.9964	1.151	5.823
20	80.0	0.020	0.0072	0.9928	1.155	21.099
30	143.0	0.030	0.0108	0.9892	1.159	37.579
35	165.0	0.035	0.0126	0.9874	1.161	43.282
40	170.0	0.040	0.0144	0.9856	1.163	44.512
45	170.0	0.045	0.0161	0.9839	1.165	44.431

SAMPLE # P-0.2-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	6.0	0.010	0.0036	0.9964	1.151	1.588
20	50.0	0.020	0.0072	0.9928	1.155	13.187
30	123.0	0.030	0.0108	0.9892	1.159	32.323
40	190.0	0.040	0.0144	0.9856	1.163	49.749
45	203.0	0.045	0.0161	0.9839	1.165	53.056
50	200.0	0.050	0.0179	0.9821	1.168	52.177

SAMPLE # P-0.2-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	35.0	0.010	0.0036	0.9964	1.151	9.264
20	95.0	0.020	0.0072	0.9928	1.155	25.055
30	150.0	0.030	0.0108	0.9892	1.159	39.418
40	175.0	0.040	0.0144	0.9856	1.163	45.821
50	180.0	0.050	0.0179	0.9821	1.168	46.959
60	175.0	0.060	0.0215	0.9785	1.172	45.488
70	160.0	0.070	0.0251	0.9749	1.176	41.436

SAMPLE # P-0.2-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	20.0	0.010	0.0036	0.9964	1.151	5.294
20	56.0	0.020	0.0072	0.9928	1.155	14.770
30	82.0	0.030	0.0108	0.9892	1.159	21.549
40	50.0	0.040	0.0144	0.9856	1.163	13.092

SAMPLE # P-0.2-5

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	13.0	0.010	0.0036	0.9964	1.151	3.441
20	33.0	0.020	0.0072	0.9928	1.155	8.703
30	78.0	0.030	0.0108	0.9892	1.159	20.498
40	110.0	0.040	0.0144	0.9856	1.163	28.802
50	125.0	0.050	0.0179	0.9821	1.168	32.610
60	130.0	0.060	0.0215	0.9785	1.172	33.791
70	140.0	0.070	0.0251	0.9749	1.176	36.257
80	140.0	0.080	0.0287	0.9713	1.181	36.123
90	148.0	0.090	0.0323	0.9677	1.185	38.046
100	150.0	0.100	0.0359	0.9641	1.189	38.418
110	150.0	0.110	0.0395	0.9605	1.194	38.275
120	142.0	0.120	0.0431	0.9569	1.198	36.098
130	142.0	0.130	0.0466	0.9534	1.203	35.963

SAMPLE # P-0.2-6

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	30.0	0.010	0.0036	0.9964	1.151	7.941
20	75.0	0.020	0.0072	0.9928	1.155	19.781
30	100.0	0.030	0.0108	0.9892	1.159	26.279
35	90.0	0.035	0.0126	0.9874	1.161	23.608
40	80.0	0.040	0.0144	0.9856	1.163	20.947
45	78.0	0.045	0.0161	0.9839	1.165	20.386

SAMPLE # P-0.2-7

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	12.0	0.010	0.0036	0.9964	1.151	3.176
20	26.0	0.020	0.0072	0.9928	1.155	6.857
30	70.0	0.030	0.0108	0.9892	1.159	18.395
40	124.0	0.040	0.0144	0.9856	1.163	32.468
50	159.0	0.050	0.0179	0.9821	1.168	41.480
60	100.0	0.060	0.0215	0.9785	1.172	25.993

SAMPLE # P-0.2-8

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	26.0	0.020	0.0072	0.9928	1.155	6.857
40	124.0	0.040	0.0144	0.9856	1.163	32.468
50	174.0	0.050	0.0179	0.9821	1.168	45.394
60	218.0	0.060	0.0215	0.9785	1.172	56.665
70	237.0	0.070	0.0251	0.9749	1.176	61.377

SAMPLE # P-10-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	12.0	0.010	0.0036	0.9964	1.151	3.176
20	44.0	0.020	0.0072	0.9928	1.155	11.605
30	120.0	0.030	0.0108	0.9892	1.159	31.535
40	173.0	0.040	0.0144	0.9856	1.163	45.298
50	199.0	0.050	0.0179	0.9821	1.168	51.916
55	203.0	0.055	0.0197	0.9803	1.170	52.862
60	172.0	0.060	0.0215	0.9785	1.172	44.708
70	154.0	0.070	0.0251	0.9749	1.176	39.882
80	142.0	0.080	0.0287	0.9713	1.181	36.639

SAMPLE # P-10-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	12.0	0.010	0.0036	0.9964	1.151	3.176
20	31.0	0.020	0.0072	0.9928	1.155	8.176
30	79.0	0.030	0.0108	0.9892	1.159	20.760
40	121.0	0.040	0.0144	0.9856	1.163	31.682
50	144.0	0.050	0.0179	0.9821	1.168	37.567
60	165.0	0.060	0.0215	0.9785	1.172	42.888
70	167.0	0.070	0.0251	0.9749	1.176	43.249
80	164.0	0.080	0.0287	0.9713	1.181	42.316

SAMPLE # P-10-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	15.0	0.010	0.0036	0.9964	1.151	3.970
20	28.0	0.020	0.0072	0.9928	1.155	7.385
30	85.0	0.030	0.0108	0.9892	1.159	22.337
40	130.0	0.040	0.0144	0.9856	1.163	34.039
50	164.0	0.050	0.0179	0.9821	1.168	42.785
60	179.0	0.060	0.0215	0.9785	1.172	46.527
70	187.0	0.070	0.0251	0.9749	1.176	48.429
80	192.0	0.080	0.0287	0.9713	1.181	49.541
90	196.0	0.090	0.0323	0.9677	1.185	50.386
100	200.0	0.100	0.0359	0.9641	1.189	51.224
110	201.0	0.110	0.0395	0.9605	1.194	51.288
120	195.0	0.120	0.0431	0.9569	1.198	49.571
130	180.0	0.130	0.0466	0.9534	1.203	45.587

SAMPLE # P-10-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	42.0	0.010	0.0036	0.9964	1.151	11.117
20	91.0	0.020	0.0072	0.9928	1.155	24.001
30	95.0	0.030	0.0108	0.9892	1.159	24.965
40	70.0	0.040	0.0144	0.9856	1.163	18.329
50	52.0	0.050	0.0179	0.9821	1.168	13.566

SAMPLE # P-10-5

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
440	44.0	0.440	0.1579	0.8421	1.362	9.843

SAMPLE # P-10-6

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	50.0	0.010	0.0036	0.9964	1.151	13.235
20	98.0	0.020	0.0072	0.9928	1.155	25.847
30	140.0	0.030	0.0108	0.9892	1.159	36.790
40	170.0	0.040	0.0144	0.9856	1.163	44.512
50	190.0	0.050	0.0179	0.9821	1.168	49.568
60	201.0	0.060	0.0215	0.9785	1.172	52.246
70	204.0	0.070	0.0251	0.9749	1.176	52.831
80	207.0	0.080	0.0287	0.9713	1.181	53.411
90	192.0	0.090	0.0323	0.9677	1.185	49.358

SAMPLE # P-100-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	1.0	0.010	0.0036	0.9964	1.151	0.265
20	1.0	0.020	0.0072	0.9928	1.155	0.264
30	2.0	0.030	0.0108	0.9892	1.159	0.526
40	2.0	0.040	0.0144	0.9856	1.163	0.524
50	4.0	0.050	0.0179	0.9821	1.168	1.044
60	5.0	0.060	0.0215	0.9785	1.172	1.300
70	6.0	0.070	0.0251	0.9749	1.176	1.554
80	6.0	0.080	0.0287	0.9713	1.181	1.548
90	7.0	0.090	0.0323	0.9677	1.185	1.799
360	12.0	0.360	0.1292	0.8708	1.317	2.776

SAMPLE # P-100-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	12.0	0.010	0.0036	0.9964	1.151	3.176
20	45.0	0.020	0.0072	0.9928	1.155	11.868
30	78.0	0.030	0.0108	0.9892	1.159	20.498
40	105.0	0.040	0.0144	0.9856	1.163	27.493
50	115.0	0.050	0.0179	0.9821	1.168	30.002
60	117.0	0.060	0.0215	0.9785	1.172	30.412
70	90.0	0.070	0.0251	0.9749	1.176	23.308
80	70.0	0.080	0.0287	0.9713	1.181	18.062

SAMPLE # P-100-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	12.0	0.010	0.0036	0.9964	1.151	3.176
20	29.0	0.020	0.0072	0.9928	1.155	7.649
30	55.0	0.030	0.0108	0.9892	1.159	14.453
40	81.0	0.040	0.0144	0.9856	1.163	21.209
50	97.0	0.050	0.0179	0.9821	1.168	25.306
55	110.0	0.055	0.0197	0.9803	1.170	28.645
60	108.0	0.060	0.0215	0.9785	1.172	28.072
70	85.0	0.070	0.0251	0.9749	1.176	22.013

SAMPLE # P-100-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	15.0	0.010	0.0036	0.9964	1.151	3.970
20	34.0	0.020	0.0072	0.9928	1.155	8.967
30	77.0	0.030	0.0108	0.9892	1.159	20.235
40	120.0	0.040	0.0144	0.9856	1.163	31.420
50	168.0	0.050	0.0179	0.9821	1.168	43.828
55	184.0	0.055	0.0197	0.9803	1.170	47.915
60	195.0	0.060	0.0215	0.9785	1.172	50.686
65	200.0	0.065	0.0233	0.9767	1.174	51.891

SAMPLE # P-100-5

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	25.0	0.010	0.0036	0.9964	1.151	6.617
20	75.0	0.020	0.0072	0.9928	1.155	19.781
30	125.0	0.030	0.0108	0.9892	1.159	32.849
40	157.0	0.040	0.0144	0.9856	1.163	41.108
50	185.0	0.050	0.0179	0.9821	1.168	48.263
60	198.0	0.060	0.0215	0.9785	1.172	51.466
70	210.0	0.070	0.0251	0.9749	1.176	54.385
80	213.0	0.080	0.0287	0.9713	1.181	54.959
90	215.0	0.090	0.0323	0.9677	1.185	55.270
100	213.0	0.100	0.0359	0.9641	1.189	54.553
110	200.0	0.110	0.0395	0.9605	1.194	51.033
120	190.0	0.120	0.0431	0.9569	1.198	48.300

SAMPLE # P-100-6

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
40	8.0	0.040	0.0144	0.9856	1.163	2.095
80	12.0	0.080	0.0287	0.9713	1.181	3.096
120	15.0	0.120	0.0431	0.9569	1.198	3.813
160	19.0	0.160	0.0574	0.9426	1.217	4.758
200	23.0	0.200	0.0718	0.9282	1.235	5.672
240	24.0	0.240	0.0861	0.9139	1.255	5.827
280	27.0	0.280	0.1005	0.8995	1.275	6.452
320	31.0	0.320	0.1148	0.8852	1.295	7.290
360	35.0	0.360	0.1292	0.8708	1.317	8.097
400	38.0	0.400	0.1435	0.8565	1.339	8.646
500	46.0	0.500	0.1794	0.8206	1.397	10.028

SAMPLE # P-100-7

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	15.0	0.010	0.0036	0.9964	1.151	3.970
20	40.0	0.020	0.0072	0.9928	1.155	10.550
30	95.0	0.030	0.0108	0.9892	1.159	24.965
40	150.0	0.040	0.0144	0.9856	1.163	39.275
50	184.0	0.050	0.0179	0.9821	1.168	48.002
60	202.0	0.060	0.0215	0.9785	1.172	52.506
70	216.0	0.070	0.0251	0.9749	1.176	55.939
85	221.0	0.085	0.0305	0.9695	1.183	56.918
90	220.0	0.090	0.0323	0.9677	1.185	56.556
95	216.0	0.095	0.0341	0.9659	1.187	55.424

SAMPLE # P-100-8

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	30.0	0.010	0.0036	0.9964	1.151	7.941
20	105.0	0.020	0.0072	0.9928	1.155	27.693
30	181.0	0.030	0.0108	0.9892	1.159	47.565
40	228.0	0.040	0.0144	0.9856	1.163	59.699
50	240.0	0.050	0.0179	0.9821	1.168	62.612
60	230.0	0.060	0.0215	0.9785	1.172	59.784
70	190.0	0.070	0.0251	0.9749	1.176	49.206

SAMPLE # P-100-9

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
40	13.0	0.040	0.0144	0.9856	1.163	3.404
80	21.0	0.080	0.0287	0.9713	1.181	5.418
120	26.0	0.120	0.0431	0.9569	1.198	6.610
160	31.0	0.160	0.0574	0.9426	1.217	7.762
200	37.0	0.200	0.0718	0.9282	1.235	9.124
240	46.0	0.240	0.0861	0.9139	1.255	11.168
360	60.0	0.360	0.1292	0.8708	1.317	13.880

SAMPLE # P-1-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	20.0	0.010	0.0036	0.9964	1.151	5.294
20	44.0	0.020	0.0072	0.9928	1.155	11.605
30	102.0	0.030	0.0108	0.9892	1.159	26.804
40	154.0	0.040	0.0144	0.9856	1.163	40.323
50	172.0	0.050	0.0179	0.9821	1.168	44.872
60	196.0	0.060	0.0215	0.9785	1.172	50.946
70	218.0	0.070	0.0251	0.9749	1.176	56.457
80	220.0	0.080	0.0287	0.9713	1.181	56.765
90	222.0	0.090	0.0323	0.9677	1.185	57.070

SAMPLE # P-1-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	12.0	0.010	0.0036	0.9964	1.151	3.176
20	38.0	0.020	0.0072	0.9928	1.155	10.022
30	84.0	0.030	0.0108	0.9892	1.159	22.074
40	125.0	0.040	0.0144	0.9856	1.163	32.729
50	173.0	0.050	0.0179	0.9821	1.168	45.133
60	202.0	0.060	0.0215	0.9785	1.172	52.506
70	225.0	0.070	0.0251	0.9749	1.176	58.270
80	234.0	0.080	0.0287	0.9713	1.181	60.378
90	230.0	0.090	0.0323	0.9677	1.185	59.126
100	230.0	0.100	0.0359	0.9641	1.189	58.907

SAMPLE # P-1-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	15.0	0.010	0.0036	0.9964	1.151	3.970
20	47.0	0.020	0.0072	0.9928	1.155	12.396
30	92.0	0.030	0.0108	0.9892	1.159	24.177
40	132.0	0.040	0.0144	0.9856	1.163	34.562
50	177.0	0.050	0.0179	0.9821	1.168	46.176
60	208.0	0.060	0.0215	0.9785	1.172	54.065
70	221.0	0.070	0.0251	0.9749	1.176	57.234
80	227.0	0.080	0.0287	0.9713	1.181	58.571
90	227.0	0.090	0.0323	0.9677	1.185	58.355

SAMPLE # P-1-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	8.0	0.020	0.0072	0.9928	1.155	2.110
40	24.0	0.040	0.0144	0.9856	1.163	6.284
60	41.0	0.060	0.0215	0.9785	1.172	10.657
80	60.0	0.080	0.0287	0.9713	1.181	15.481
100	78.0	0.100	0.0359	0.9641	1.189	19.977
120	90.0	0.120	0.0431	0.9569	1.198	22.879
140	96.0	0.140	0.0502	0.9498	1.207	24.221
160	102.0	0.160	0.0574	0.9426	1.217	25.541
180	110.0	0.180	0.0646	0.9354	1.226	27.334
360	115.0	0.360	0.1292	0.8708	1.317	26.604

SAMPLE # C-0.1-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	15.0	0.010	0.0036	0.9964	1.151	3.970
20	43.0	0.020	0.0072	0.9928	1.155	11.341
30	82.0	0.030	0.0108	0.9892	1.159	21.549
40	125.0	0.040	0.0144	0.9856	1.163	32.729
50	174.0	0.050	0.0179	0.9821	1.168	45.394
60	201.0	0.060	0.0215	0.9785	1.172	52.246

SAMPLE # C-0.1-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
340	82.0	0.340	0.1220	0.8780	1.306	19.126

SAMPLE # C-0.1-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	20.0	0.010	0.0036	0.9964	1.151	5.294
20	50.0	0.020	0.0072	0.9928	1.155	13.187
30	98.0	0.030	0.0108	0.9892	1.159	25.753
40	157.0	0.040	0.0144	0.9856	1.163	41.108
50	204.0	0.050	0.0179	0.9821	1.168	53.220
60	228.0	0.060	0.0215	0.9785	1.172	59.264
70	229.0	0.070	0.0251	0.9749	1.176	59.306

SAMPLE # C-0.1-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
20	37.0	0.020	0.0072	0.9928	1.155	9.758
40	100.0	0.040	0.0144	0.9856	1.163	26.184
60	152.0	0.060	0.0215	0.9785	1.172	39.509
80	201.0	0.080	0.0287	0.9713	1.181	51.863
100	205.0	0.100	0.0359	0.9641	1.189	52.504
120	206.0	0.120	0.0431	0.9569	1.198	52.368

SAMPLE # C-0.1-5

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	18.0	0.010	0.0036	0.9964	1.151	4.765
20	39.0	0.020	0.0072	0.9928	1.155	10.286
30	82.0	0.030	0.0108	0.9892	1.159	21.549
40	142.0	0.040	0.0144	0.9856	1.163	37.181
50	187.0	0.050	0.0179	0.9821	1.168	48.785
60	202.0	0.060	0.0215	0.9785	1.172	52.506
70	218.0	0.070	0.0251	0.9749	1.176	56.457

SAMPLE # C-1-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	13.0	0.010	0.0036	0.9964	1.151	3.441
20	25.0	0.020	0.0072	0.9928	1.155	6.594
30	87.0	0.030	0.0108	0.9892	1.159	22.863
40	167.0	0.040	0.0144	0.9856	1.163	43.727
50	208.0	0.050	0.0179	0.9821	1.168	54.264
60	210.0	0.060	0.0215	0.9785	1.172	54.585

SAMPLE # C-1-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	9.0	0.010	0.0036	0.9964	1.151	2.382
20	45.0	0.020	0.0072	0.9928	1.155	11.868
30	100.0	0.030	0.0108	0.9892	1.159	26.279
40	165.0	0.040	0.0144	0.9856	1.163	43.203
50	206.0	0.050	0.0179	0.9821	1.168	53.742
60	206.0	0.060	0.0215	0.9785	1.172	53.546
70	185.0	0.070	0.0251	0.9749	1.176	47.911

SAMPLE # C-1-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	15.0	0.010	0.0036	0.9964	1.151	3.970
20	43.0	0.020	0.0072	0.9928	1.155	11.341
30	85.0	0.030	0.0108	0.9892	1.159	22.337
40	125.0	0.040	0.0144	0.9856	1.163	32.729
50	155.0	0.050	0.0179	0.9821	1.168	40.437
60	178.0	0.060	0.0215	0.9785	1.172	46.268
70	195.0	0.070	0.0251	0.9749	1.176	50.500
80	208.0	0.080	0.0287	0.9713	1.181	53.669

SAMPLE # C-1-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	10.0	0.010	0.0036	0.9964	1.151	2.647
20	20.0	0.020	0.0072	0.9928	1.155	5.275
30	55.0	0.030	0.0108	0.9892	1.159	14.453
40	125.0	0.040	0.0144	0.9856	1.163	32.729
50	190.0	0.050	0.0179	0.9821	1.168	49.568
60	233.0	0.060	0.0215	0.9785	1.172	60.564

SAMPLE # C-10-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	8.0	0.010	0.0036	0.9964	1.151	2.118
20	22.0	0.020	0.0072	0.9928	1.155	5.802
30	55.0	0.030	0.0108	0.9892	1.159	14.453
40	113.0	0.040	0.0144	0.9856	1.163	29.587
50	170.0	0.050	0.0179	0.9821	1.168	44.350
60	224.0	0.060	0.0215	0.9785	1.172	58.224
70	230.0	0.070	0.0251	0.9749	1.176	59.565
80	219.0	0.080	0.0287	0.9713	1.181	56.507

SAMPLE # C-10-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	13.0	0.010	0.0036	0.9964	1.151	3.441
20	45.0	0.020	0.0072	0.9928	1.155	11.868
30	102.0	0.030	0.0108	0.9892	1.159	26.804
40	162.0	0.040	0.0144	0.9856	1.163	42.417
50	195.0	0.050	0.0179	0.9821	1.168	50.872

SAMPLE # C-10-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	12.0	0.010	0.0036	0.9964	1.151	3.176
20	36.0	0.020	0.0072	0.9928	1.155	9.495
30	80.0	0.030	0.0108	0.9892	1.159	21.023
40	140.0	0.040	0.0144	0.9856	1.163	36.657
50	194.0	0.050	0.0179	0.9821	1.168	50.611
60	214.0	0.060	0.0215	0.9785	1.172	55.625
70	213.0	0.070	0.0251	0.9749	1.176	55.162

SAMPLE # C-10-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
40	56.0	0.040	0.0144	0.9856	1.163	14.663
80	90.0	0.080	0.0287	0.9713	1.181	23.222
120	145.0	0.120	0.0431	0.9569	1.198	36.861
130	175.0	0.130	0.0466	0.9534	1.203	44.320
140	189.0	0.140	0.0502	0.9498	1.207	47.686
150	170.0	0.150	0.0538	0.9462	1.212	42.730

SAMPLE # C-10-5

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
360	67.0	0.360	0.1292	0.8708	1.317	15.500

SAMPLE # C-100-1

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
10	48.0	0.010	0.0036	0.9964	1.151	12.705
20	96.0	0.020	0.0072	0.9928	1.155	25.319
30	120.0	0.030	0.0108	0.9892	1.159	31.535
40	128.0	0.040	0.0144	0.9856	1.163	33.515
50	133.0	0.050	0.0179	0.9821	1.168	34.697
60	137.0	0.060	0.0215	0.9785	1.172	35.610
70	143.0	0.070	0.0251	0.9749	1.176	37.034
80	145.0	0.080	0.0287	0.9713	1.181	37.413

SAMPLE # C-100-2

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
5	10.0	0.005	0.0018	0.9982	1.149	2.652
10	40.0	0.010	0.0036	0.9964	1.151	10.588
15	67.0	0.015	0.0054	0.9946	1.153	17.703
20	101.0	0.020	0.0072	0.9928	1.155	26.638
25	130.0	0.025	0.0090	0.9910	1.157	34.224
30	146.0	0.030	0.0108	0.9892	1.159	38.367
35	156.0	0.035	0.0126	0.9874	1.161	40.921

SAMPLE # C-100-3

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
5	8.0	0.005	0.0018	0.9982	1.149	2.121
10	18.0	0.010	0.0036	0.9964	1.151	4.765
15	40.0	0.015	0.0054	0.9946	1.153	10.569
20	77.0	0.020	0.0072	0.9928	1.155	20.308
25	102.0	0.025	0.0090	0.9910	1.157	26.853
30	180.0	0.030	0.0108	0.9892	1.159	47.302
35	227.0	0.035	0.0126	0.9874	1.161	59.545
40	230.0	0.040	0.0144	0.9856	1.163	60.222
45	231.0	0.045	0.0161	0.9839	1.165	60.374

SAMPLE # C-100-4

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
5	12.0	0.005	0.0018	0.9982	1.149	3.182
10	23.0	0.010	0.0036	0.9964	1.151	6.088
15	45.0	0.015	0.0054	0.9946	1.153	11.890
20	85.0	0.020	0.0072	0.9928	1.155	22.418
25	137.0	0.025	0.0090	0.9910	1.157	36.067
30	185.0	0.030	0.0108	0.9892	1.159	48.616
35	235.0	0.035	0.0126	0.9874	1.161	61.643
40	232.0	0.040	0.0144	0.9856	1.163	60.746

SAMPLE # C-100-5

DIAL READ (X*10E-3)	LOAD DIAL READ	L1	L1/L(E)	1-E	A/(1-E)	STRESS (PSI)
5	17.0	0.005	0.0018	0.9982	1.149	4.508
10	49.0	0.010	0.0036	0.9964	1.151	12.970
15	95.0	0.015	0.0054	0.9946	1.153	25.101
20	150.0	0.020	0.0072	0.9928	1.155	39.561
25	196.0	0.025	0.0090	0.9910	1.157	51.600
30	224.0	0.030	0.0108	0.9892	1.159	58.865