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EVALUATION OF THICKENING AND DEWATERING
CHARACTERISTICS OF SRC-I WASTEWATER TREATMENT
SLUDGES

Final Technical Report

Work Performed Under Contract No. AC05-78OR03054

Catalytic, Inc.
Philadelphia, Pennsylvania

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy



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CHARACTERISTICS OF SRC-I WASTEWATER
TREATMENT SLUDGES**

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TABLE OF CONTENTS

	<u>PAGE</u>
ABSTRACT	1
I. SUMMARY	2
II. INTRODUCTION	3
III. BACKGROUND	4
IV. TREATMENT REQUIREMENTS	9
V. INVESTIGATIVE STUDY	11
A. Characterization	11
B. Conditioning Screening	16
C. Thickening Tests	19
D. Aerobic Sludge Digestion	28
E. Vacuum Filtration	34
F. Pressure Filtration	36
G. Centrifugation	41
H. Dewatering by Belt Filtration	45
I. RCRA Leachate Evaluation	48
VI. DISCUSSION	50
A. Thickening and Conditioning	50
B. Aerobic Sludge Digestion	56
C. Dewatering Equipment	57
VII. CONCLUSIONS AND RECOMMENDATIONS	62
VIII. BIBLIOGRAPHY	65
APPENDIX A	66
APPENDIX B	125

ABSTRACT

The proposed SRC-I Demonstration Plant in Newman, Kentucky, will generate sludges in its wastewater treatment facilities. A number of these sludges have been produced during laboratory treatability testing of simulated process waste streams. As an extension of that work, this study presents the results of a test program conducted on these sludges. Chemical conditioning, aerobic digestion, gravity thickening, and dewatering are evaluated, both for individual sludges and combinations thereof. The test results have identified requisite design changes for the proposed wastewater treatment facilities.

I. SUMMARY

The SRC-I Demonstration Plant in Newman, Kentucky, will generate several different sludges as a result of providing extensive wastewater treatment. Because construction of this plant has been postponed indefinitely, there has been an opportunity to generate additional data pertinent to waste treatment. Accordingly, this report presents the results of a study on the thickening and dewatering characteristics of several of the wastewater treatment sludges.

The study included:

- o Evaluation of chemical conditioning agents.
- o Aerobic digestion of biological sludges.
- o Gravity thickening.
- o The relative effectiveness of dewatering by centrifuge, vacuum filter, belt filter, and pressure filter.

Sludges were tested individually and in combination. The results indicated that the biological sludge could be best dewatered by pressure filtration. The chemical sludges should be combined prior to dewatering, which should be provided by a belt filter.

The tar acid sludge will be kept separate, due to its low pH, and ultimate disposal will be by incineration. The tar acid sludge was more concentrated than had been expected. As a result, thickening, rather than centrifuging, is the recommended treatment for this sludge.

All sludges were tested for leachate toxicity by the extraction procedure method. The results were negative, indicating the sludges are non-hazardous in heavy metal concentrations, according to RCRA classification.

II. INTRODUCTION

To reduce America's dependence on imported petroleum, the U.S. Department of Energy (DOE) initiated the Solvent-Refined Coal (SRC-I) Direct Coal Liquefaction Project. The purpose was to demonstrate the technical and economic feasibility of coal liquefaction. A prime factor in establishing this feasibility was the overall environmental acceptability of the process, including control of gaseous, liquid, and solid wastes. Under its prime contract (No. DE-AC05-78-OR0-3054) with DOE, the International Coal Refining Company (ICRC) completed the baseline design of a 6000-TPD demonstration plant in April, 1982.

DOE has subsequently decided to postpone indefinitely the construction of the demonstration plant. This postponement has provided an opportunity to upgrade the baseline design, and a major effort has since been made to generate additional design information for the wastewater and solid wastes treatment facilities. This post-baseline work included extensive laboratory treatability studies. The purposes were to evaluate alternate treatment schemes and to establish design criteria for individual unit processes. Various sludges were generated during the course of the treatability testing. The waste treatment facility design included thickening, dewatering, and landfilling of all wastewater sludges. When the design criteria were prepared for the revised baseline design, very little data was available on the characteristics of the sludges, especially when combined. This report documents the results of subsequent testing, which better defines the dewatering characteristics.

III. BACKGROUND

One primary objective of ICRC's post-baseline environmental program was to compare two alternative wastewater treatment schemes. One included phenol extraction before biological treatment, and the other did not. Under a previous work agreement, Catalytic, Inc., a subcontractor to International Coal Refining Company (ICRC), operated a number of biological reactors utilizing a strong SRC-I sour water collected from the Fort Lewis, Washington, pilot plant. The impacts of phenol extraction on secondary (biooxidation) and tertiary (coagulation, filtration, carbon adsorption, and ozonation) treatment processes were assessed. Also under that work agreement, samples for toxicological testings at SRI-International were produced. All results are documented in a report (1) issued in March, 1984.

In that report, it was recommended that phenol extraction be employed. Phenol extraction has been incorporated in the revised design of the waste treatment system, as specified in a document prepared by ICRC (2). Effluent limitations are also listed therein. The actual system design was by Catalytic and is documented in another report (3). Under that revised design, the treatment plant effluent is discharged to the river. In contrast, the baseline design incorporates a zero-discharge treatment system.

The revised baseline design prepared by Catalytic included a process flow diagram and mass balance. This quantified all sludges, and specified the equipment required for thickening and dewatering. The overall treatment system is shown as a block flow diagram on Figure 1. Figure 2 shows just those portions of the treatment system relevant to sludge treatment. The quantities of these sludges, on both a wet and dry weight basis, are listed in Table 1.

FIGURE 1 - BLOCK FLOW DIAGRAM

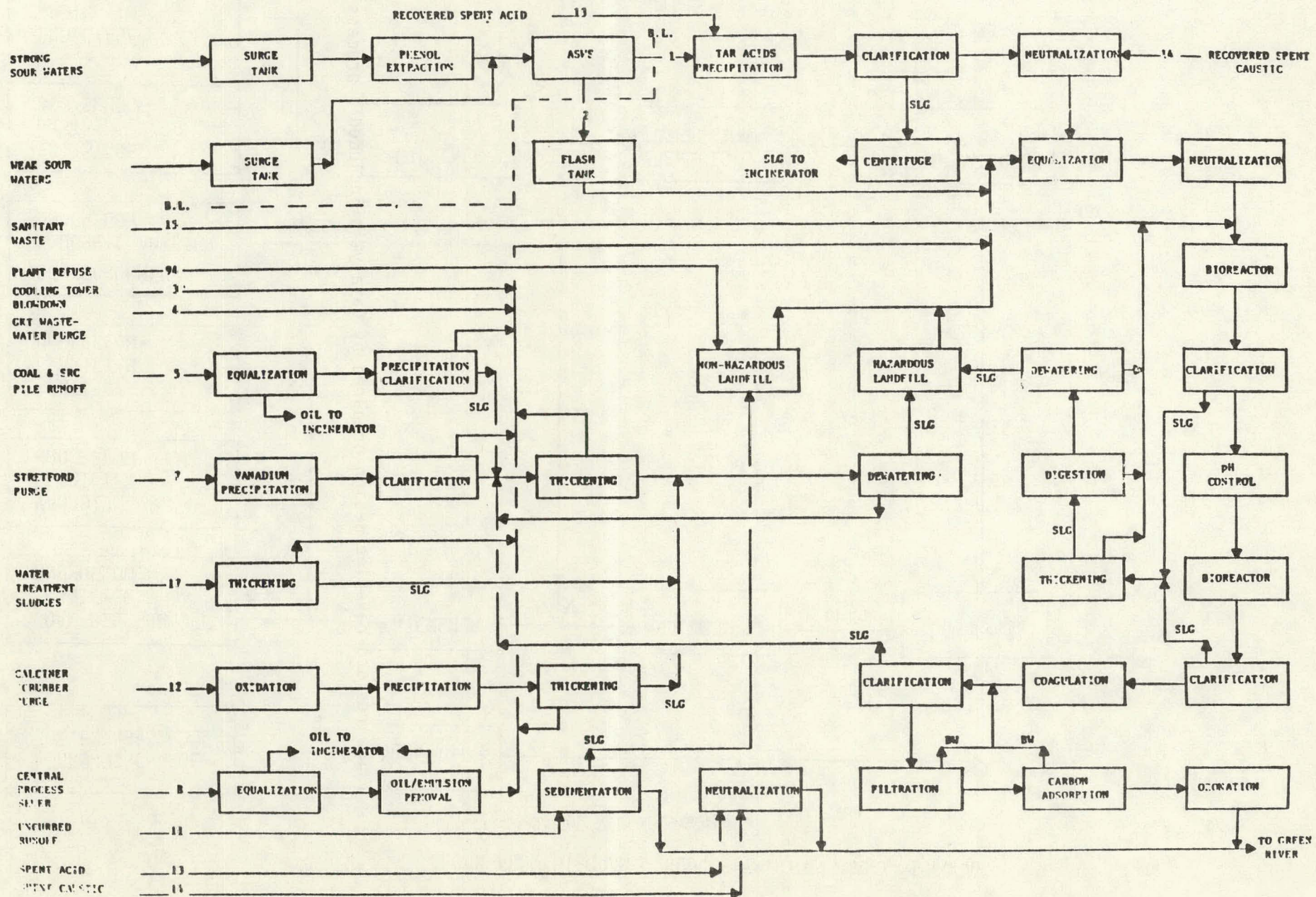


FIGURE 2
BLOCK FLOW DIAGRAM - SLUDGE TREATMENT AND DISPOSAL

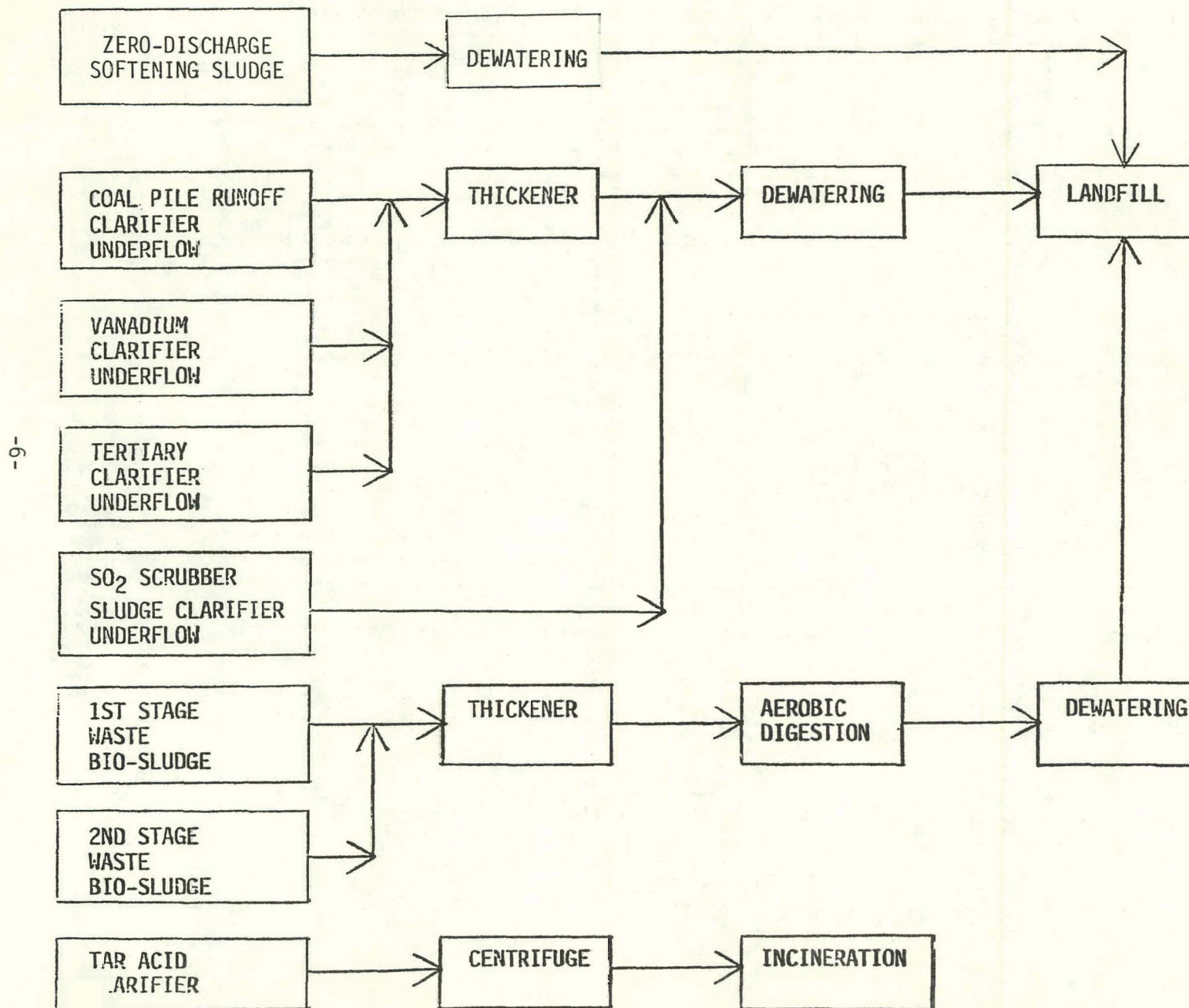


Table 1
Wastewater Sludges

<u>Type</u>	<u>lb/hr dry</u>	<u>lb/hr/wet</u>	<u>wt. % TSS^e</u>
Tar Acid precipitation ^c	28	3,500	0.8-1.8
Vanadium-bearing sludge	10	175	5.7
Scrubber sludge	760	2,570	30
Coal/SRC piles runoff solids	3,100 ^a (970) ^b	53,000 ^a (16,000) ^b	6
Biological solids (undigested)			
1st Stage Bioreactor	340	33,640	1
2nd Stage Bioreactor	140	14,100	1
Coagulation sludge	433	113,950	0.38
Softening sludge ^d	2,080	6,933	30

- Notes:
- a. Based on 25-year, 24-hr storm, equalized over 2-week period.
 - b. Annualized values.
 - c. Highly variable.
 - d. Exists only in zero discharge mode.
 - e. Assumed.

The primary objective in the previous study (1) was to generate data for comparison of the two alternative treatment schemes (with and without phenol extraction). As part of this comparison, clarification and thickening tests were conducted, primarily on biological sludges. Virtually no dewatering tests were performed, and dewatering equipment was sized based on previous experience and literature references.

The overall objective of this study is to generate empirical data for sludge thickening and dewatering. This data can be used to select proper sludge handling and dewatering equipment, as well as to establish practical loading rates (i.e., equipment sizing). In addition, the effectiveness of various conditioning chemicals will be evaluated over a range of dosages.

IV. TREATMENT REQUIREMENTS

As shown on Figure 2, the ultimate disposal of all sludges will be on-site. Landfilling will be used in all cases, with the single exception of the tar acid sludge, which will be incinerated. Sludge treatment must be sufficient to insure that these disposal methods are practical.

The primary object of sludge treatment is simply to remove water. This is necessary for two reasons. First, the dryer the sludge cake, the smaller the required landfill volume. Obviously, landfill costs will be inversely related to solids content. Second, the sludge must be in a condition suitable for landfilling; it must be capable of being discharged from a dump truck, spread, and compacted. No free water should be present. No specific solids content is required; ease of handling is as much a function of sludge type as of cake dryness. For the tar acid sludge, where the proposed disposal method is via incineration, the sludge should be maintained in a liquid or semi-liquid state, because it will be transported in a tank truck and pumped to the incinerator. Therefore, this sludge should be concentrated as much as practical, but remain fluid enough to allow pumping. Centrifugation is the anticipated treatment step.

For the biological sludges, thickening and dewatering are not the only treatments required. These sludges are putrescent at ambient temperatures and should not be landfilled directly. Consequently, a biological aerobic digestion step must be provided to first reduce the volatile solids content. The degree of treatment is arbitrary, as there is no specified efficiency required for digestion. Rather, volatile solids levels are measured daily in a laboratory test. The daily and cumulative removals are then evaluated to choose a digestion period.

The treatment requirements for all other sludges are thickening and/or dewatering. The coal pile runoff, vanadium, and tertiary coagulation sludges will be combined, thickened, and dewatered. The softening sludge (for zero discharge only) and the SO₂ scrubber sludge can be dewatered without an intermediate thickening step.

Because the landfills will be designed according to RCRA specifications (double lined), all leachate will be collected and recycled to the wastewater treatment facilities. Therefore, there are no limitations on leachate quantities or constituents. However, it is prudent engineering practice to identify hazardous wastes. Therefore, leaching tests were conducted in this study, using the EPA extraction procedure for hazardous waste classification.

V. INVESTIGATIVE STUDY

A. CHARACTERIZATION

As shown on Figure 2, six sludges are produced by the various wastewater treatment facilities. To these, a softening sludge is an addition required for the zero discharge treatment scheme. (The revised design, as shown on Figure 1, is based on a constant discharge to the Green River). Not all of the sludges were available, and testing was confined to the following ones, plus combinations thereof:

Tar Acid
Vanadium
Biological
Tertiary Coagulation
Softening

The sludges for which no samples were available were the SO₂ scrubber blowdown and the coal pile/SRC pile runoff. However, the settling and dewatering properties of these sludges (predominantly calcium sulfate and iron hydroxides) are well known, so their absence is not crucial.

The five sludges tested were generated in the following ways:

1. Tar Acid

Tar acid sludge is generated by a chemical precipitation step, which is part of the pretreatment of the main process waste stream. The wastewater used to simulate this stream was obtained from the DOE-owned coal liquefaction pilot plant at

Fort Lewis, Washington. Samples of the Process Recycle Water (PRW) were collected from August 12 to 14, 1980, when the pilot plant was running in the SRC-I mode. (The plant was designed to primarily run in the SRC-II mode). This wastewater has been thoroughly characterized in an earlier study (4).

The sludge was generated by the following treatment sequence. First, the wastewater was treated by solvent extraction to remove phenolics. Then it was steam stripped to remove ammonia and hydrogen sulfide. The pH was then lowered to 2.5, causing a precipitation of dissolved organics. These solids, known as tar acids, will resolubilize if the pH is raised to a neutral level. These treatment steps are detailed in a previous study (1).

2. Vanadium

The SRC-I process both removes and recovers sulfur from coal. As part of the recovery process, a vanadium salt is used to oxidize hydrogen sulfide. A blowdown from this step is known as the Stretford purge, and this stream receives segregated treatment before being mixed with other plant wastewaters (Figure 1). This pretreatment step produces an iron vanadate sludge. As described in another study (1), this sludge is formed by raising the wastewater pH to 10, then adding 4,000 mg/l of ferric sulfate. The wastewater sample used to produce this sludge was obtained from a Beavon-Stretford sulfur removal unit at the Getty Refinery in Delaware City, Delaware. This unit was similar to the one designed for the SRC-I Demonstration Plant.

3. Biological

Secondary wastewater treatment, as shown on Figure 1, is provided by a two-stage activated sludge system. Under steady state conditions, this system will produce biomass, or solids, at a relatively steady rate, requiring sludge wasting on a regular basis. This waste sludge, which is taken from the clarifier underflow, must be thickened, digested, and dewatered. During a previous study (1), the activated sludge process was simulated by bench-scale reactors, operating on a continuous flow basis. This included both single-stage bioreactors with powdered activated carbon (PAC), and two-stage bioreactors with very minimal carbon addition (NPAC). During that work, waste sludge from both types of biosystems was aerobically digested. However, because sludge treatment was not within the scope of that project, the results were not included in the final study report. The results of the aerobic digestion tests are included in this report in Section V-D. The data presented in Columns 3 and 4 of Table 2 refer to the sludges generated during the previous study. All other treatability results presented herein were developed as part of this sludge study.

At the completion of the above study, four of the bioreactors (comprising NPAC Systems 1 and 2) were kept in operation and are currently being used to determine biokinetic coefficients. Throughout the entire operation of these four bioreactors, sludge was wasted regularly. These sludges were mixed together and placed in refrigerated storage at 4°C. The combined sludge was then aerobically digested, prior to the thickening and dewatering tests reported herein (Column 1 on Table 2). However, not all thickening tests were run on digested sludge; three were run on undigested sludge. In these cases, fresh sludge was used, taken from the bioreactors for the biokinetic study (Column 2 on Table 2).

Table 2
SLUDGE CHARACTERISTICS

Parameter	Sludge Description										
	Digested HPAC Biological	Undigested HPAC Biological	Digested PAC Biological	Undigested PAC Biological	Tar Acid Precipitate	Vanadium Precipitate	Softening Sludge	4FAC Eff. Coag. Precipitate	PAC Eff. Coag. Precipitate	Composite Vanadium + NPAC Eff. Coag.	Composite Vanadium + Soft+NPAC Coag.
TSS (mg/l)	8173	10825	13130	11535	17710	57840	290035	3843	5215	3940	18473
(Vol. %)	11.40%	< 0.1%	2.05%	< 0.1%	0.98%	2.33%	3.97%	< 0.1%	0.74%	0.54%	1.45%
TVSS (mg/l)	5155	7069	11070	9325	4076	6300	6420	1293	1950	1220	4533
TS (mg/l)	15115	14197	17745	16085	22245	242180	310670	8450	8555	10160	24600
TVS (mg/l)	5245	7069	11070	9325	4076	6300	16470	165	1950	1700	3340
pH	6.3	7.6	6.2	7.5	4.3	11.7	12.0	7.0	6.3	7.2	7.9
Solids Texture	Very fine, small particles	Very fine, small particles	Very fine, small particles	Very fine, small particles	Very fine, sand like particles	Fine, small particles	Very fine, small sand like particles	Very fine, small particles	Thick, dense small fine particles	Very fine, small particles	Fine, small particles
Solids Color	Very dark brown, almost black	Very dark brown, almost black	Black	Very dark black	Chocolate-brown slate	Dark brown olive	Yellowish white	Chocolate brown with slight yellow tinge	Very dark brown, almost black	Very dark chocolate brown	Chocolate milk brown
Liquid Color	Brown Trans-luscent	Grey-black transparent	Cloudy, grey black trans-luscent	Yellowish grey-trans-luscent	Light brown transparent	Dark red maroon	Deep yellow transparent	Reddish-brown transparent	Greenish-grey transparent	Yellowish-brown transparent	Reddish-brown transparent
Odor	Sweet, biological smell	Aerobic-sweet biological smell - if septic - unpleasant	Sweet, biological smell	Aerobic-sweet biological smell - if septic - unpleasant	Slight, sweet not unpleasant	Very strong unpleasant "refinery" smell	Slight, sweet not unpleasant	Slight "refinery" smell	Slight not unpleasant	Yes, not unpleasant	Slight, not unpleasant
Thickening Tests											
Supernatant											
SS (mg/l)	218	42	402	-	4	10	16	4	14	4	6
DOC (mg/l)	-	61	-	-	1415	-	36	23	16	31	28
Conductivity ($\mu\text{mho/cm@25}^\circ\text{C}$)	6549	6105	6882	-	8109	180375	17760	6600	6040	7548	6350
Sludge											
SVI	71	68	26	7	48	17	3	290	75	236	32
Settleable Solids											
1 HR (% Vol.)	45%	57%	21%	45%	70%	96%	65%	78%	31%	80%	49%
2 HR (% Vol.)	34%	43%	18%	45%	47%	90%	77%	58%	24%	63%	35%
24 HR (% Vol.)	23%	25%	14%	-	20%	-	58%	71%	16%	21%	15%
Resistivity (sec/ml^2)	0.3975	0.0501	0.2925	0.0249	0.0068	0.0276	0.0093	0.0654	0.0440	0.0952	0.0558

4. Tertiary Coagulation

The tertiary wastewater treatment facilities also produce sludge. Again referring to Figure 1, chemical addition and coagulation/clarification immediately follow secondary treatment. The treatment sequence consists of first adding ferric chloride at a dosage of 6,000 mg/l, which causes a drop in pH and a precipitation of solids. Lime is then added to raise the pH to neutral, plus to aid in coagulating the solids. Polymer (Magnifloc 835A) is also added at a dosage of 0.5 mg/l. This procedure was followed to generate sludges from two types of secondary effluents. Both effluents were produced in the previously mentioned study (1). One was the effluent from a two-stage activated sludge system, operated without high doses of powdered activated carbon (NPAC). The second was a single-stage activated sludge unit, operated with a high level of powdered carbon (PAC).

5. Softening

The revised baseline design of the wastewater treatment facilities does not include a softening process. However, softening would be required to achieve zero discharge, which is still a viable option. Therefore, tests were run on a softening sludge. This sludge was generated by further treatment of the wastewater, following the coagulation step described above. The wastewater pH was raised to 10, and 6,000 mg/l of sodium carbonate added. This precipitated a calcium carbonate sludge.

The characteristics of the sludges described above are listed on Table 2. The plots made to determine resistivity are included in the Appendix, Figures A-1 to A-11.

Also included on Table 2 are two composite sludges. The first is a combination of the vanadium and NPAC tertiary coagulation sludges. The other composite is a combination of the above two sludges, plus the softening sludge. These are referenced subsequently as Composites 13 and 14, respectively.

B. CONDITIONING SCREENING

The removal of water from wastewater sludges is often greatly facilitated if the sludge is pretreated, or conditioned. Conditioning serves to create and maintain a porous structure in the sludge, allowing a more rapid and complete removal of water. Conditioning by chemical means is the method most frequently employed. Both inorganic conditioners (such as ferric and aluminum compounds) and organic conditioners (synthetic polyelectrolytes, or polymers) are commonly used. Both types were evaluated as part of this study.

Conditioning screening tests provide a rapid means of comparing the relative effectiveness of conditioning agents. The scope of this study includes several sludges. When these are considered in relation to different conditioning agents, each at varying dosages, the resulting test matrix is prohibitive, both from a scheduling standpoint and, more importantly, in regard to the available quantities of sludge samples. Preliminary screening work shows which chemicals are most effective, thus reducing subsequent development work to a manageable level and conserving the limited quantities of samples.

Jar Tests

A convenient means of screening different polymers is the jar test. This is a simple procedure, the first step of which is to add polymer solutions to 50 ml samples of sludge. Following a 30 second period of rapid mixing, the samples are slowly agitated for 3 minutes, causing an agglomeration of the solids into large particles, or floc.

The samples are then allowed to settle. The clarity of the supernatant and the appearance of the floc structure are qualitative indications of the polymers' effectiveness.

This jar test procedure was used to evaluate numerous polymers for each available sludge. Specific polymers tested were selected based on previous experience with industrial sludges and are listed in Table 3. Polyelectrolyte solutions (0.1 percent) were added to sludge samples in doses ranging from 0.5 to 2 percent (dry weight basis). Observations noting general floc size and supernatant quality were recorded; however, no quantitative measurements were made. Rather, these tests provided a means for evaluating the relative effectiveness of many polymers, thereby reducing the number of conditioning agents for subsequent quantitative testing.

The jar tests showed a medium molecular weight, cationic polymer (Percol 722) to be a very effective flocculent for all sludges. This conditioner was prepared from a dry micro-bead of medium charge density. Other polyelectrolytes were neither as effective nor as universally applicable. Therefore, Percol 722 cationic polymer was selected for all further screening and development tests.

Buchner Funnel Tests

The Buchner funnel test is another screening procedure. This was used to evaluate the effectiveness of both the polymer (Percol 722) and the inorganic conditioners: ferric chloride, alum and lime. The test is conducted by pouring a measured volume of sludge into a funnel containing a glass microfiber filter paper, and then applying a vacuum. A constant vacuum is maintained and is consistent for each test. Measurements are then taken of the elapsed time required to produce discreet quantities of filtrate.

Table 3

Polymers Screened Via Jar Test

<u>Brand</u>	<u>Type</u>
Nalco - 7122	Liquid cationic, high MW, moderate charge density.
- 7735	Liquid cationic, moderate MW, very high charge density.
- 7763	Liquid anionic, moderate MW, moderate charge density.
- 7766	Liquid anionic, high MW, moderate charge density.
Allied Colloids - Percol 722	Dry cationic, moderate MW, moderate charge density.
- Percol 728	Dry cationic, very high MW, moderate charge density.
- Percol 757	Dry cationic, high MW, very high charge density.
- Percol 763	Dry cationic, high MW, high charge density.
American Cyanamid - Magnifloc 577C	Liquid cationic, moderate MW, high charge density.
- Magnifloc 835A	Dry anionic, high MW, moderate charge density.
- Magnifloc 1839A	Liquid anionic, high MW, low charge density.

The purpose of the Buchner funnel test is to define the resistivity for each sludge with the conditioning agents investigated. Generally, there is an inverse relationship between the dewaterability of the sludge and the resistivity. A graphic interpretation of the resistivity is obtained by plotting the time divided by the filtrate volume (seconds/milliliters) versus the filtrate volume (milliliters). Resistivity is determined by calculating the slope of the line through this data. Resistivity plots for each Buchner funnel test are presented as Figures A-12 to A-41 in the Appendix. A comparison of the results obtained for each sludge appears in the following Tables 4 to 8, as specified below.

Table 4 - Digested NPAC Biological.

Table 5 - Softening.

Table 6 - NPAC Effluent Coagulation Precipitate.

Table 7 - NPAC Effluent Coagulation and Vanadium Precipitate.

Table 8 - NPAC Effluent Coagulation, Vanadium, and Softening.

C. THICKENING TESTS

Thickening is typically the first step in removing water from sludges to reduce their volume, and the design of gravity thickeners requires knowledge of the settling characteristics of the sludge being thickened. Batch settling tests are necessary to yield the data required for rational analysis.

Sludges are sufficiently high in solids concentration that they exhibit zone-settling characteristics. The appearance of a distinct horizontal interface between the solids and the liquid is the characteristic feature of zone subsidence and is the basis for measurement of sludge settling properties. In laboratory settling tests, a 1,000-ml graduated cylinder is filled with a representative sample of

Table 4

Conditioner Screening - Buchner Funnel Test Results

Sludge Type: NPAC Eff. Coag. Precip. Initial % Solids: 1.3

<u>Conditioner</u>	<u>Dose (wt.%)</u>	<u>Time (sec.) to 40 ml Filtrate</u>	<u>Cake % Solids</u>	<u>Resistivity (sec/ml²)</u>
Percol 722	0.5	30	10.4	2.2×10^{-2}
	1.0	26	7.6	ND
Ferric chloride	10	51	40.8	2.5×10^{-2}
Calcium hydroxide	10	49	12.7	3.2×10^{-2}
Alum	10	54	11.6	2.1×10^{-2}

Table 5

Conditioner Screening - Buchner Funnel Test Results

Sludge Type: NPAC Eff. Coag. & Vanadium Precip. Initial % Solids: 1.2

<u>Conditioner</u>	<u>Dose (wt.%)</u>	<u>Time (sec.) to 40 ml Filtrate</u>	<u>Cake % Solids</u>	<u>Resistivity (sec/ml²)</u>
Percol 722	1.0	20	8.6	2.2×10^{-2}
Ferric chloride	10	74	11.1	4.1×10^{-2}
Calcium hydroxide	10	80	7.7	5.2×10^{-2}
Alum	10	115	7.0	9.1×10^{-2}

Table 6

Conditioner Screening - Buchner Funnel Test Results

Sludge Type: NPAC Coag. & Vanadium & Softening Initial % Solids: 10.3

<u>Conditioner</u>	<u>Dose (wt. %)</u>	<u>Time (sec.) to 30 ml Filtrate</u>	<u>Cake % Solids</u>	<u>Resistivity (sec/ml²)</u>
Percol 722	0.1	14	31.8	1.8×10^{-2}
	0.25	13	39.6	2.0×10^{-2}
Ferric chloride	10	52	35.1	4.1×10^{-2}
Calcium hydroxide	10	29	33.0	2.2×10^{-2}
Alum	10	50	32.0	3.9×10^{-2}

Table 7

Conditioner Screening - Buchner Funnel Test Results

Sludge Type: Digested NPAC Bio.		Initial % Solids: 2.7		
<u>Conditioner</u>	<u>Dose (wt.%)</u>	<u>Time (sec.) to 30 ml Filtrate</u>	<u>Cake % Solids</u>	<u>Resistivity (sec/ml²)</u>
Percol 722	0.5	42	7.6	5.36×10^{-2}
	1.0	95	5.7	9.52×10^{-2}
Ferric chloride	5	30	24.2	3.25×10^{-2}
	10	20	22.0	3.02×10^{-2}
	15	14	10.1	8.52×10^{-3}
Calcium hydroxide	5	50	11.2	5.40×10^{-2}
	10	45	12.0	4.44×10^{-2}
	15	37	15.5	3.12×10^{-2}
Alum	5	36	15.6	5.30×10^{-2}
	10	30	11.0	3.00×10^{-2}

Table 8

Conditioner Screening - Buchner Funnel Test Results

Sludge Type: Softening

Initial % Solids: 27.5

<u>Conditioner</u>	<u>Dose (wt.%)</u>	<u>Time (sec.) to 20 ml Filtrate</u>	<u>Cake % Solids</u>	<u>Resistivity (sec/ml²)</u>
Precol 722	0.05	8	49.1	ND ¹
	0.1	9	57.9	ND ¹
	0.2	11	53.9	7.2×10^{-3}
Ferric chloride	5	6	50.0	ND ¹
Alum	5	5	51.1	ND ¹
None	0	20	49.1	ND ¹

Notes: ¹ Could not be determined from 50-ml sample test

the sludge and a plot of the position of the liquid-solids interface as a function of time is obtained. The contents of the column are stirred very slowly throughout the test to minimize the wall effects caused by the small diameter of the cylinder.

Batch settling tests were conducted for each of the available sludges. The height (cm) of the sludge interface is plotted versus time (minutes) for each test; these curves are included in the Appendix (Figures A-42 to A-77). Initial and supernatant suspended solids concentrations were analyzed, and pH, temperature and final sludge volume were recorded. The Sludge Volume Index (SVI), defined as the volume occupied by a gram of sludge after 30 minutes of setting, was determined for each sludge. Fresh samples of undigested PAC biological sludge were not available for testing, and no thickening or dewatering results for this sludge are reported herein. The characterization data presented in Table 2, Column 2, is based on a sample stored during a previous treatability study (1).

To evaluate the effect of polymer addition on thickening, settling tests were also conducted for each sludge with varying doses of Percol 722. This polymer was determined by jar testing to be an effective flocculent for all sludges tested. (Refer to Sludge Conditioning Screening Section.) Polymer solution (0.1 percent) was added to each sludge sample and flocculated within a 1-liter graduated cylinder prior to the start of each thickening test. Interface position versus time plots for each sludge are presented in the Appendix (Figures A-42 to A-77) for polymer doses typically ranging from 0.1 to 0.5 percent on a dry weight basis.

A summary of thickening test data for each sludge, with and without polymer, is presented in Table 9, which follows. Zone settling velocities and thickened solids concentration at selected time intervals are presented for purposes of comparison.

Table 9
Thickening Test Results

Sludge Type	Polymer Dose (wt.%)	Zone Settling Velocity (ft./day)	Initial Solids Conc. (%)	Thickened Solids Conc. (%)			Figure No.
				@45 min.	@90 min.	Ultimate	
Undigested NPAC Bio.	None	19.8	1.08	1.74	2.25	4.32	1A-1
	0.1	39.5	1.01	2.10	2.80	----	1A-2
	0.3	79.1	1.01	2.60	2.73	3.26	1A-3
Digested NPAC Bio.	None	44.8	0.82	1.64	2.28	3.81	1-1
	0.1	112.0	0.82	3.15	3.15	3.15	1-2
	0.2	201.6	0.82	3.15	3.15	3.15	1-3
	0.3	403.2	0.82	3.15	3.15	3.15	1-4
Digested PAC Bio.	None	107.5	1.31	4.85	6.24	8.45	2-1
	0.04	336.0	1.31	6.85	8.19	8.45	2-2
	0.08	510.7	1.31	6.24	6.72	----	2-3
Tar Acid Precip.	None	9.6	1.77	2.27	3.28	8.85	4-1
	0.1	17.8	1.77	2.60	3.69	7.53	4-2
	0.2	113.4	1.77	6.81	7.08	7.08	4-3
	0.3	386.4	1.77	6.32	6.56	6.56	4-4
Vanadium Precip.	None	0.8	5.68	5.80	6.04	----	5-1
	0.01	18.5	5.68	9.16	14.95	31.56	5-2
	0.02	12.1	5.68	8.11	10.52	36.64	5-3

Table 9
Thickening Test Results

Sludge Type	Polymer Dose (wt.%)	Zone Settling Velocity (ft./day)	Initial Solids Conc. (%)	Thickened Solids Conc. (%)			Figure No.
				@45 min.	@90 min.	Ultimate	
Softening Slg.	None	6.0	31.44	35.73	38.34	54.39	6-1
	0.01	3.5	30.02	31.94	35.74	73.22	6-2
NPAC Eff. Coag. Precip.	None	10.1	0.30	0.38	0.46	1.76	7-1
	0.05	53.8	0.38	0.90	1.19	1.95	7-2
	0.2	38.6	0.38	0.74	0.97	1.65	7-3
PAC Eff. Coag. Precip.	None	67.2	0.48	1.41	1.71	3.0	8-1
	0.1	162.4	0.48	2.4	2.67	3.0	8-2
	0.2	739.2	0.48	2.53	2.53		8-3
	0.3	806.4	0.48	2.53	2.59		8-4
	0.4	1041.6	0.48	2.46	2.53	4.0	8-5
	0.5	1226.4	0.48	2.59	2.67		8-6
Composite of Vanadium & NPAC Coag.	None	3.4	0.39	0.46	0.54	1.90	13-1
	0.04	64.5	0.39	0.95	1.18		13-2
	0.1	60.5	0.39	0.98	1.18	1.70	13-3
Composite of Vanadium & NPAC Coag. & Softening Slgs.	None	12.3	1.85	3.42	4.51	12.76	14-1
	0.03	121.0	1.85	6.17	8.22		14-2
	0.04	152.4	1.85	8.04	9.74		14-3
	0.05	241.9	1.85	9.25	10.28		14-4
	0.06	174.7	1.85	8.41	10.28	14.23	14-5

D. AEROBIC SLUDGE DIGESTION

Waste biological sludge consists mainly of excess biomass generated as a result of organic removal in the secondary treatment facilities. Typically, biological sludge has a noxious nature and must be stabilized prior to landfill. The objectives of stabilization are to prevent offensive odor conditions and to reduce the solids quantities that must be subsequently handled.

The term digestion is considered synonymous with biological sludge stabilization. Both aerobic and anaerobic digestion processes are widely used. Aerobic digestion was selected for this study because it is less susceptible to upset conditions.

In principle, aerobic digestion can be considered as a continuation of the activated sludge process. In digestion, however, the external source of organic material (i.e., soluble BOD) has been exhausted, and the microorganisms must enter a state of endogenous respiration to satisfy the energy required for cellular maintenance. Over an extended period of time, the total quantity of biomass is reduced, and the stable portion remaining is suitable for disposal.

Aerobic digestion of two activated sludges was monitored in batch reactors. As noted in the Characterization Section of this report, the sludge sources were bench-scale bioreactors being run as part of another study.

The digestion process was monitored by placing 1.5 liters of sludge in a plastic container. Air was continually pumped into the sludge and dispersed by porous stone diffusers at the bottom of the container. The air volume was sufficient to mix the sludge and maintain the solids particles in suspension. It also supplied the oxygen necessary for the biochemical digestion reactions. Daily measurements were taken of total suspended solids (TSS), volatile suspended solids (VSS), pH, and oxygen uptake rate (OUR). The tests were conducted at approximately 22°C.

The data from both digestion tests is listed in Tables 10 and 11. The total and volatile solids are of prime interest. These values are plotted versus cumulative digestion time on Figures 3 and 4 for the NPAC and PAC sludges, respectively. As the figures indicate, the solids data for the PAC sludge was subject to much greater fluctuations than for the NPAC sludge. These apparent changes were due to the powdered activated carbon in the system. The carbon was prepared by grinding granular carbon in the laboratory. The resulting powdered carbon was not as uniformly fine as commercially available powdered carbons. In addition, the carbon particles tended to agglomerate due to attached biological growth. Because of these factors, any given sample of sludge might contain some disproportionately large particles, thereby causing somewhat erratic results in measurements of suspended solids.

As Figure 3 shows, the daily reductions in TSS and VSS gradually decreased for the NPAC sludge. This is normal for a biological process. This trend was not evident for the PAC sludge, due to the data scattering described above. Presumably, the same rate-dampening effect would occur. However, because it is not apparent from the data points, least square plots are presented on Figure 4.

For both sludges, the ratio of VSS to TSS remained relatively constant throughout the digestion process, even though the digestion process should only utilize the volatile fraction. However, this effect has been noted previously (5), and is explained by solubilization of the non-volatile fraction upon cell lysis. Also in regard to the VSS to TSS ratio, the value for the NPAC sludge was considerably less than the PAC sludge (approximately 70% vs. 90%, respectively). This is due to the powdered carbon, a portion of which evidently is measured as volatile solids. The carbon is supposedly non-volatile, and this has been confirmed for the virgin carbon. When used in the PAC system, however, its volatility increases. The reason for this is speculative, but it has occurred in previous treatability work.

Table 10
Aerobic Digestion - NPAC Sludge

Date	pH	OUR (mg/l/hr)	TSS (mg/l)	VSS (mg/l)	VSS/TSS (%)
4/28	6.3	20	16,200	12,000	74
29	6.8	16	14,930	10,560	71
30	6.6	14	15,260	10,600	69
5/1	6.7	8	14,500	8,960	62
2	7.5	6	13,890	9,790	70
3	7.3	6	13,870	9,620	69
4	7.3	6	13,410	9,330	70
5	7.0	8	12,970	9,010	69
6	7.1	-	12,690	8,790	69
7	6.9	-	12,590	8,770	70
8	6.7	-	12,510	8,660	69
9	6.7	8	11,530	7,990	69
10	6.8	7	10,860	7,610	70
11	6.8	9	10,980	7,680	70
12	6.6	3	10,320	7,170	69
13	6.9	4	10,250	7,220	70
14	6.8	4	10,530	7,420	70
15	6.7	6	9,720	6,840	70
16	7.0	3	9,510	6,590	69
17	7.0	4	8,900	6,160	69
18	---	1.9	8,530	5,920	69
19	---	1.7	8,750	6,110	70
20	---	1.5	8,310	6,060	73
21	---	1.5	8,420	5,970	71
22	---	1.5	6,620	4,680	71
23	---	1.2	7,840	5,630	72
24	---	0.9	8,070	5,710	71

Table 11
Aerobic Digestion - PAC Sludge

Date	pH	OUR (mg/l/hr)	TSS (mg/l)	VSS (mg/l)	VSS/TSS (%)
6/21	---	---	50,430	43,890	87
22	7.0	11	59,070	50,990	86
23	6.2	20	54,920	49,860	91
24	5.9	---	60,220	52,900	88
25	5.9	22	46,700	41,340	89
26	6.0	20	53,200	46,500	87
27	8.0	24	52,780	46,400	88
28	5.8	11	51,060	44,660	87
29	6.6	8	53,400	46,820	88
30	5.9	1.0	53,980	47,420	88
7/1	6.3	---	48,520	42,980	89
2	6.4	1.3	47,120	41,160	87
3	8.8	---	48,070	42,210	88
4	6.4	1.0	45,880	37,890	83
5	7.1		47,520	41,760	88
6	7.1		39,980	35,100	88
7	6.8		38,870	33,910	87
8	7.1		44,520	38,660	87
9	7.8		34,890	30,670	88
10	6.8		34,800	30,460	88
11	6.3		41,950	37,050	88
12	6.3		33,810	30,040	89
13	6.6		30,510	27,050	89
14	6.9		30,160	26,850	89
15	6.5		31,010	27,760	90
16	7.9		21,810	19,510	89
17	7.7		34,930	30,430	87

Table 11 (Cont.)
Aerobic Digestion - PAC Sludge

Date	pH	OUR (mg/l/hr)	TSS (mg/l)	VSS (mg/l)	VSS/TSS (%)
7/18	7.4		38,000	32,950	87
19	7.2		35,620	31,070	87
20	7.2		35,870	30,850	86
21	7.0		32,700	28,600	87
22	6.5		24,880	22,180	89
23	6.5		24,770	21,880	88
24	6.4		24,740	21,880	88
25	6.9		31,130	27,110	87
26	6.6		22,660	20,000	88
27	6.4		19,720	17,640	89

Figure 3
AEROBIC DIGESTION
 NPAC BIO SLUDGE

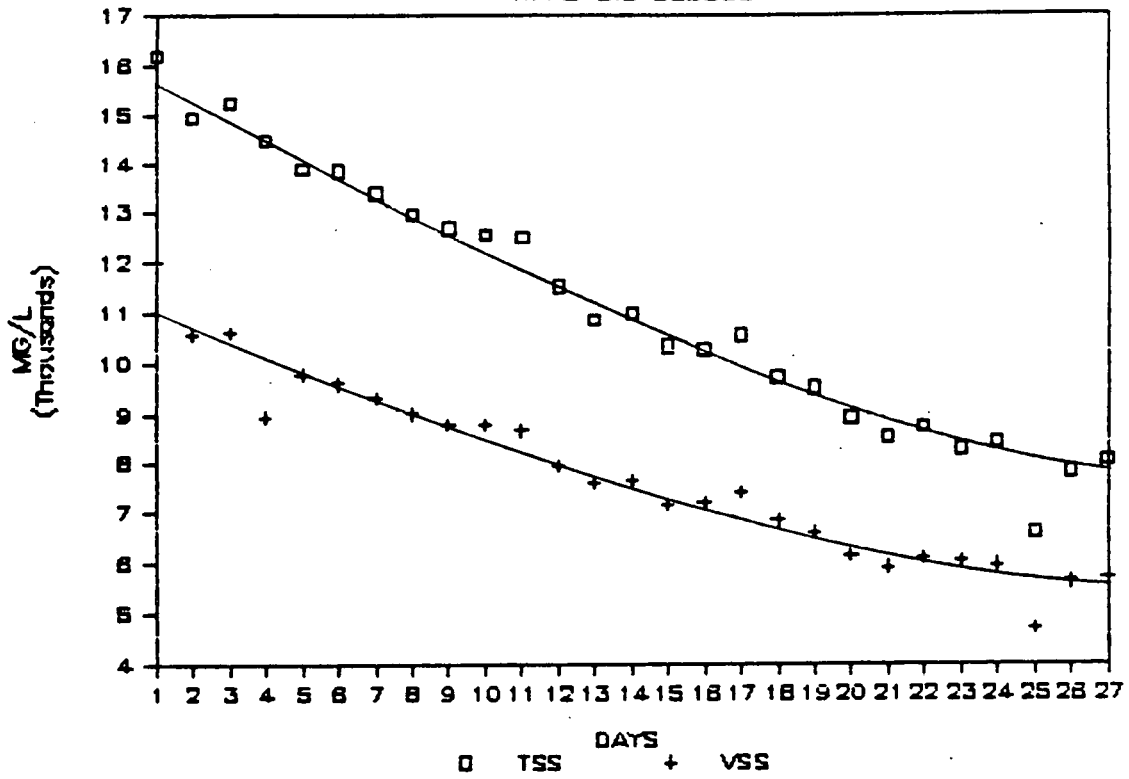
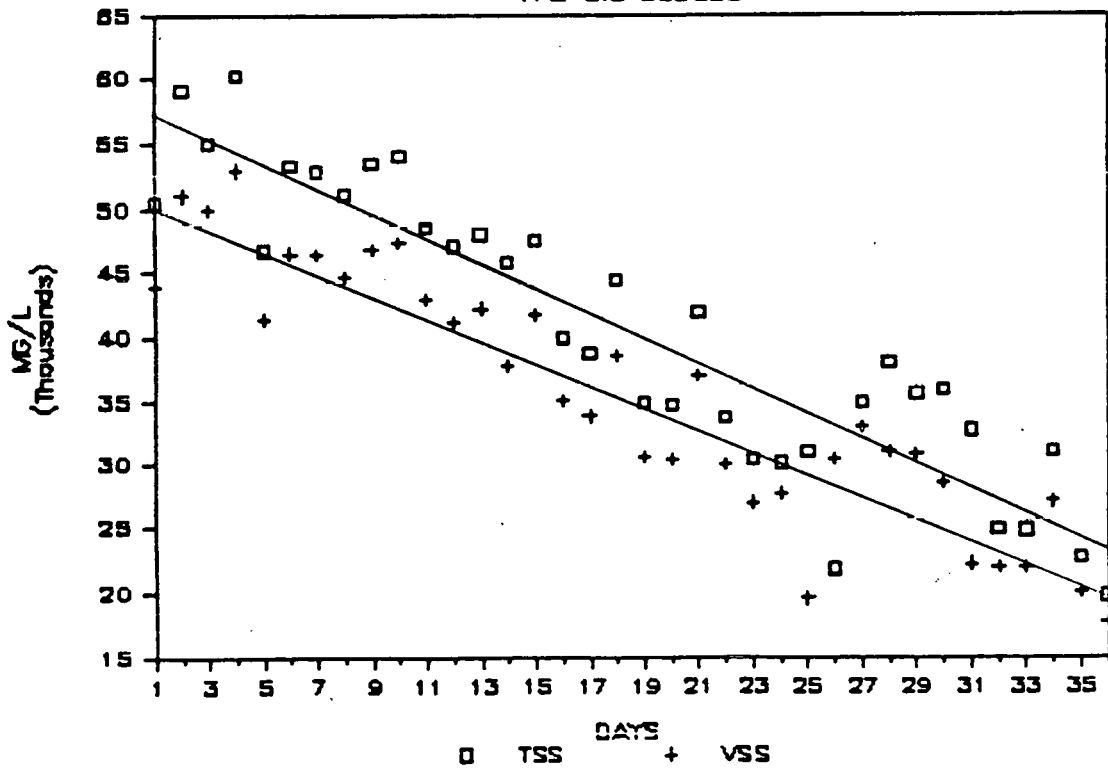


Figure 4
AEROBIC DIGESTION
 PAC BIO SLUDGE



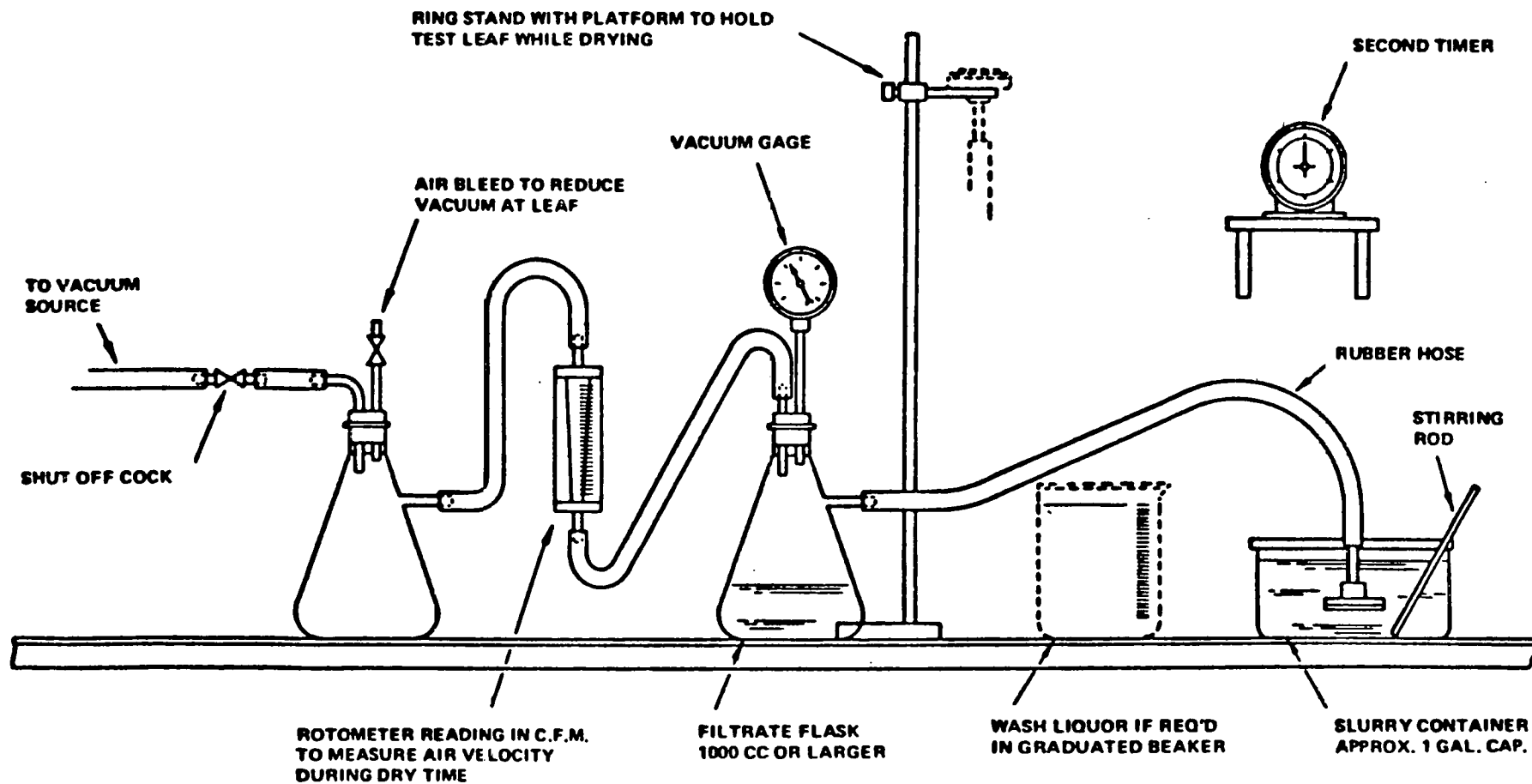
E. VACUUM FILTRATION

The vacuum filtration process was evaluated using the filter leaf test. Types and dosages of chemical conditioners were based on the results of the screening tests, as discussed in the Conditioning Screening Section of this report. The test apparatus is shown on Figure 5.

The procedure is to submerge the filter leaf in the agitated sludge container for a short time. The driving force produced by the applied vacuum draws the sludge to the filter leaf surface, where a cloth prevents the solids from passing. The filtrate is drawn through and collected in the receiving flask. The period of submergence is called the form time. The leaf is then removed, and, still under vacuum, the accumulated sludge continues to dewater until the cake cracks, at which point the vacuum is essentially lost. This period is known as the dry time. Several tests may be required to find the proper filter cloth for any given sludge. Its weave must be sufficiently tight to retain most solids, but not so fine that it clogs, or blinds.

The tertiary coagulation sludge and the composite sludges could not be dewatered by this method. The solids either passed through the filter cloth or blinded almost immediately. Blinding effectively cuts off the applied vacuum and prevents any further cake build-up. For the coagulation sludges, this blinding was not caused by the cloth, but by the initial sludge deposits. Final cake thicknesses of less than 1/32 of an inch were observed. In the case of the digested PAC sludge, it appears that the cloth itself was blinded. This was due to very fine carbon particles that were trapped in the mesh. Different cloths were tested without success.

Figure 5
Filter Leaf Test Apparatus



By contrast, the softening sludge was easily dewatered by vacuum filtration. A form time of 30 seconds and a drying time of one minute produced a 69% solids cake. Chemical conditioning was not required; almost identical results were obtained both with and without polymer addition. The cake was readily separable from the cloth, falling off when the filter leaf was inverted. The cloth used was Eimco No. PO-801HF, a polyethylene mono-filament with a 1/1 plain weave.

The digested NPAC biological sludge could also be dewatered by vacuum filtration. Form and dry times of one minute each resulted in a 25%-solids cake. Two conditioning agents (FeCl_3 and a polymer) were required. The cake did not fall off the cloth, as was the case with the softening sludge, nor could it be removed by blowing. Mechanical prying was necessary. The filter cloth was Eimco No. NY-529F, a nylon, multi-filament with a 2/2 twill weave. The results of the tests are summarized on Table 12, below.

F. PRESSURE FILTRATION

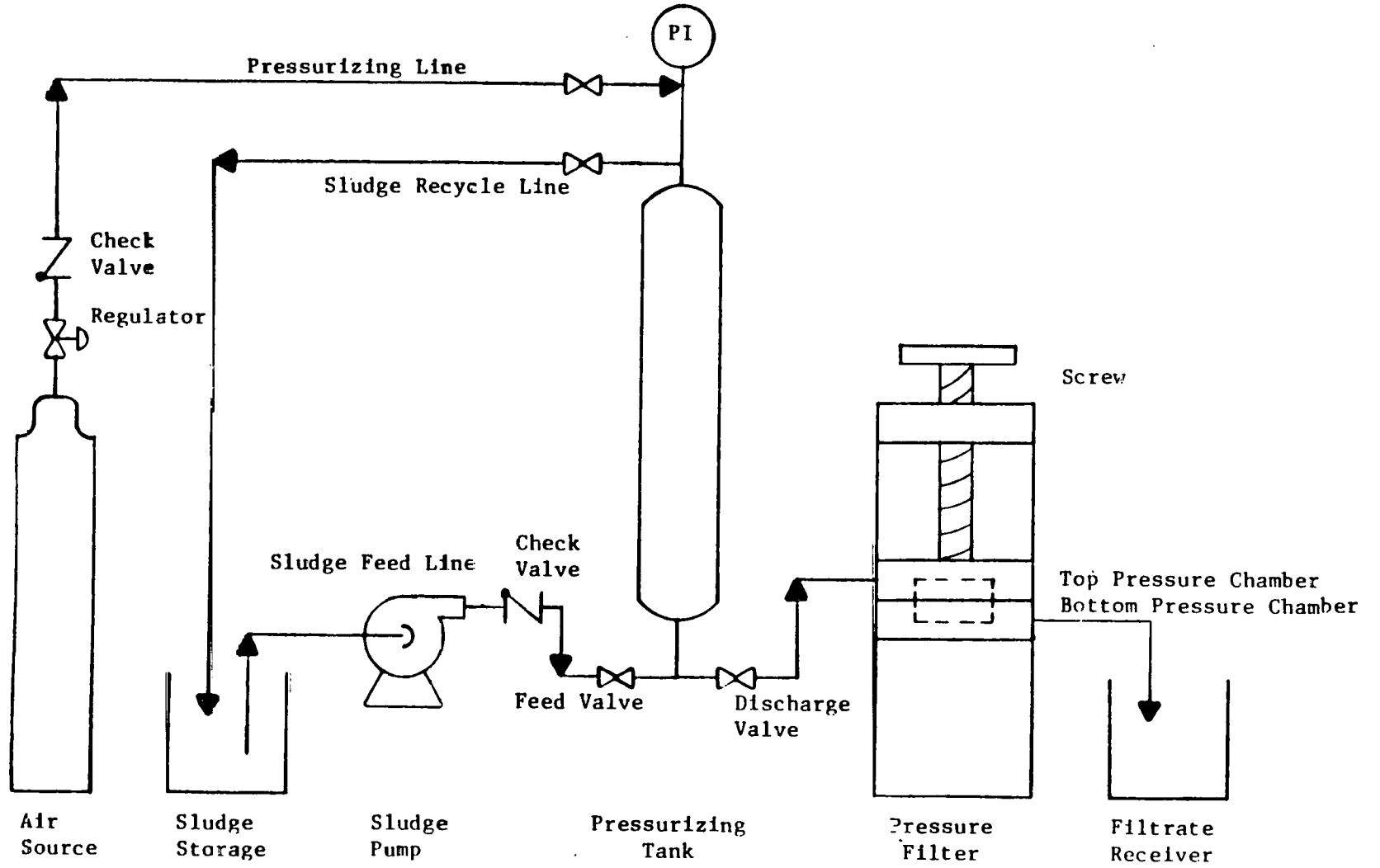
Pressure filtration generally produces a dryer sludge cake than can be achieved by other mechanical dewatering methods. This is due to the high pressure (over 150 psig) used to drive water from the sludge. Because of these high pressures, this unit process may be effective in cases where other methods cannot be used.

Figure 6 is a schematic diagram showing the bench-scale pressure filter that was used in this study. Sludge was pumped from the storage tank to the pressurizing tank until it was completely filled (as indicated by a discharge of sludge from the recycle line). The pump was then shut off, and the feed and recycle valves closed. The pressurizing valve was opened, and the regulator was used to increase the pressure from 0 to 150 psig over a 1-minute period, thereby pushing the sludge from the tank to the top chamber of the filter. The pressure was

Table 12
Vacuum Filter Leaf Test Summary

Sludge	Chemical Conditioner		Slurry Solids (%)	Cake Solids (%)	Filtrate Solids (mg/l)	Temperature (°F)
	Name	Dosage (% DWB)				
Softening	None	--	27.9	69.2	750	68
Softening	Percol 722	0.1	21.9	69.6	600	68
Digested NPAC	FeCl ₃	10	2.1	24.7	261	68
	Percol 722	1				
Digested PAC						Would Not Dewater
NPAC Coagulation						Would Not Dewater
PAC Coagulation						Would Not Dewater
Composite 13						Would Not Dewater
Composite 14						Would Not Dewater

Figure 6
Pressure Filter Apparatus



maintained at 150 psi for one hour, during which time the filtrate was gradually forced through the filter cloth. The test run was then ended, and the filtrate quantity and sludge cake were measured. The results of all tests are listed below in Table 13. The filter cloth used was Eimco No. DA 755F, a Dacron multi-filament cloth with a 3/1 chain weave and a thread count of 206 x 98.

As the results show, the pressure filter was able to dewater the tertiary coagulation sludge, which had not been possible with the vacuum filter leaf. Polymer alone and polymer in conjunction with ferric chloride were used to condition the sludge. The results were similar; both sludge cakes were approximately 20% solids.

Both PAC and NPAC digested biological sludges were also tested. The PAC sludge produced a dryer cake than the NPAC sludge (38% and 28% solids, respectively). This difference was due to the carbon particles, and independent of the initial solids content. Identical results were obtained for thickened (5%) and unthickened (1.1%) PAC sludges. All of the biological sludges were conditioned with polymer and ferric chloride. The filtrate solids were low (less than 200 mg/l) in all three tests.

Two composite sludges were also tested. The first, a vanadium and NPAC coagulation sludge, conditioned with polymer only, produced a cake comparable to the coagulation sludge alone. The filtrate solids were lower with this composite than for the coagulation sludge. The other composite was a combination of vanadium, NPAC coagulation, and softening sludges. The softening sludge, primarily composed of calcium carbonate, dewateres very easily, as was shown by the vacuum filter leaf tests. This composite was, likewise, readily dewaterable. A 56% cake was produced, and the filtrate solids were only 35 mg/l. Again, a 1% polymer dose was added.

Table 13

Pressure Filtration Test Summary

<u>Sludge</u>	<u>Conditioning Agent</u>	<u>Initial Solids</u>	<u>Filtrate Volume</u>	<u>Filtrate Solids</u>	<u>Cake Solids</u>
NPAC Coagulation Sludge	1% Percol 722	1.3%	500ml	144mg/L	18.7%
NPAC Coagulation Sludge	1% Percol 722 10% FeCl ₃	1.3%	420ml	674mg/L	20.3%
Sludge #13 Composite	1% Percol 722	1.3%	270	88mg/L	20.7%
Sludge #14 Composite	1% Percol 722	10.4%	420	35mg/L	55.7%
NPAC Digested Bio Sludge	1% Percol 722 10% FeCl ₃	2.7%	450	145	27.7%
PAC Digested Bio Sludge	1% Percol 722 10% FeCl ₃	1.1%	530	187mg/L	38.0%
PAC Digested Bio Sludge (Thickened)	1% Percol 722 10% FeCl ₃	5.0%	250	122	37.9%

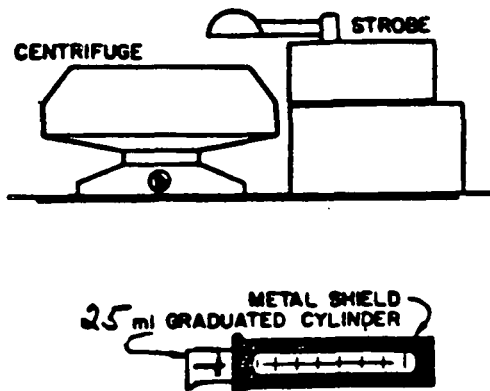
G. CENTRIFUGATION

Centrifuge screening tests were conducted for several sludges, using a laboratory scale centrifuge. These tests show cake solids as a function of both spin time and centrifugal acceleration, or "g" forces. Sludges were tested both with and without polymer. (The polymer was Percol 722, as noted in the Conditioning Section of this report).

The procedure is a refinement of the normal batch spin test (6). The sludge is placed in a plastic graduated cylinder, rather than a test tube. The bottom flange of the cylinder is cut off to allow it to fit into the centrifuge. Also, a slot is cut in the metal tube holder. Through this slot, the lab technician can observe both the sludge interface and the graduation marking (see Figure 7). Of course, the tube cannot normally be seen when spinning. Therefore, a strobe light is synchronized with the time of rotation of the centrifuge, making the graduated cylinder appear stationary during the test. This allows continual observation of the sludge layer.

Figure 7

Centrifuge Apparatus



The test is conducted by placing 25 ml of sludge in a test tube and spinning it at a given "g" force. As the test proceeds, the sludge layer moves down the graduated cylinder (actually outward, as the cylinder is positioned horizontally). The technician then records the interface level for different time intervals.

Centrifuge tests were conducted on several sludges. Tar acid sludge was of special interest because of its low pH. It is formed by a chemical precipitation under acidic conditions, and it cannot be neutralized without resolubilizing the tar acids. Therefore, the materials of construction of any thickening or dewatering device must withstand the corrosive nature of the sludge. Centrifuges are commonly available in corrosion-resistant alloys, suitable for this application. Both thickened and unthickened tar acid sludges were tested.

The results of all spin tests are shown graphically on Figures A-78 to A-104 in Appendix A. On any given figure, data points may be plotted for more than one "g" force. This is due to the nature of the test, which allows the technician to see the sludge level while the centrifuge is running. If the level is not dropping, the centrifuge speed is increased. This is a time-saving procedure that reduces the total number of spin tests required. The results are summarized in Table 14, below. All percentages are shown on a dry weight basis.

The addition of polymer had little effect on the cake solids of the tar acid sludges. It did significantly reduce supernatant solids, but this is of little importance for wastewater sludges. The thickened sludges (approximately 9%) achieved marginally higher cake solids contents than the unthickened ones (1.5%). Also, the final cake solids were affected very little by the "g" force.

Table 14
Centrifuge Test Summary

<u>Sludge</u>	<u>Initial Solids Conc. (%)</u>	<u>Polymer Dosage, Dry Weight (%)</u>	<u>Centrifugal Acceleration (XG)</u>	<u>Cake Solids Conc. (%)</u>	<u>Supernatant Conc. (mg/l)</u>	<u>Figure No.</u>
Tar Acid	1.50	0	598	25.0		C-25
	1.50	1.0	593	25.0		C-24
	8.95	0	260	30.0	--	C-1
	8.95	0	482	30.0	--	C-1
	8.95	0	616	30.0	130	C-1
	7.16	1.0	252	27.5	--	C-2
	7.16	1.0	462	29.8	--	C-2
	7.16	1.0	605	32.5	15	C-2
	7.16	1.0	605	32.5	12	C-3
NPAC Coag.	1.54	0	477	4.83	--	C-4
	1.54	0	576	5.15	35	C-4
	1.54	1.0	73	4.54	19	C-5
	1.7	1.0	182	7.08	--	C-6
	1.7	1.0	310	7.08	--	C-6
	1.7	1.0	436	7.72	14	C-6
	1.64	1.0	426	7.45	15	C-7
PAC Coag.	1.54	0	436	5.13	27	C-8
	1.54	1.0	76	5.5	21	C-9
	1.54	1.0	205	7.0	19	C-10
	1.54	1.0	431	7.0	13	C-11
NPAC Bio.	2.42	0	487	11.02	37	C-12
	2.42	1.0	82	7.58	23	C-13
	2.42	1.0	226	8.66	22	C-14
	2.42	1.0	402	10.1	17	C-15
	2.42	1.0	488	11.02	17	C-16

Table 14
Centrifuge Test Summary

<u>Sludge</u>	<u>Initial Solids Conc. (%)</u>	<u>Polymer Dosage, Dry Weight (%)</u>	<u>Centrifugal Acceleration (XG)</u>	<u>Cake Solids Conc. (%)</u>	<u>Supernatant Conc. (mg/l)</u>	<u>Figure No.</u>
PAC Bio.	5.10	0	462	18.23	--	C-17
	5.10	0	599	18.23	40	C-17
	5.10	1.0	51	15.95	23	C-18
	5.10	1.0	195	18.23	17	C-19
	5.10	1.0	482	23.2	--	C-20
	5.10	1.0	564	25.5	11	C-20
Vanadium Sludge	20.0	0	542	62.6	73	C-21
	18.9	1.0	250	52.5	37	C-22
	18.9	1.0	548	59.0	42	C-23
Composite No. 13 (1)	1.23	1.0	559	6.81	21	C-26
Composite No. 14 (2)	10.2	0.1	553	51.0	32	C-27

- (1) NPAC Coagulation; vanadium
(2) NPAC Coagulation; vanadium; softening

Tertiary coagulation sludges from both PAC and NPAC systems were tested. The results were very similar. In each case, the addition of polymer resulted in a marked increase in cake solids content (5% without polymer; 7% with polymer). As with the tar acids, the "g" force had little effect, except for the lowest spin speed.

The digested biological sludges exhibited increased cake solids with higher "g" forces. This is due to the flocculent nature of the sludge. Both NPAC and PAC sludges were tested, at initial solids contents of 2.4 and 5.1 percent, respectively. The solids content of the NPAC sludge cake increased from 7.5 to 11 percent with increasing "g" forces. For the PAC sludge, the increase was from 16 to 25.5 percent. Polymer addition did not significantly affect either sludge.

The vanadium sludge had a high initial solids content (20%), and centrifuging approximately tripled this. It exhibited little improvement in cake solids due to polymer, and a fairly flat response to an increased "g" force.

H. DEWATERING BY BELT FILTRATION

Belt filter presses employ single or double moving belts to dewater sludges continuously. The belt filtration process includes three basic operational stages: conditioning of the feed slurry, gravity draining of free water, and compression of the sludge for removal of bound water.

A laboratory screening procedure has been developed to simulate belt filter press dewatering performance. However, the results of screening tests are sufficient only for evaluation of sludge conditioning. Typically, pilot scale testing is necessary to develop quantitative data needed for design. Pilot tests could not be conducted in our laboratory; therefore, samples of several sludges were sent to Arus-Andritz, Inc., a

manufacturer of belt filters. Arus-Andritz conducted screening and development testing of digested NPAC biological sludge, NPAC effluent coagulation sludge, and two combination sludges, which have been described previously.

A summary of the results obtained for belt filtration testing is presented in Table 15. Conditioner screening of twenty organic polyelectrolytes with a wide range of relative molecular weights and charge density indicated that Percol 728 was a very effective agent for each sludge tested. This cationic polymer has a moderate charge density and very high molecular weight.

Pilot testing performed by Arus-Andritz consisted of a batch simulation of each zone of the belt filtration process. After conditioning, the readily drainable water is separated from the slurry by discharge of the conditioned material onto a moving belt in a gravity drainage simulation. This step would typically last one or two minutes in an actual field installation. The drained sludge is then compressed between two belts in a section of the process referred to as the wedge zone. A moving wedge is formed between the two belts as they pass through rollers of decreasing diameters. The pressure exerted in this region is approximately 3 psig. A final zone of high pressure is simulated by passing the semi-dewatered sludge through an S-shaped configuration formed by seven small diameter rollers. This path exerts a shear force which opens additional drainage channels. The pressure in this zone is typically 18 psig. The solids content levels of the cake discharged from the high pressure zone are presented in Table 15 for each sludge tested. The throughput values tabulated represent a design loading to the dewatering process on a dry solids basis. Relative filtrate quality is summarized in terms of percent solids capture.

Table 15
Belt Filter Test Summary

Sludge	<u>Chemical Conditioner</u>		Slurry Solids (%)	Cake Solids (%)	Solids Capture (%)	Throughput (lbs/hr/m) (1)
	Name	Dosage (%)				
NPAC Coagulation	Percol 728	0.65	1.8	17	90	417
NPAC Digested Biological	Percol 728	0.35	3.2	16.5	95	240
Composite 13 ⁽²⁾	Percol 728	0.45	1.3	20.0	94	430
Composite 14 ⁽³⁾	Percol 728	0.20	8.9	50.0	95	2500

- (1) Pounds dry solids/hr/meter of belt width
- (2) NPAC tertiary coagulation; vanadium
- (3) NPAC tertiary coagulation; vanadium; softening

I. RCRA LEACHATE EVALUATION

The extraction procedure (EP) toxicity test is an EPA approved method of determining whether a sludge is hazardous according to RCRA classification. In this test, leachate is generated under acidic conditions and analyzed for several toxic parameters. The EPA has established maximum permissible EP leachate concentrations for eight heavy metals and six pesticide compounds. If any one of these maximum permissible concentrations is exceeded, the waste is classified as hazardous.

Four sludges were tested by the EP toxicity testing procedure (see Appendix B for description of the procedure). Prior to the test, the sludges were thickened and dewatered to simulate their actual compositions prior to disposal in a landfill (or elsewhere). The sludges evaluated were as follows:

- Digested Biological Sludge.
- Stetford Purge (Vanadium Bearing) Sludge.
- Softening Sludge.
- NPAC Coagulation Sludge.

The leachates of the four sludges were analyzed for the eight heavy metals. Since no pesticide compounds or related species are inherent to any of the sludges, no pesticide analyses were conducted. The eight heavy metals, their limiting maximum concentrations, and the actual levels found in the four sludges tested are contained in Table 16. The testing results indicate that all four of the sludges fall well below the RCRA established maximum heavy metal concentrations.

Table 16

EP Toxicity Test (All Concentrations in mg/l; ND = Non-Detectable*)

Sludge	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
Maximum Permissible Concentration	5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0
Digested Bio. (NPAC)	ND	ND**	ND	ND	ND		ND*	ND
Vanadium Precipitate	ND	ND***	ND	ND	ND		ND	0.074
Softening Sludge	ND	ND***	ND	ND	ND		ND	0.129
NPAC Coagulation Sludge	ND	ND**	ND	ND	ND		ND	ND

*Non-Detectable - i.e. Below the limits of detectability, as follows:

Arsenic	- .015 mg/l	Barium	- 3.0 mg/l*** - .3 mg/l**
Cadmium	- 0.12 mg/l	Chromium	- 1.5 mg/l
Lead	- .15 mg/l	Mercury	- mg/l
Selenium	- .05 mg/l (Except Soft. Sludge Limit is .07 mg/l)		
Silver	- .06 mg/l		

VI. DISCUSSION

A. THICKENING AND CONDITIONING

The degree to which a sludge will concentrate in a thickener depends on both the solids loading rate and the pretreatment provided. The batch settling tests described in the previous section can be used to predict thickener performance under varying combinations of these factors. Table 17 shows underflow concentrations and corresponding unit area loadings (lbs./day/ft.²) for different polymer dosages. The underflow solids concentrations are somewhat arbitrary, in that a settling curve represents a continuous range of concentrations as a function of detention time, or loading rates. The underflow concentrations shown on Table 17 are reasonable values, generally three to four times the initial solids concentrations. In all cases, of course, the design underflows are less than the ultimate concentrations attained in the batch settling tests.

The unit area loadings are not design values, and would typically be decreased by a scale-up factor of at least 150% for actual operating conditions. The loading rates shown in Table 17 illustrate the relative ease or difficulty of thickening the different sludges, as well as the effects of a flocculent aid.

Biological Sludges

The initial (feed) solids concentrations of the NPAC biological sludges were typically one percent. Batch testing indicates that this sludge can be concentrated threefold via gravity thickening. There is no appreciable difference in the thickened solids concentrations of undigested and digested NPAC sludges.

Table 17
Analysis of Thickening Test Data

<u>Sludge Type</u>	<u>% Solids of Feed</u>	<u>Design Underflow (% Solids)</u>	<u>Percol 722 Dose (% by dry wt.)</u>	<u>Design Unit Area Loading (Lb./day/ft²)</u>
Undigested NPAC Bio.	1.1	3	None	8.73
	1.0	3	0.1	14.9
	1.0	3	0.3	24.3
Digested NPAC Bio.	0.8	3	None	9.59
	0.8	3	0.1	27.2
	0.8	3	0.2	45.4
	0.8	3	0.3	57.9
Digested PAC Bio.	1.3	6	None	26.1
	1.3	6	0.04	64.6
	1.3	6	0.08	67.8
Tar Acid Precip.	1.8	6	None	6.10
	1.8	6	0.1	6.10*
	1.8	6	0.2	87
	1.8	6	0.3	81.3
Vanadium Precip.	5.7	Would Not Thicken	None	---
	5.7	20	0.01	52.8
	5.7	20	0.02	39.1
Softening Slg.	31.4	40	None	300
	30.0	40	0.01	229

* Test terminated after 90 minutes. No significant change in comparison to no-polymer case.

Table 17

Analysis of Thickening Test Data

<u>Sludge Type</u>	<u>% Solids of Feed</u>	<u>Design Underflow (% Solids)</u>	<u>Percol 722 Dose (% by dry wt.)</u>	<u>Design Unit Area Loading (Lb./day/ft²)</u>
NPAC Eff.	0.3	1	None	1
Coag. Precip.	0.4	1	0.05	7.95
	0.4	1	0.2	5.23
PAC Eff.	0.5	2	None	4.15
Coag. Precip.	0.5	2	0.1	24.9
	0.5	2	0.2	62.3
	0.5	2	0.3	83.1
	0.5	2	0.4	83.1
	0.5	2	0.5	166
Composite of NPAC Eff.	0.4	1	None	1
Coag. and Vanadium Precip.	0.4	1	0.04	9.04
	0.4	1	0.1	9.25
Composite of NPAC Eff.	1.8	9	None	1.75
Coag. and Vanadium and Softening Slg.	1.8	9	0.03	39.1
	1.8	9	0.04	50.4
	1.8	9	0.04	63.8
	1.8	9	0.06	47.9

Thickened solids concentrations for digested PAC biological sludge (6% solids) were generally twice those achievable for NPAC sludges. This represents a concentration of approximately 4.5 times the feed solids, which were about 1.3%. It is expected that a comparable thickened solids concentration would be obtained for undigested PAC sludge. However, this could not be confirmed because the undigested sludge was not available for testing.

The addition of an effective flocculent (Percol 722 polymer) to the biological sludges tested made no appreciable impact on the final thickened solids concentrations in the batch tests. However, polymer addition did significantly increase the settling velocity and solids flux, as shown on Tables 9 and 17, respectively. Generally, unit area solids loading (limiting flux) increased with increasing dosage of polymer.

Tar Acid Precipitate

The initial solids concentration of the tar acid sludge was approximately 1.8 percent. Batch testing indicated that a six percent thickened concentration was an achievable level, representing roughly a threefold concentration via gravity thickening. Polymer addition to tar acid sludge made no appreciable change in the achievable solids concentration. A polymer dosage of 0.2 percent (dry weight basis) did significantly improve the limiting solids flux, however. At a dose less than 0.2 percent, no improvement over the limiting flux for unconditioned sludge was apparent. A dosage in excess of 0.2 percent proved counter productive, decreasing the limiting flux.

Vanadium Precipitate

The vanadium-bearing sludge consisted of approximately 5.7 percent solids prior to thickening. Unconditioned vanadium sludge (without polymer) settled very poorly and essentially would not thicken. Thickening was greatly improved by polymer addition, after which concentrations of 20 percent solids

were achievable. As with the tar acid sludge, it was found that an optimum polymer dosage existed. A peak unit area of loading was reached with a polymer addition of 0.01 percent. A dosage in excess of this amount decreased the limiting flux.

Softening Sludge

The calcium carbonate sludge produced by the tertiary softening process settled to a solids concentration of approximately 30% in the softening clarifier. The batch tests showed this could be thickened further, and, as Table 17 indicates, a 40% underflow concentration was chosen. This represents only a 33% increase in solids concentration, rather than 300-400% achieved with other sludges. However, the nature of the softening sludge is such that it settles so readily in the clarifier that further thickening is of marginal benefit. Also, to concentrate past the 40% solids level could cause severe operational problems with both the thickener mechanism and pumps. Because the sludge thickens so readily, polymer was found to be detrimental, resulting in a decreased flux rate.

Tertiary Coagulation Sludges

The initial solids concentration of the NPAC tertiary coagulation sludge was typically 0.3-0.4 percent. Batch thickening tests indicate that this can be concentrated to one percent solids. Conditioning this sludge with polymer proved every effective. A dry weight dosage of 0.05 percent increased the limiting solids flux by an order of magnitude compared to the unconditioned sludge flux. A polymer dosage in excess of 0.05 percent produced no further increase, however.

Thickened solids concentration for PAC tertiary coagulation sludge were approximately 2 percent solids, which is twice that achievable for NPAC coagulation sludge. This represents a concentration of four times the feed solids (0.5%) via gravity thickening. In addition to a higher underflow concentration, the PAC coagulation sludge exhibited higher flux rates. This is apparently due to the presence of carbon fines not removed in the biological solids clarifiers.

Although polymer addition increased the flux for both NPAC and PAC coagulation sludges, it made no appreciable change in the thickened concentration obtained for either. There was, however, one notable difference in the effect of polymer on these two sludges. As noted above, the NPAC sludge showed a decreasing flux above a polymer dosage of 0.05 percent. In contrast, the PAC coagulation sludge produced higher fluxes with higher polymer doses (up to 0.5%).

Composite Sludges

Thickening and dewatering each sludge separately would undoubtedly be the most expensive treatment scheme. Also, apart from cost considerations, mixing sludges would reduce the number of pieces of equipment, thereby simplifying the entire sludge treatment process. Therefore, two composite sludges were tested to confirm the practicality of thickening sludge mixtures.

The first composite was made from the NPAC effluent coagulation and vanadium sludges. Tar acids were not added because the low pH of that stream mandates that it be segregated. Biological sludges were likewise not added, because they are digested following thickening. The results of the thickening tests are very similar to those for the coagulation sludge alone. This is not surprising, since the weighted percentage of the coagulation sludge is much higher than the vanadium sludge (mixes are based on the weights listed in Table 1). At feed, underflow, and polymer values corresponding to the tests run on the coagulation sludge, the composite showed a slightly higher flux. This is reasonable, since the vanadium flux was about five times higher than the coagulation. There did not appear to be any problems associated with combining these two sludges.

The second composite contained the softening, NPAC coagulation, and vanadium sludges. The underflow concentration and flux were, as expected, within the range of values of the individual sludges. The sludge thickened from 1.8% to 9%, a fivefold increase. The optimum polymer dosage was 0.05%, after which the flux rate decreased.

B. AEROBIC SLUDGE DIGESTION

Digestion tests conducted on both NPAC and PAC sludges showed steady decreases in total and volatile suspended solids. Time plots of these values (Figures 3 and 4) show a much smoother curve for the NPAC sludge than the PAC sludge. As explained in the Investigative Section, the apparently erratic shifts in the PAC data are due to the presence of activated carbon particles in the sludge.

Because of the activated carbon, the PAC sludge was much more concentrated than the NPAC; the initial suspended solids concentrations were 50,200 and 12,000 mg/l, respectively. As mentioned previously, these digestions were conducted as part of an earlier study, and were not run on thickened sludges. The current design provides thickening prior to digestion.

Table 18 shows reductions in VSS based on the curves (not the actual data points) in Figures 3 and 4. These reductions are expressed in two ways: first, as percentage of the initial VSS concentration, and, second, as absolute differences in concentration. On a percentage basis, the NPAC sludge is more readily stabilized, exhibiting a 48% reduction after 20 days, compared to only a 32% reduction for the PAC sludge. In that same 20-day period, however, the VSS concentration was reduced by 5,800 mg/l in the NPAC system, compared to 15,900 mg/l for the PAC sludge. The percentage reductions provide the most useful data for this evaluation. Not only are the initial concentrations of the two sludges quite different, but, because the test was run on unthickened sludges, they are not representative of the current design scheme.

Table 18
Aerobic Sludge Digestion

	<u>NPAC Sludge</u>		<u>PAC Sludge</u>	
	<u>15 Days</u>	<u>20 Days</u>	<u>15 Days</u>	<u>20 Days</u>
VSS (mg/l)	7,100	6,200	38,500	34,300
VSS Removal (%)	41	48	23	32
VSS Removal (mg/l)	4,900	5,800	11,700	15,900

The main purpose of the digestion tests was to establish a digestion period for each sludge. For the NPAC sludge, the rate of removal of VSS decreased steadily. This is characteristic of a biological system with a decreasing substrate concentration. As Figure 3 shows, only marginal removals can be expected after 20 days. For the PAC sludge, the data scatter makes it impossible to establish a smooth curve similar to Figure 3. However, it is apparent that a longer detention is required. A 30-day digestion period corresponds to a 49% VSS removal. Although the data scatter tends to obscure the direction of the curve, the last five data points do indicate that minimal reductions occur after 30 days.

C. DEWATERING EQUIPMENT

The purpose of the bench-scale dewatering tests was to establish the efficacy of the alternative devices for dewatering the various sludges. As expected, some sludges could be successfully dewatered by all devices, while others proved more difficult. As such, no method of dewatering all sludges is dictated on the basis of the test results. Rather, the tests have shown which sludges are easily dewatered and which are problematic. Also, the relative quantities of conditioning chemicals have been established, and final solids contents can be predicted. This information is summarized below in Table 19.

Table 19

Summary of Dewatering Results

Sludge	Dewatering Device	Solids Content		Chemical Conditioner (1)	
		Initial (%)	Final (%)	Name	Dosage (%)
Tar Acid	Centrifuge	7.2	28	None	
NPAC Coagulation	Centrifuge	1.7	7.7	Percol 722	1.0
	Vacuum Filter	1.3	Would not dewater		
	Belt Filter	1.8	17	Percol 728	0.65
	Pressure Filter	1.3	18.7	Percol 722	1.0
PAC Coagulation	Centrifuge	1.5	7.0		
	Vacuum Filter	1.4	Would not dewater		
Softening	Vacuum Filter	27.9	69.2	None	
Vanadium	Centrifuge	20.0	62.6	None	
NPAC Digested Biological	Centrifuge	2.4	11.0	None	
	Vacuum Filter	2.1	24.7	} Percol 722 { FeCl ₃	1.0
					10.0
	Belt Filter	3.2	16.5	Percol 728	0.35
	Pressure Filter	2.7	27.7	} Percol 722 { FeCl ₃	1.0
			10.0		
PAC Digested Biological	Centrifuge	5.1	25.5	Percol 722	1.0
	Vacuum Filter	1.7	Would not dewater		
	Pressure Filter	5.0	37.9	} Percol 722 { FeCl ₃	1.0
			10.0		
Composite 13 ⁽²⁾	Centrifuge	1.2	5.8	Percol 722	1.0
	Vacuum Filter	1.3	Would not dewater		
	Belt Filter	1.3	20.0	Percol 728	0.45
	Pressure Filter	1.3	20.7	Percol 722	1.0
Composite 14 ⁽³⁾	Centrifuge	10.2	51.0	Percol 722	0.1
	Vacuum Filter	10.4	Would not dewater		
	Belt Filter	8.9	50.0	Percol 728	0.2
	Pressure Filter	10.4	55.7	Percol 722	1.0

(1) Dry weight basis

(2) NPAC tertiary coagulation; vanadium

(3) NPAC tertiary coagulation; vanadium; softening

As noted previously, centrifuging was the only dewatering technique considered for the tar acid sludge. This was not because other equipment would not be effective, but due to the acidic nature of the sludge. Its low pH dictates that it be kept separate from other sludges, in order to prevent the precipitated tar acids from resolubilizing. The relatively high initial solids concentration (7%) indicates a significant presence of calcium sulfate, in addition to the tar acids.

The dewatering results indicate that centrifuging is effective. However, the centrifuge cake cannot be handled as a liquid, which was the original intent. This problem might require a revision in the handling procedures for the dewatered sludge, in order to maintain the current disposal method, which is incineration. Alternatively, the sludge could be kept in a pumpable state by partially by-passing the centrifuge, and controlling the solids content based on handleability.

The coagulation sludges are by far the most difficult to dewater. Vacuum filtration is unsuccessful, due to cloth blinding. Theoretically, precoating the filter could alleviate this problem. However, due to the very thin cake formed (1/32 inch), this process is still not considered feasible. The centrifuge is also not very effective, concentrating the solids to less than 8%. The belt filter and pressure filter both produce acceptable cakes. The solids contents are surprisingly close; the pressure filter produces an 18.7% solids cake, versus 17% for the belt filter. The pressure filter does provide a much better solids capture. The filtrate solids concentration of 144 mg/l is an order-of-magnitude less than the belt filter (2,000 mg/l). However, although a 2,000 mg/l filtrate is very high, it is not prohibitive.

The softening sludge, primarily calcium carbonate, is the most readily dewaterable sludge. Because this sludge settles to almost a 30% solids concentration, it can be fed directly to a dewatering device without prior thickening. Vacuum filtration of the unthickened sludge

produces a cake concentration of 70% solids. Because this sludge is so easily dewatered, it was not tested for other dewatering devices. It can obviously be dewatered by any of the different types of equipment.

Limited quantities of the vanadium sludge were available. Centrifuging is the only test that was run, achieving a threefold concentration. The quantities of this sludge are comparatively small, and separate treatment is not practical. Further testing, using the other dewatering devices, was conducted on composite sludges containing vanadium, as is discussed later in this section.

Digested biological sludges were tested by all four dewatering devices. Both PAC and NPAC sludges were examined. The NPAC digested biological sludge is dewaterable by any of the four types of equipment. However, the centrifuge produces only an 11% solids cake, which is not considered satisfactory. Best results are achieved by the vacuum and pressure filters, producing 25% and 28% solids cakes, respectively. The belt filter is a feasible alternative, but the 16% cake produced can only be considered marginally acceptable. For the PAC sludge, vacuum filtration cannot be used, as the fine carbon particles tend to blind the cloth. Insufficient quantities were available for testing by the belt filter. However, due to the carbon, the cake concentration can be expected to exceed the 16% achievable for the NPAC sludge. Pressure filtration is the most effective method tested and results in 38% solids cake. For both the PAC and NPAC digested biological sludges, conditioning with ferric chloride (10% dosage) is required for pressure filtration.

Due to the obvious economic advantages of combining sludges prior to dewatering, two composite sludges were tested. One contained NPAC coagulation plus vanadium sludges; the other contained these same two sludges plus the softening sludge. (Softening is an option, dependent

upon the inclusion of a zero discharge design). It is assumed that the calciner scrubber blowdown and cool/SRC pile runoff sludges would also be added, but, as explained previously, these were not available for testing. As is the case for the coagulation sludges alone, the composite cannot be effectively dewatered by vacuum filtration, due to cloth blinding. Both pressure and belt filtration are satisfactory, and produce similar results.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. With the single exception of the softening sludge, chemical conditioning of all sludges tested resulted in significant increases in thickener loading rates. A cationic polyelectrolyte of moderate molecular weight and charge density, such as Allied Colloids Percol 722, was an effective conditioning agent for thickening of all sludges tested.
2. The softening precipitate settles so readily and to such a high solids content that further thickening is unnecessary and could prove detrimental in terms of subsequent handling.
3. Stabilization of NPAC biological sludge by aerobic digestion prior to sludge thickening did not increase the underflow concentration in comparison to the undigested sludge, and produced only a moderate increase in loading rate.
4. Both the PAC and NPAC biological sludges can be stabilized by aerobic digestion. The NPAC sludge is more readily stabilized, requiring a digestion period of approximately 20 days, versus 30 days for the PAC sludge.
5. The tar acid sludge was characterized by a much higher solids content than anticipated. Both the thickened (7% to 9% solids) and unthickened (1.5% solids) tar acid sludges can be concentrated by centrifugation. The resulting cakes (25% to 32% solids) cannot be classified as semi-liquids and are unsuitable for the current design, based on handling considerations.

6. The most effective dewatering devices are belt and pressure filters. For the chemical sludges, the pressure filter produces a slightly dryer cake than the belt filter. For the biological sludges, the difference is much more significant, with the pressure filter cake reaching almost twice the solids content of the belt filter cake.
7. Vacuum filtration is not effective on the coagulation or composite sludges, due to cloth blinding.
8. The coagulation sludge is very difficult to dewater, even with pressure filtration.
9. The feasibility of combining sludges prior to thickening and/or dewatering has been confirmed.
10. The leachate from four sludges (digested biological, vanadium, softening, and NPAC coagulation) were tested for heavy metals by the EPA extraction procedure. All concentrations were well below the RCRA limits.

B. RECOMMENDATIONS

1. The thickened tar acid sludge, at approximately 7% solids, exceeds the current design of 2% solids in the centrifuge cake. Based on handling considerations, this sludge should be fed directly to the incinerator. Therefore, the centrifuge should be deleted, and a thickening step added.
2. Aerobic digestion should be provided for the biological sludge. For the current design, based on NPAC sludge, the digestion period should be increased from 15 to 20 days.

3. The chemical sludges should be combined prior to dewatering, and belt filtration is the recommended dewatering method. This process is less energy intensive than pressure filtration, and produces a cake of approximately equal solids content (polymer doses are similar).

4. The biological sludges should be dewatered by pressure filtration, due to the significantly higher solids content achieved. The current design provides belt filtration.

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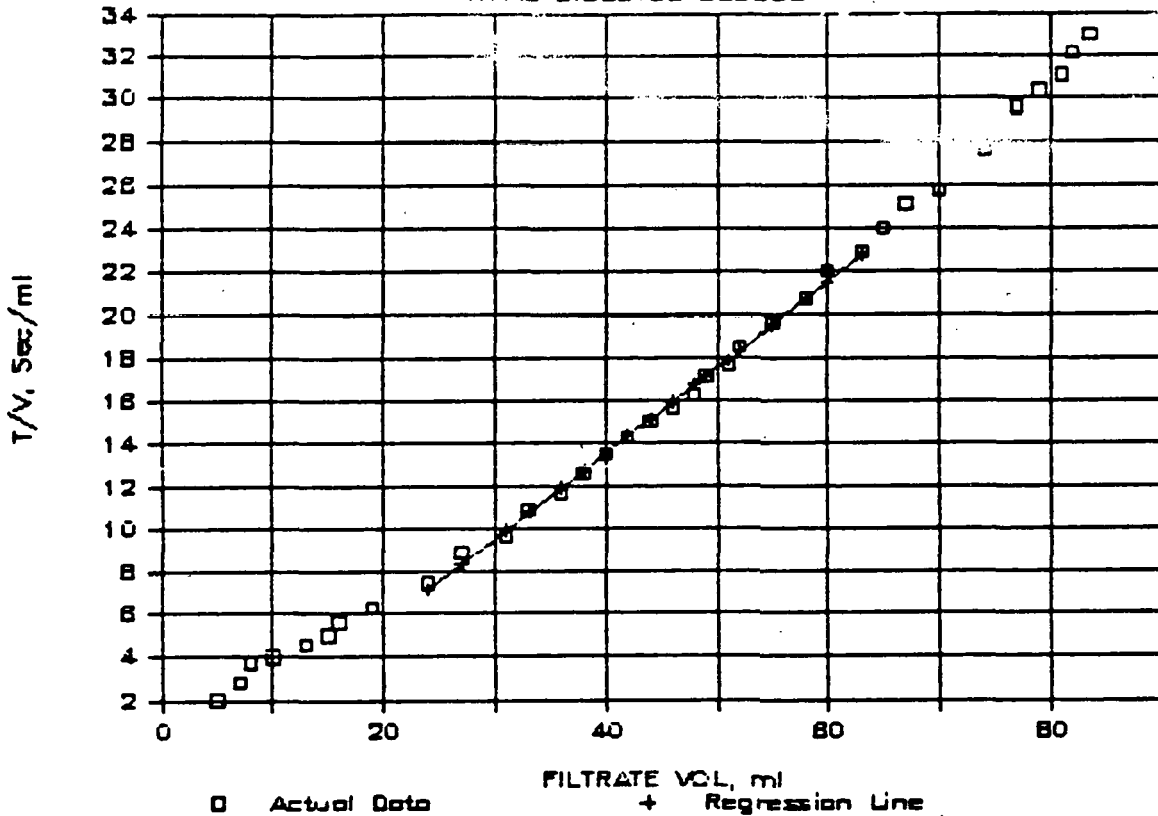
APPENDIX A

FIGURES

Figure A-1

VACUUM FILT.—SPECIFIC RESISTANCE

NPAC DIGESTED SLUDGE



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : NPAC DIGESTED SLUDGE

DATE: JAN. 20, 1984

VACUUM: 28 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 238000 mg/L

FEED SOLIDS 8125 mg/L

FILTER TYPE: What. #1

SLUDGE TEMP. 21 Centigrade

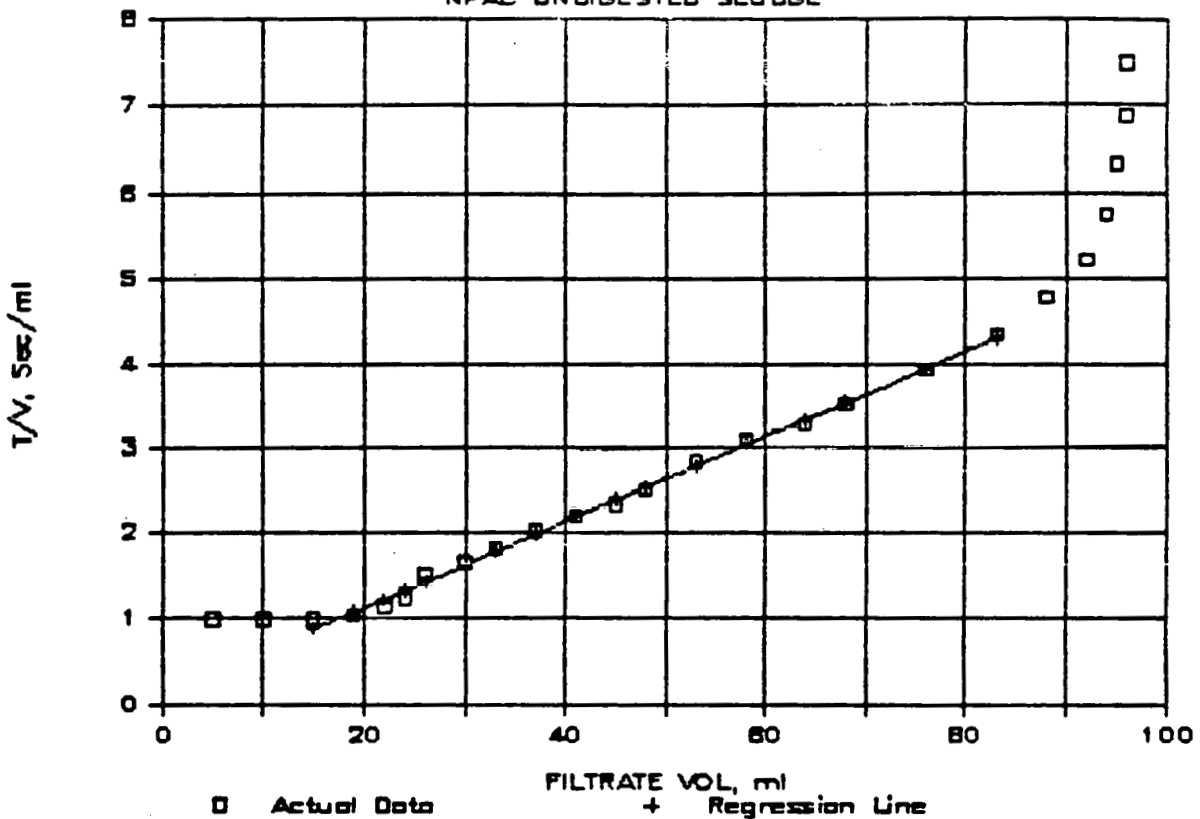
SLUDGE pH: 6.3

CONDITION AGENT: NONE

DOSAGE: 0 ml per 100 ml Sludge

Figure A-2

VACUUM FILT.—SPECIFIC RESISTANCE
NPAC UNDIGESTED SLUDGE



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : NPAC UNDIGESTED SLUDGE

DATE: DEC. 16, 1983

VACUUM: 27.5 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 208000 mg/L

FEED SOLIDS 11165 mg/L

FILTER TYPE: What. #1

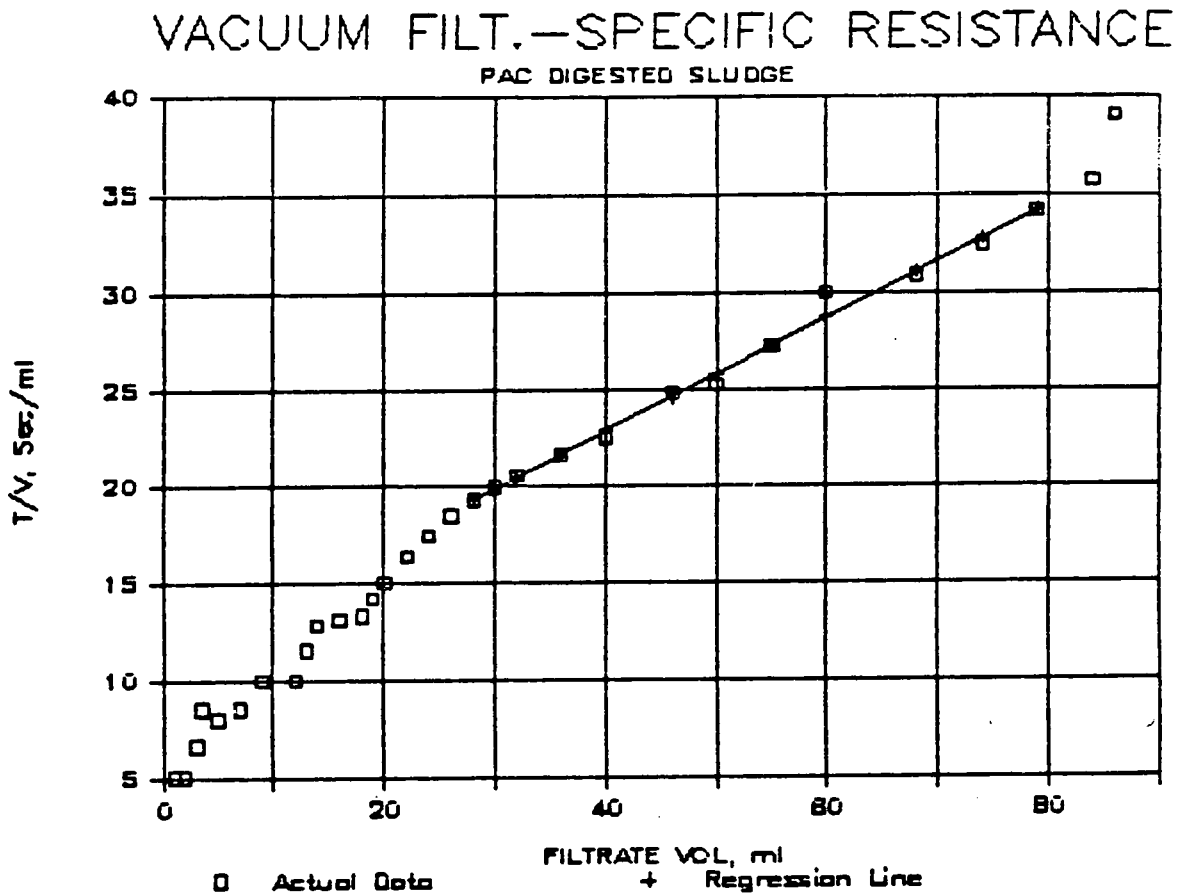
SLUDGE TEMP. 19.5 Centigrade

SLUDGE pH: 7.4

CONDITION AGENT: NONE

DOSAGE: 0 mls per 100 mls Sludge

Figure A-3



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : PAC DIGESTED SLUDGE

DATE: FEB. 16, 1984

VACUUM: 28 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 402400 mg/L

FEED SOLIDS 13130 mg/L

FILTER TYPE: What. #1

SLUDGE TEMP. 14 Centigrade

SLUDGE pH: 6.4

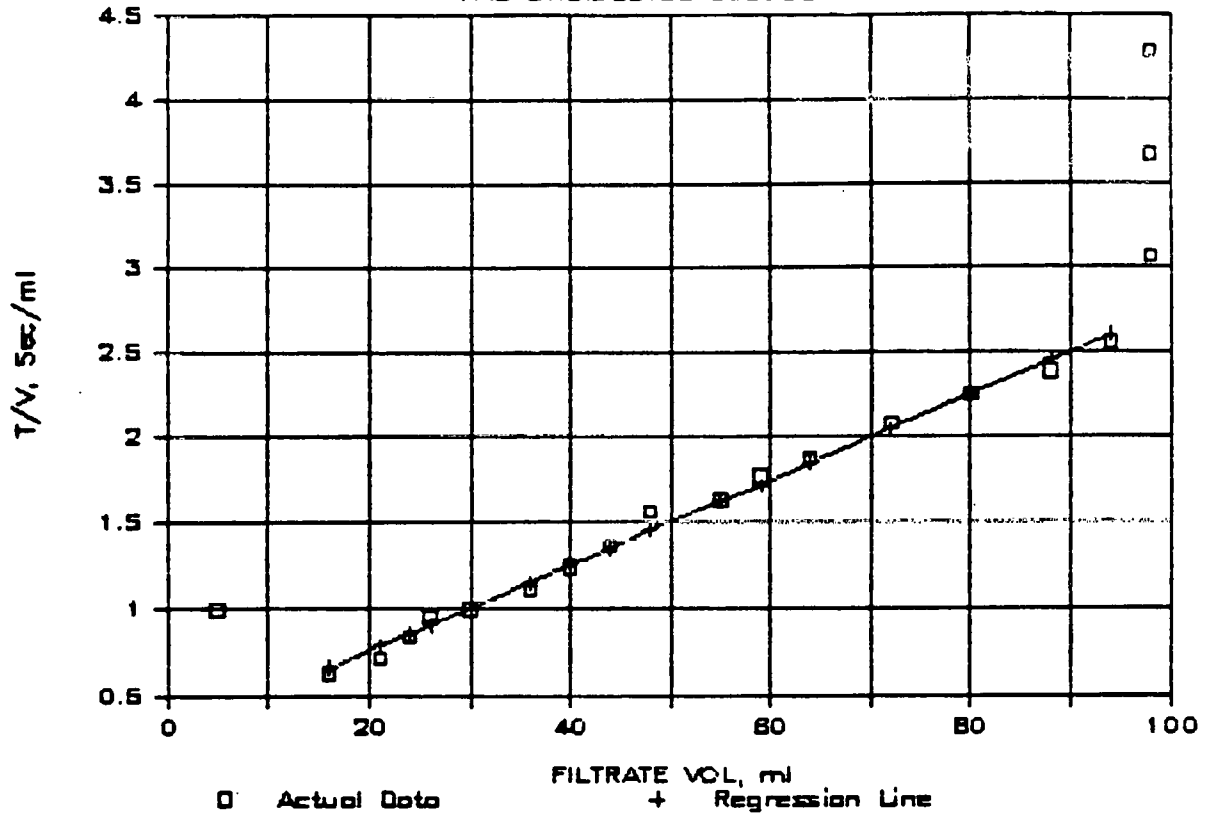
CONDITION AGENT: NONE

DOSAGE: 0 mls per 100 mls Sludge

Figure A-4

VACUUM FILT.—SPECIFIC RESISTANCE

PAC UNDIGESTED SLUDGE



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : PAC DIGESTED SLUDGE

DATE: DEC. 16, 1983

VACUUM: 27 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 288000 mg/L

FEED SOLIDS 11535 mg/L

FILTER TYPE: What. #1

SLUDGE TEMP. 19 Centigrade

SLUDGE pH: 7.5

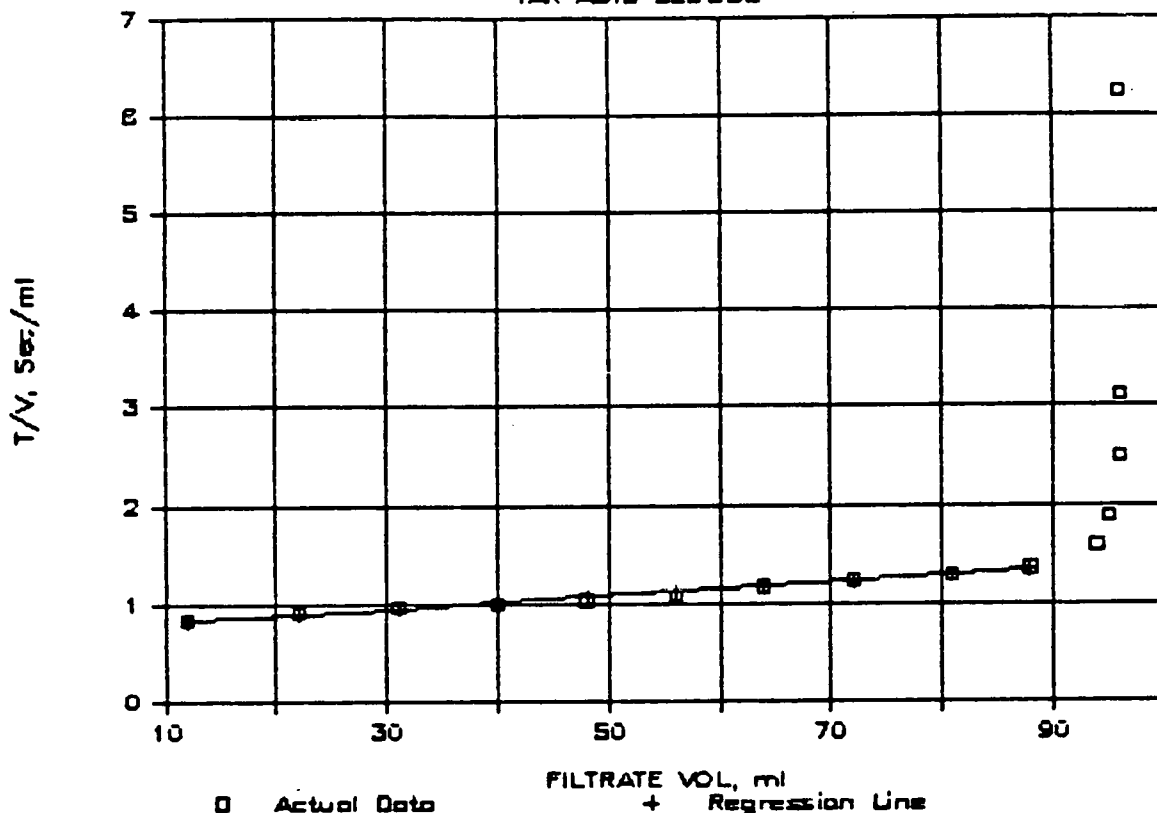
CONDITION AGENT: NONE

DOSAGE: 0 mls per 100 mls Sludge

Figure A-5

VACUUM FILT.—SPECIFIC RESISTANCE

TAR ACID SLUDGE

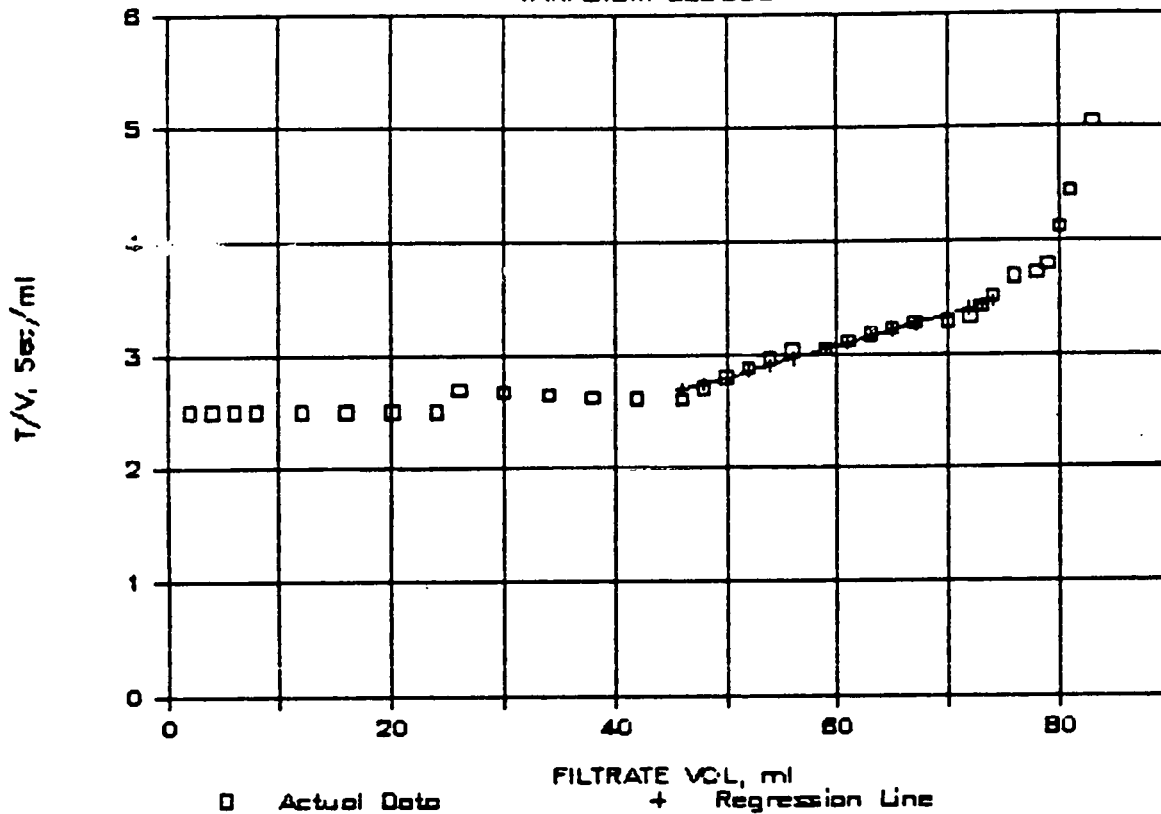


VACUUM FILTRATION - BUCHNER FUNNEL TEST
 CLIENT: ICRC
 SAMPLE : TAR ACID SLUDGE
 DATE: DEC. 14, 1983
 VACUUM: 27 inches Hg.
 VISCOSITY 0.01 poise
 FILTER DIAMETER 7 centimeters
 CAKE SOLIDS 375000 mg/L
 FEED SOLIDS 18095 mg/L
 FILTER TYPE: What. #1
 SLUDGE TEMP. 19 Centigrade
 SLUDGE pH: 4.3
 CONDITION AGENT: NONE
 DOSAGE: 0 ml per 100 ml Sludge

Figure A-6

VACUUM FILT.—SPECIFIC RESISTANCE

VANADIUM SLUDGE



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : VANADIUM SLUDGE

DATE: FEB. 16, 1984

VACUUM: 20 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 548800 mg/L

FEED SOLIDS 56800 mg/L

FILTER TYPE: What. #1

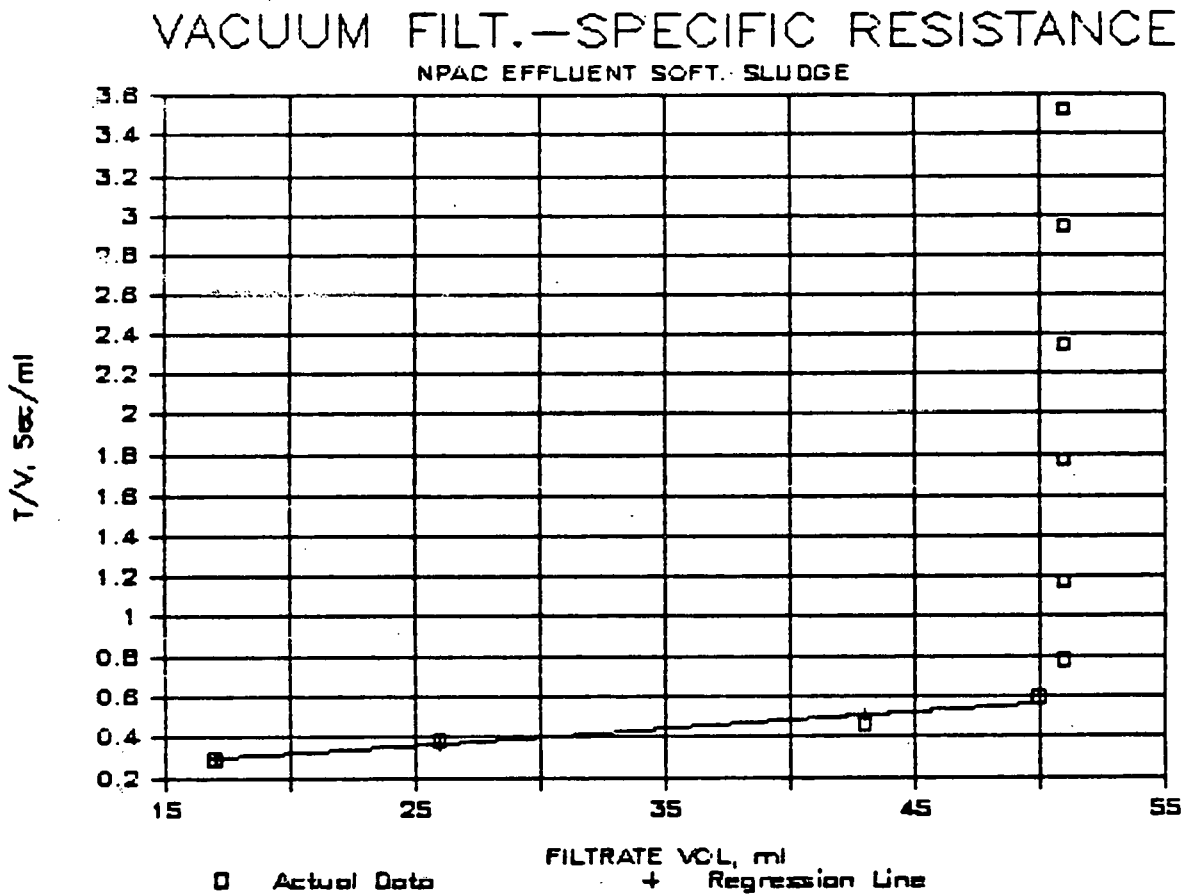
SLUDGE TEMP. 21 Centigrade

SLUDGE pH: 11.5

CONDITION AGENT: NONE

DOSAGE: 0 mls per 100 mls Sludge

Figure A-7



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : NPAC EFFLUENT SOFT. SLUDGE

DATE: JAN. 30, 1984

VACUUM: 27 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 546700 mg/L

FEED SOLIDS 403735 mg/L

FILTER TYPE: What. #1

SLUDGE TEMP. 14.5 Centigrade

SLUDGE pH: 12

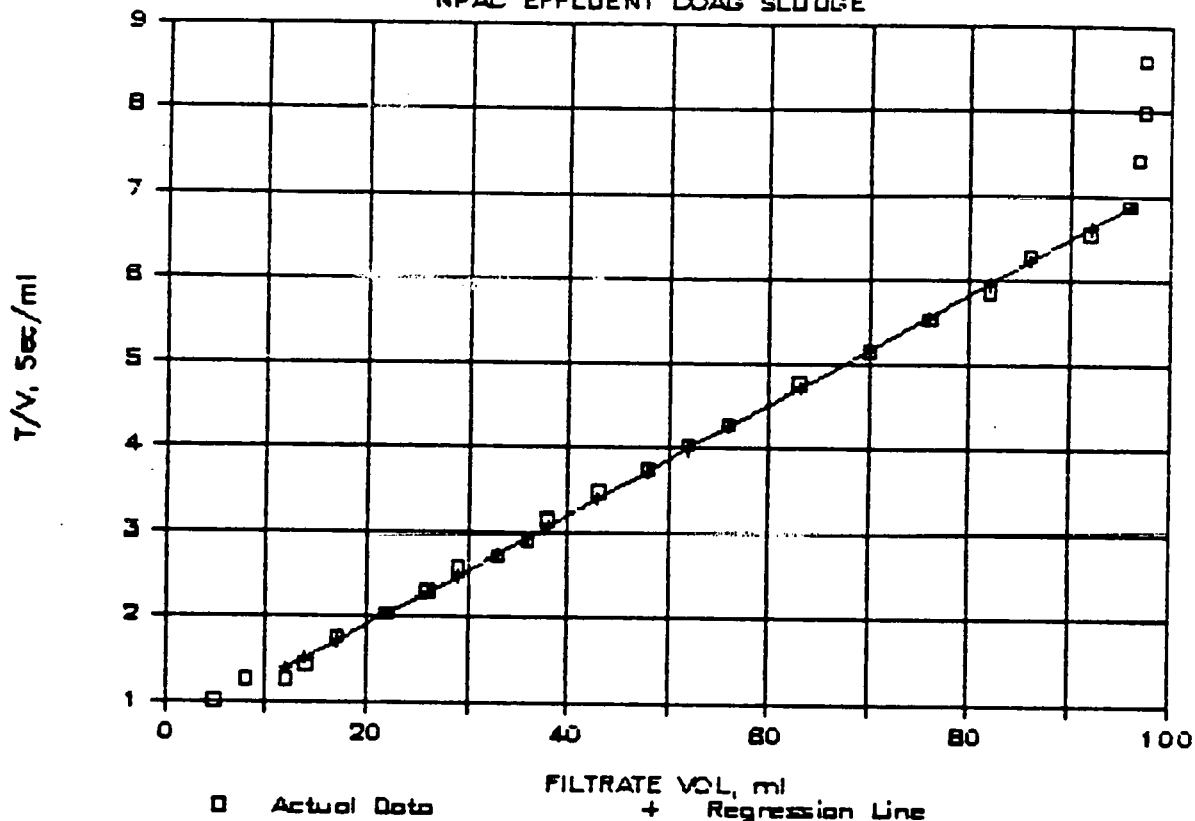
CONDITION AGENT: NONE

DOSAGE: 0 mls per 100 mls Sludge

Figure A-8

VACUUM FILT.—SPECIFIC RESISTANCE

NPAC EFFLUENT COAG SLUDGE



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : NPAC EFFLUENT COAG SLUDGE

DATE: DEC. 15, 1983

VACUUM: 27 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 207000 mg/L

FEED SOLIDS 2723 mg/L

FILTER TYPE: What. #1

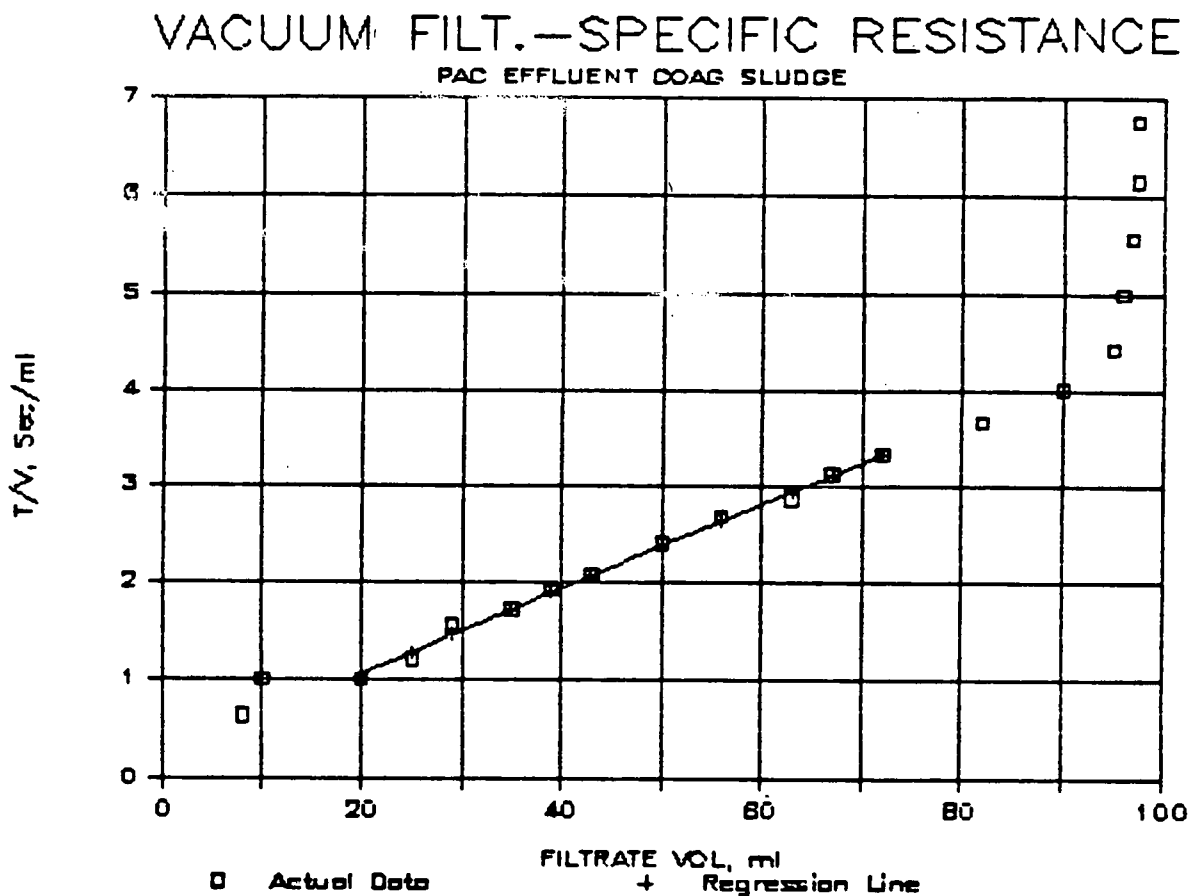
SLUDGE TEMP. 19 Centigrade

SLUDGE pH: 6.8

CONDITION AGENT: NONE

DOSAGE: 0 ml per 100 ml Sludge

Figure A-9



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : PAC EFFLUENT COAG SLUDGE

DATE: DEC. 14, 1983

VACUUM: 27 inches Hg.

VISCOSITY 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 229000 mg/L

FEED SOLIDS 5215 mg/L

FILTER TYPE: What. #1

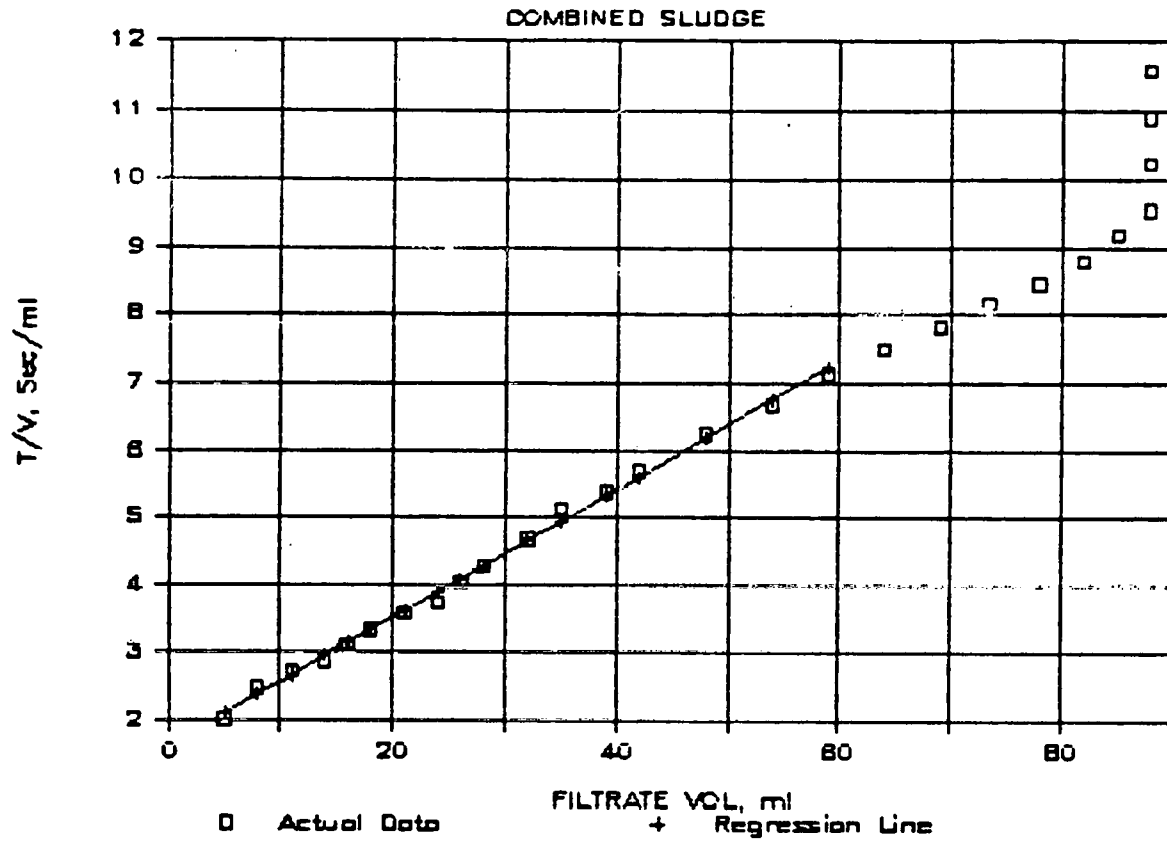
SLUDGE TEMP. 14 Centigrade

SLUDGE pH: 6.8

CONDITION AGENT: NONE

DOSAGE: 0 mlc per 100 mlc Sludge

VACUUM FILT.—SPECIFIC RESISTANCE



VACUUM FILTRATION - BUCHNER FUNNEL TEST

CLIENT: ICRC

SAMPLE : COMBINED SLUDGE #13

DATE: FEB. 7, 1984

VACUUM: 28 inches Hg.

VISCOSITY . 0.01 poise

FILTER DIAMETER 7 centimeters

CAKE SOLIDS 207000 mg/L

FEED SOLIDS 3940 mg/L

FILTER TYPE: What. #1

SLUDGE TEMP. 13.5 Centigrade

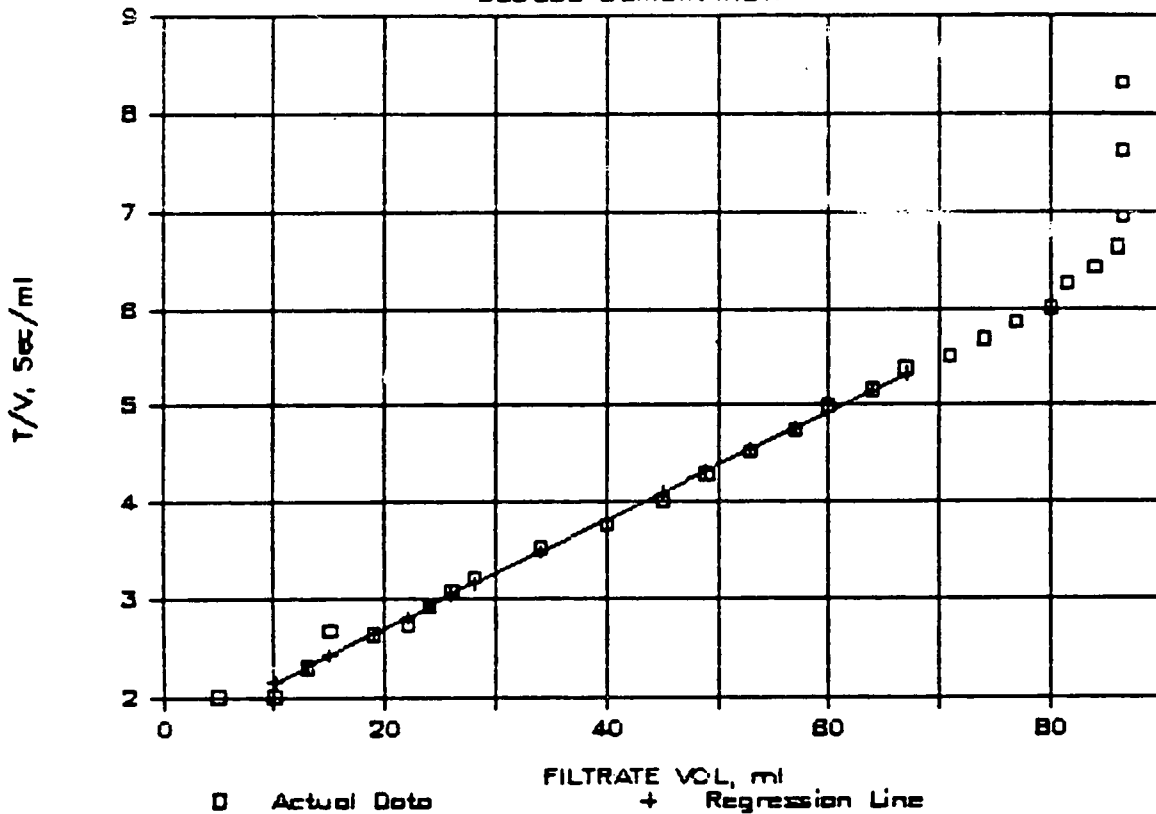
SLUDGE pH: 7.2

CONDITION AGENT: NONE

DOSAGE: 0 mls per 100 mls Sludge

VACUUM FILT.—SPECIFIC RESISTANCE

SLUDGE COMBINATION



VACUUM FILTRATION - BUCHNER FUNNEL TEST
 CLIENT: ICRC
 SAMPLE : COMBINED SLUDGE #14
 DATE: FEB 8, 1984
 VACUUM: 28 inches Hg.
 VISCOSITY 0.01 poise
 FILTER DIAMETER 7 centimeters
 CAKE SOLIDS 207000 mg/L
 FEED SOLIDS 18473 mg/L
 FILTER TYPE: What. #1
 SLUDGE TEMP. 18 Centigrade
 SLUDGE pH: 7.9
 CONDITION AGENT: NONE
 DOSAGE: 0 mls per 100 mls Sludge

Figure A-12

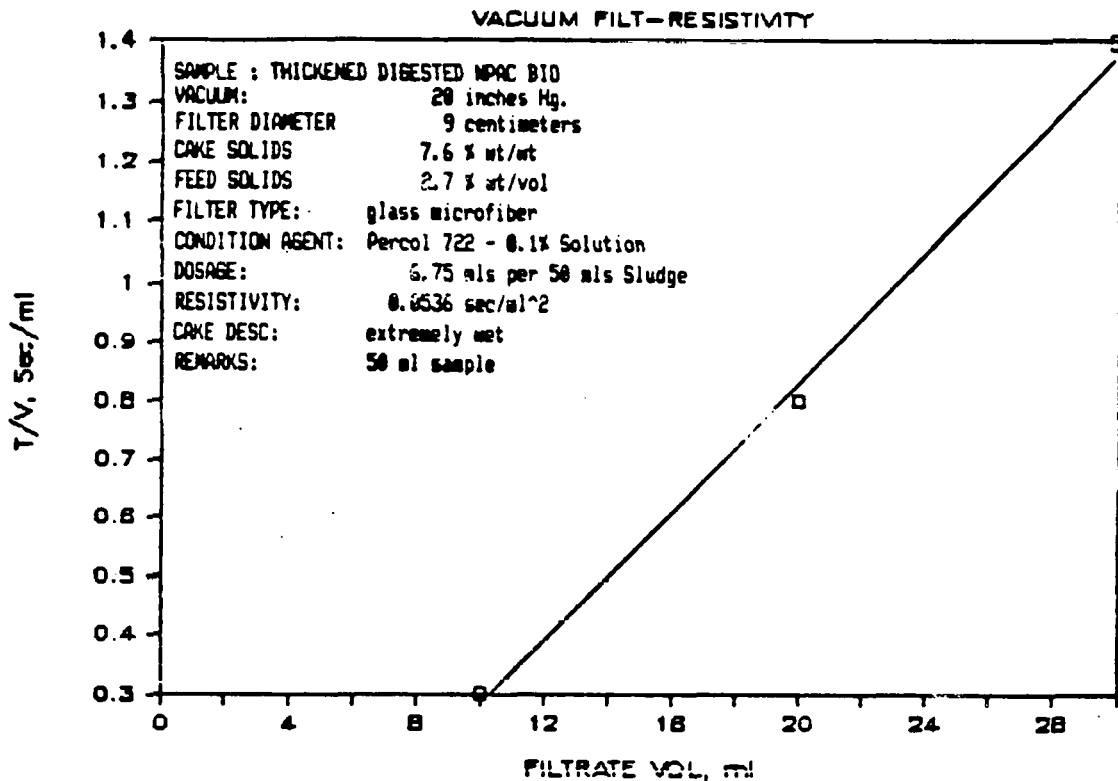


Figure A-13

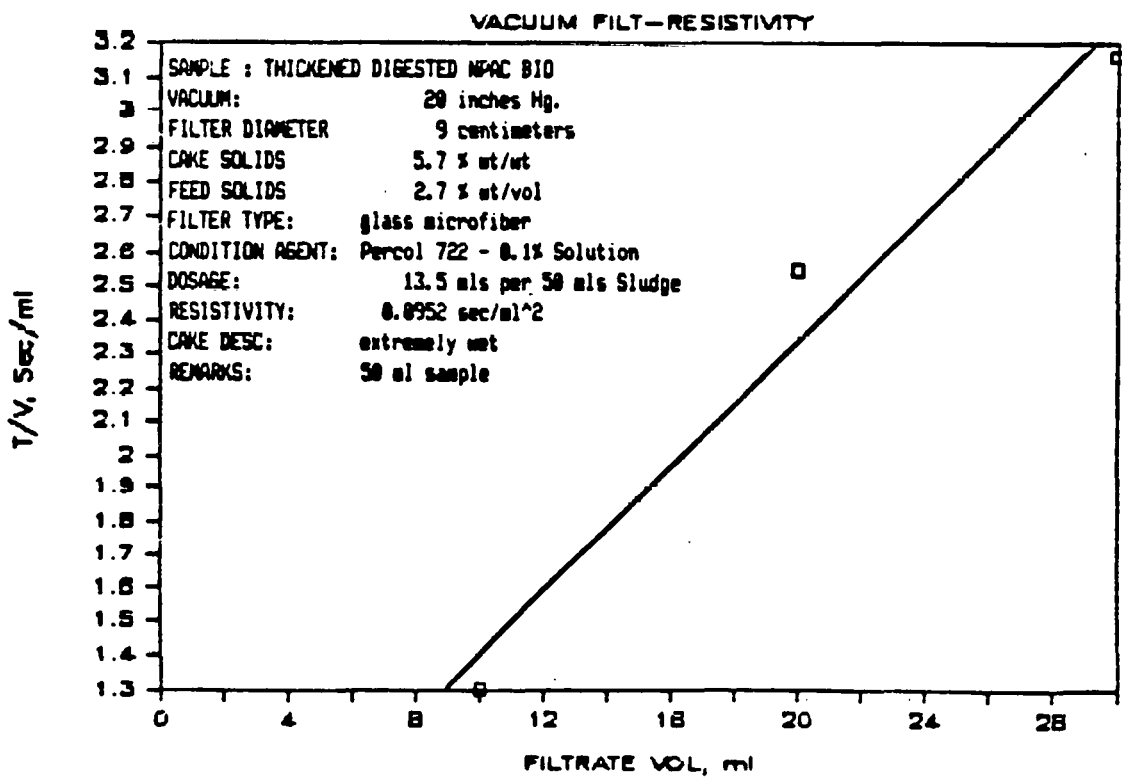


Figure A-14

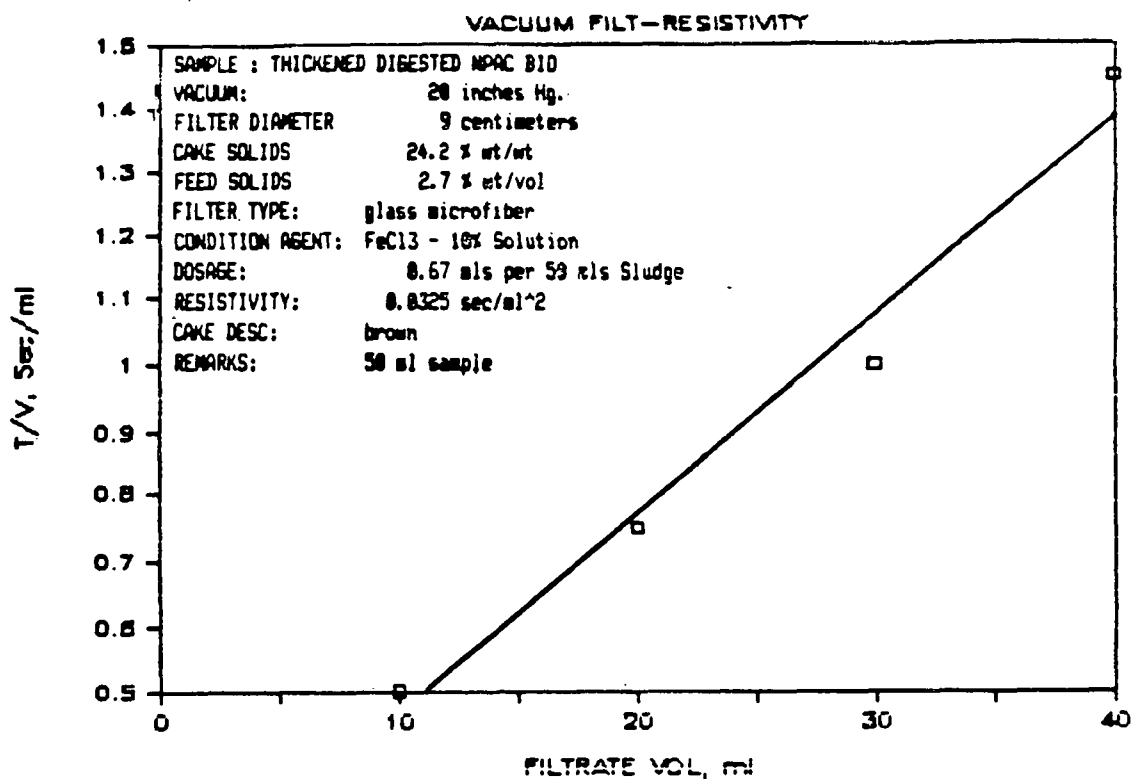


Figure A-15

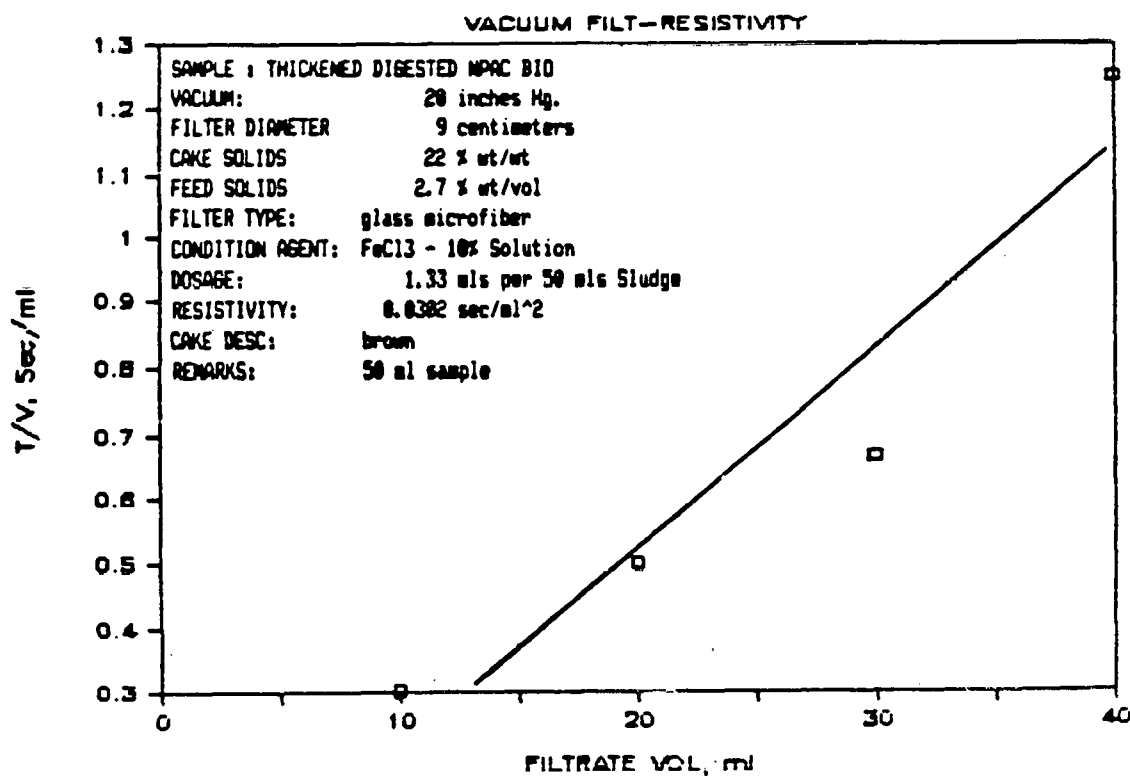


Figure A-16

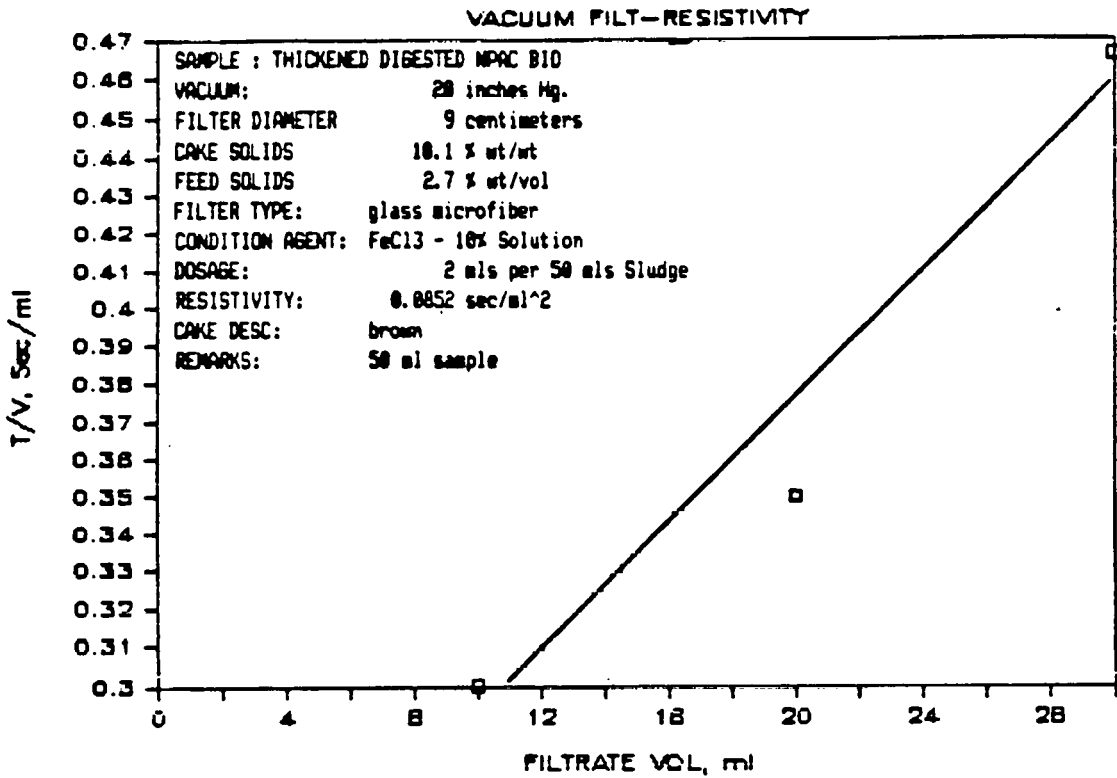


Figure A-17

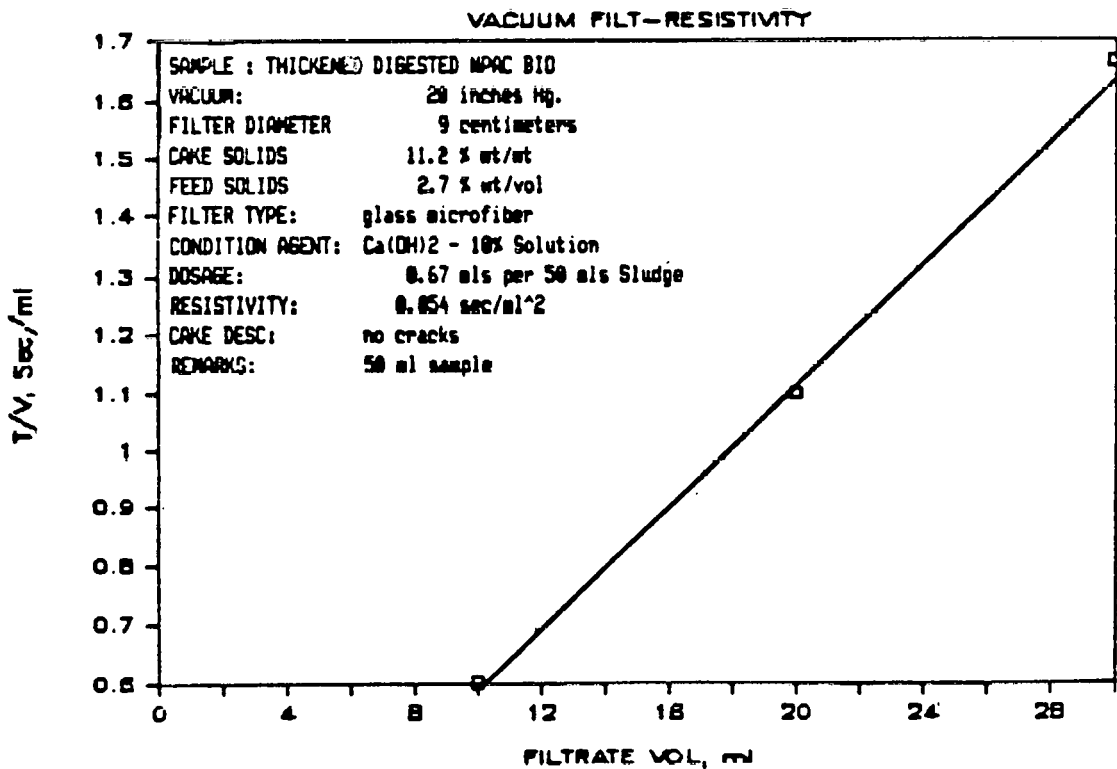


Figure A-18

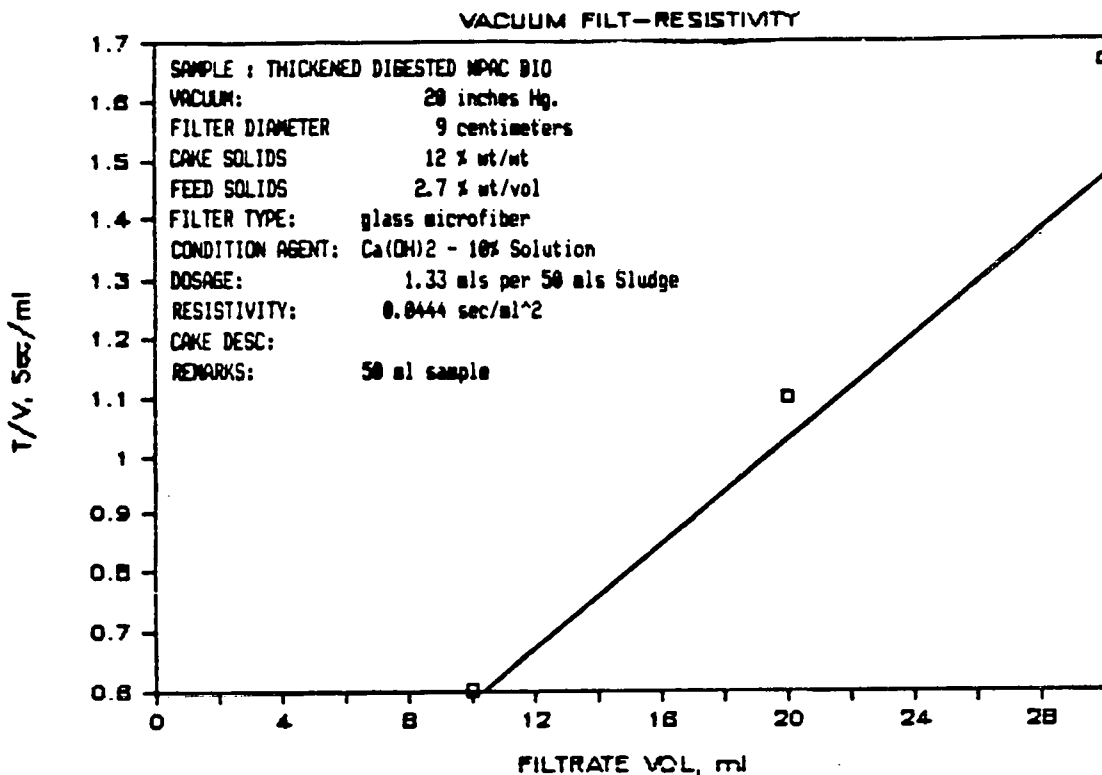


Figure A-19

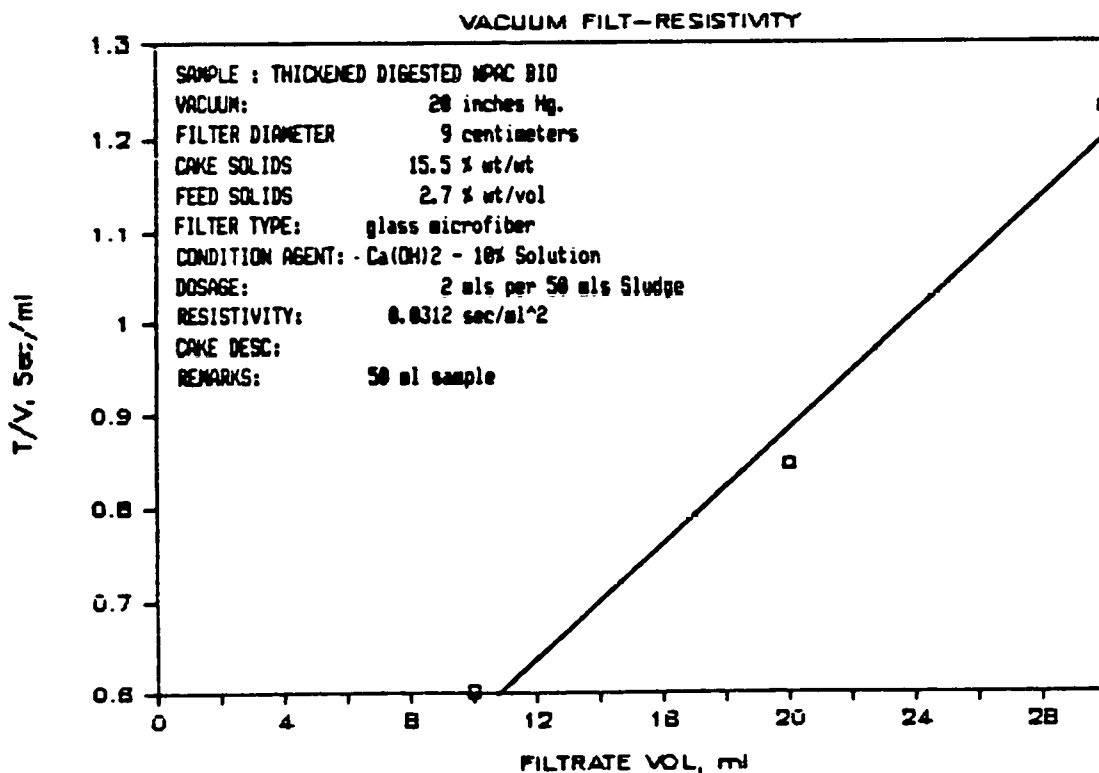


Figure A-20

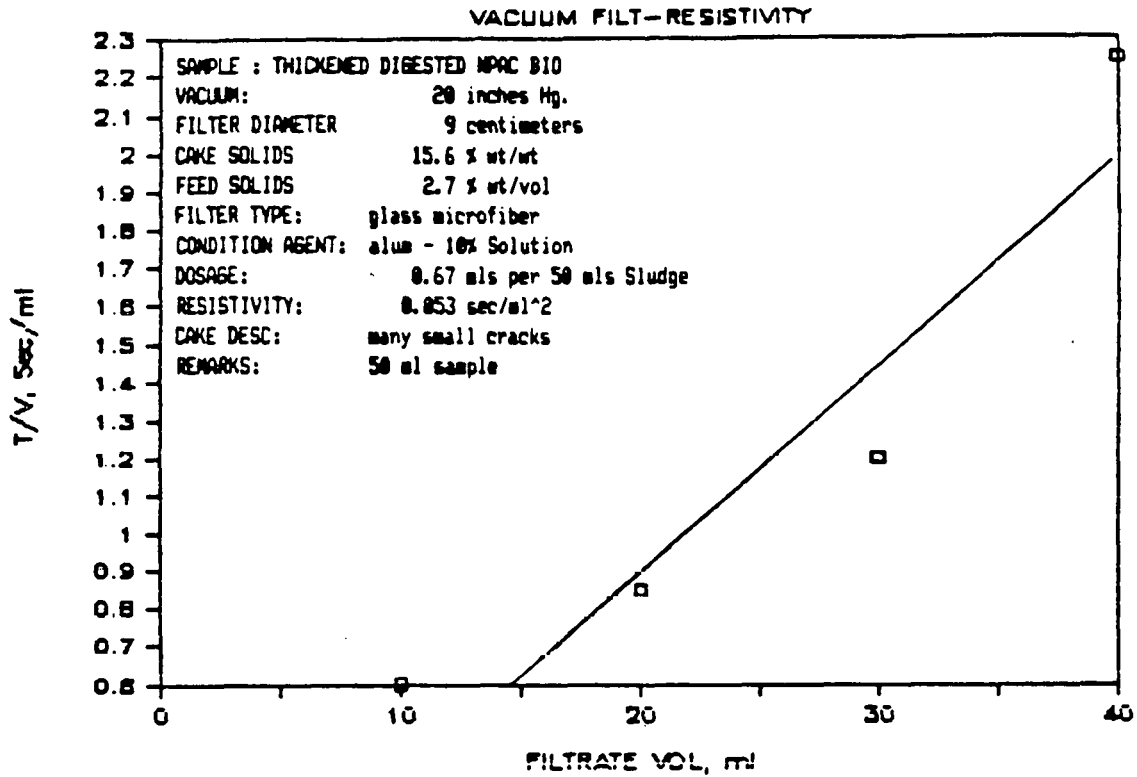


Figure A-21

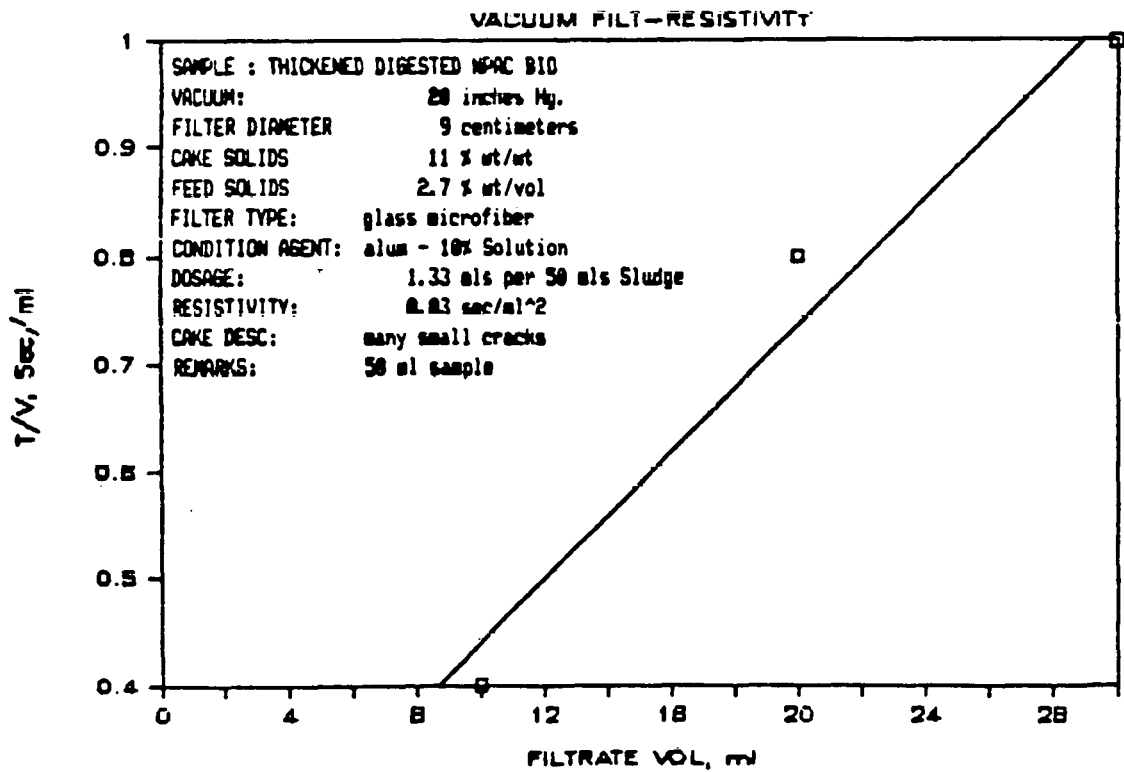


Figure A-22

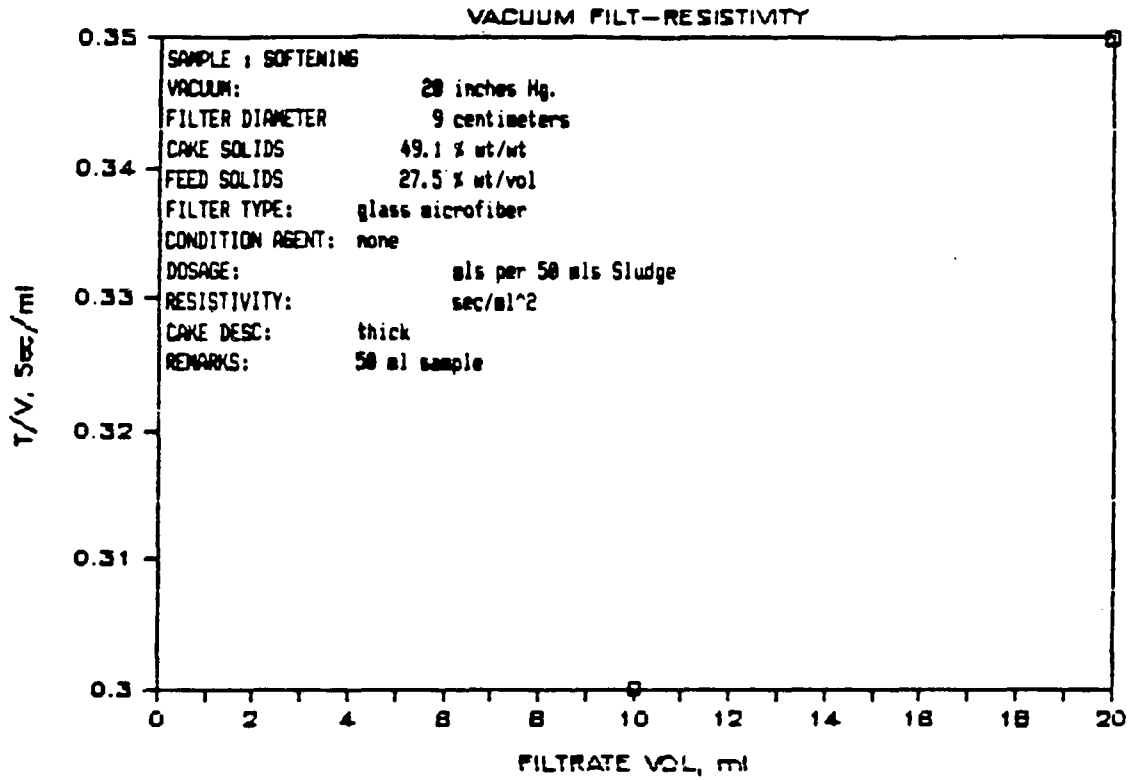


Figure A-23

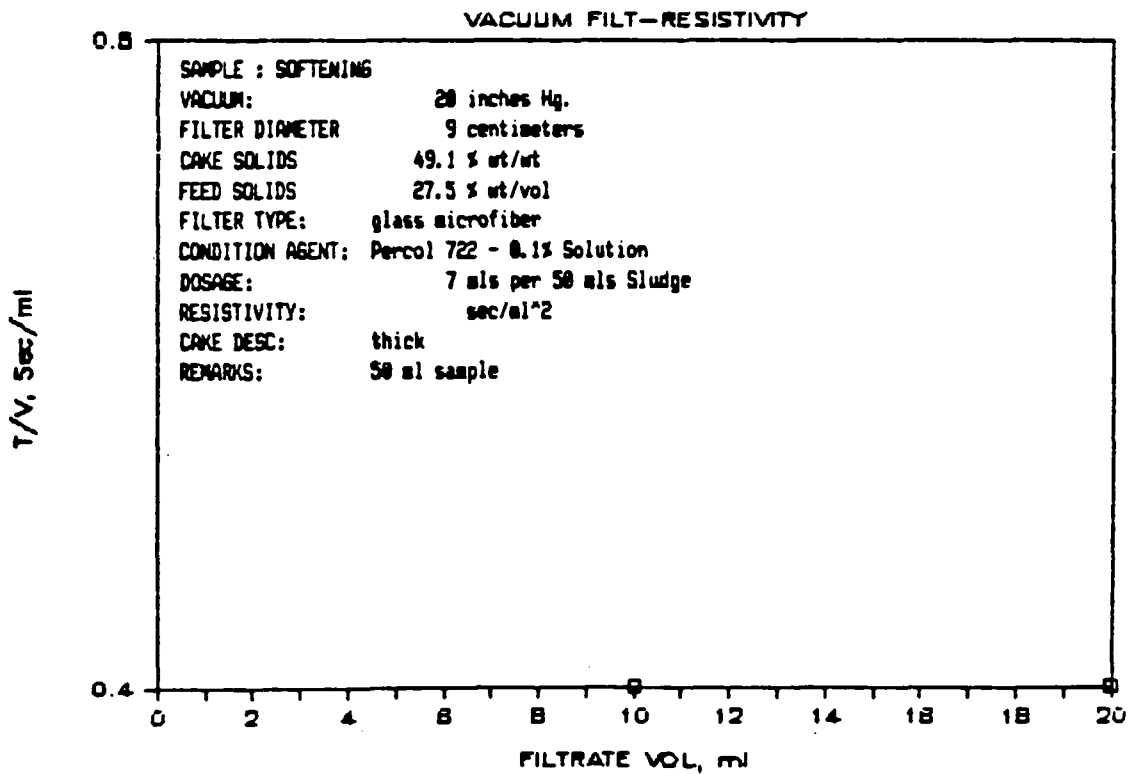


Figure A-24

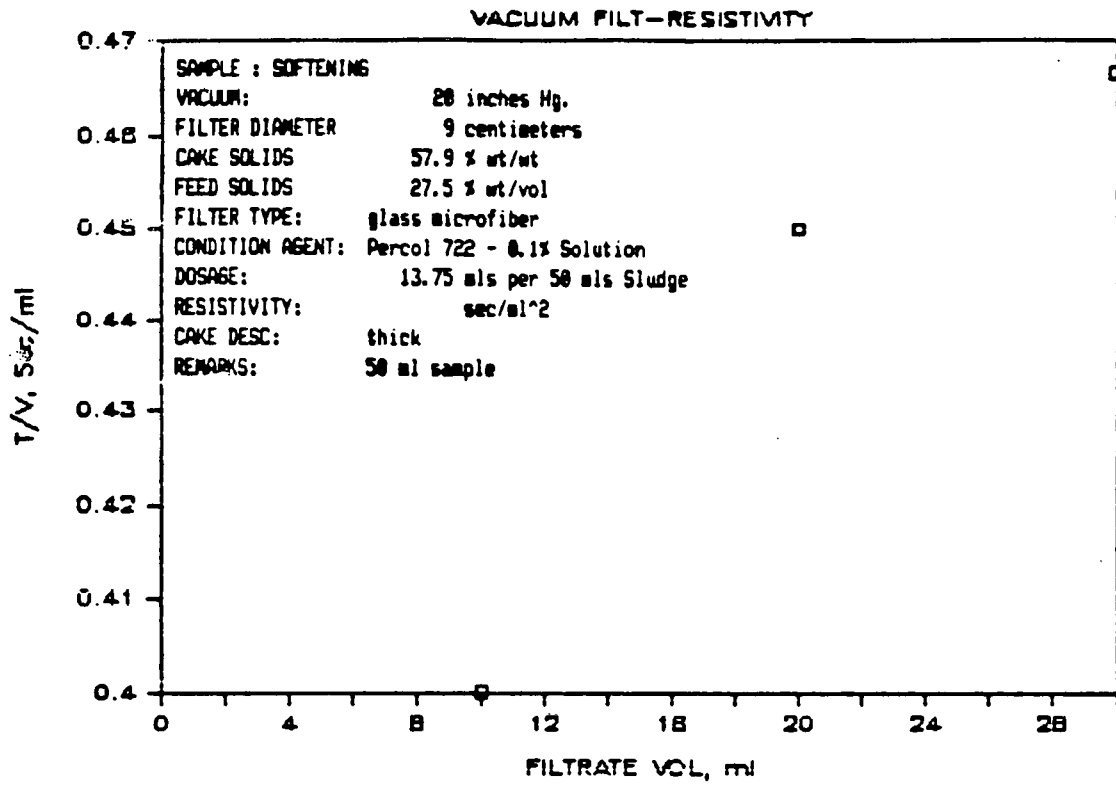


Figure A-25

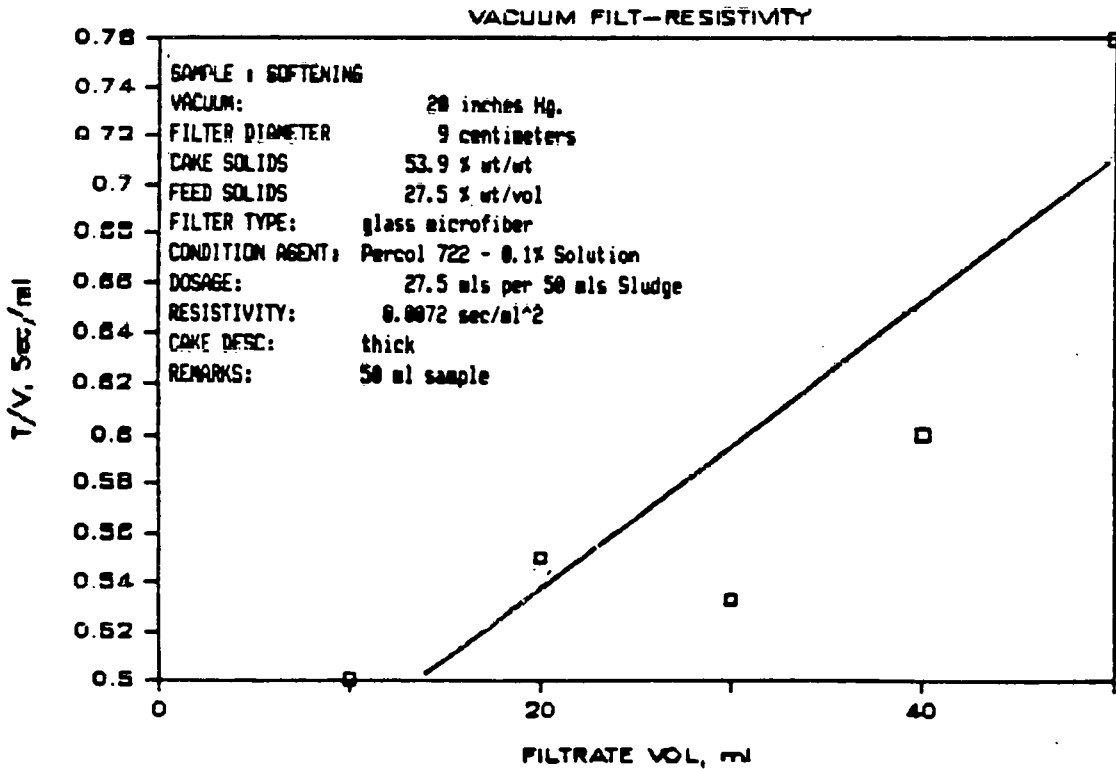


Figure A-26

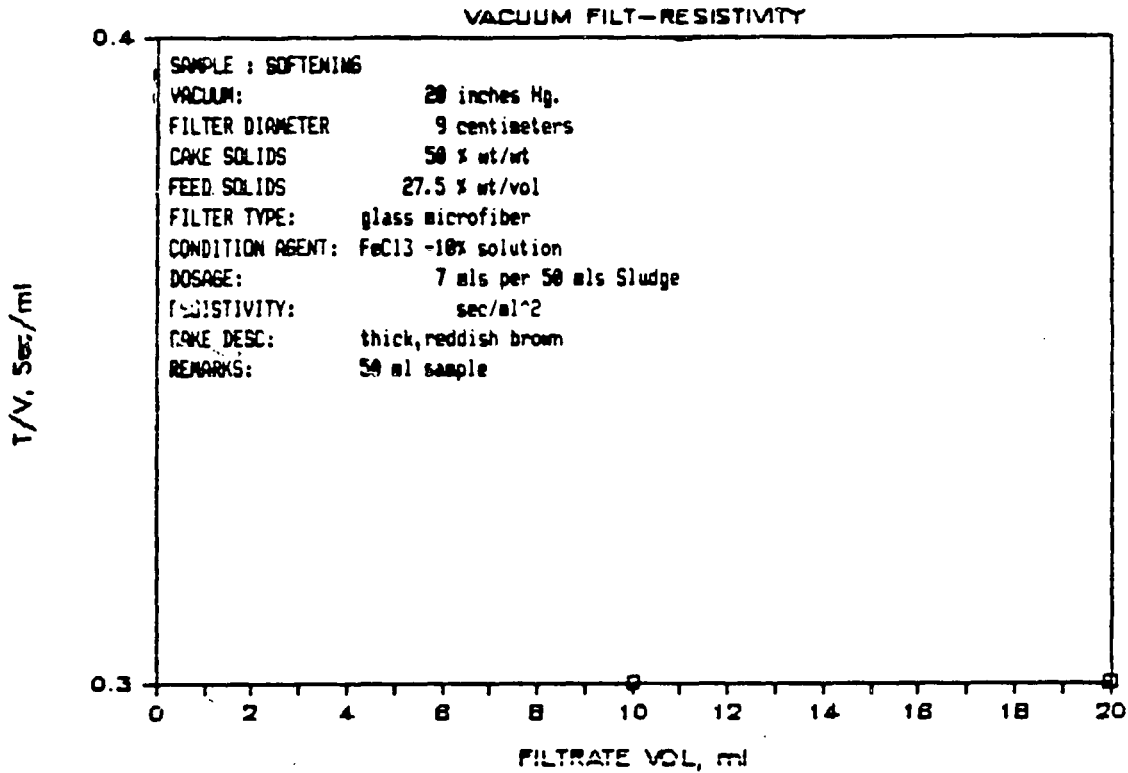


Figure A-27

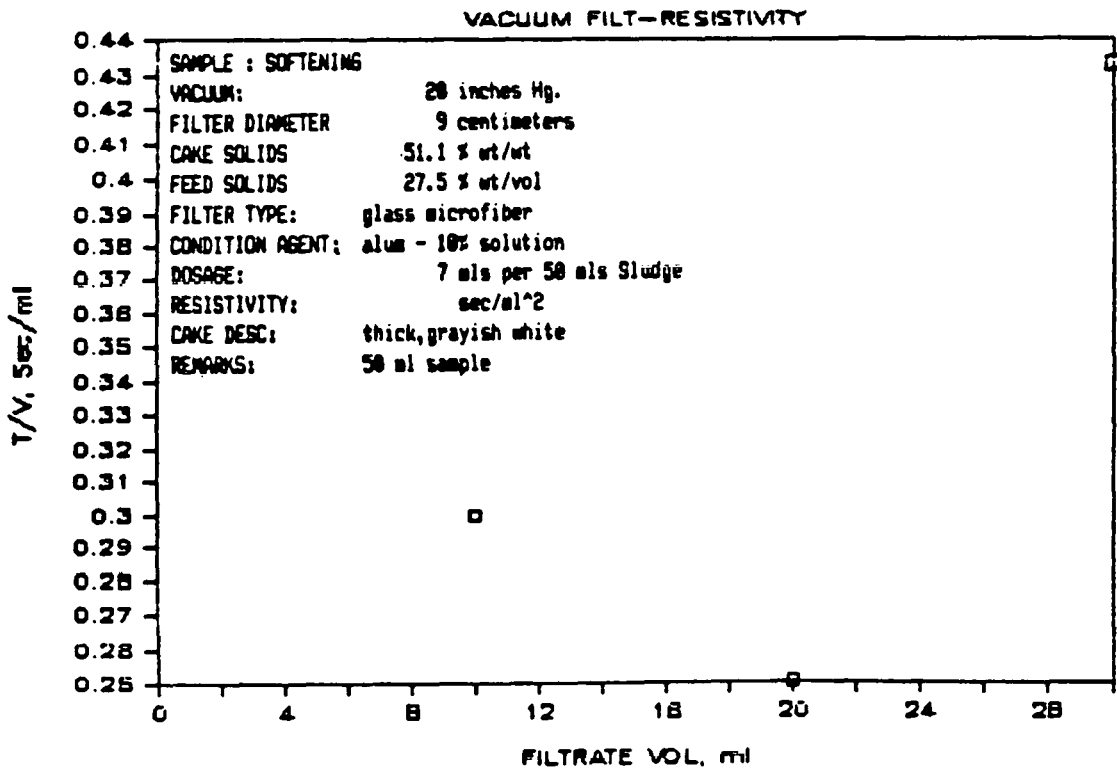


Figure A-28

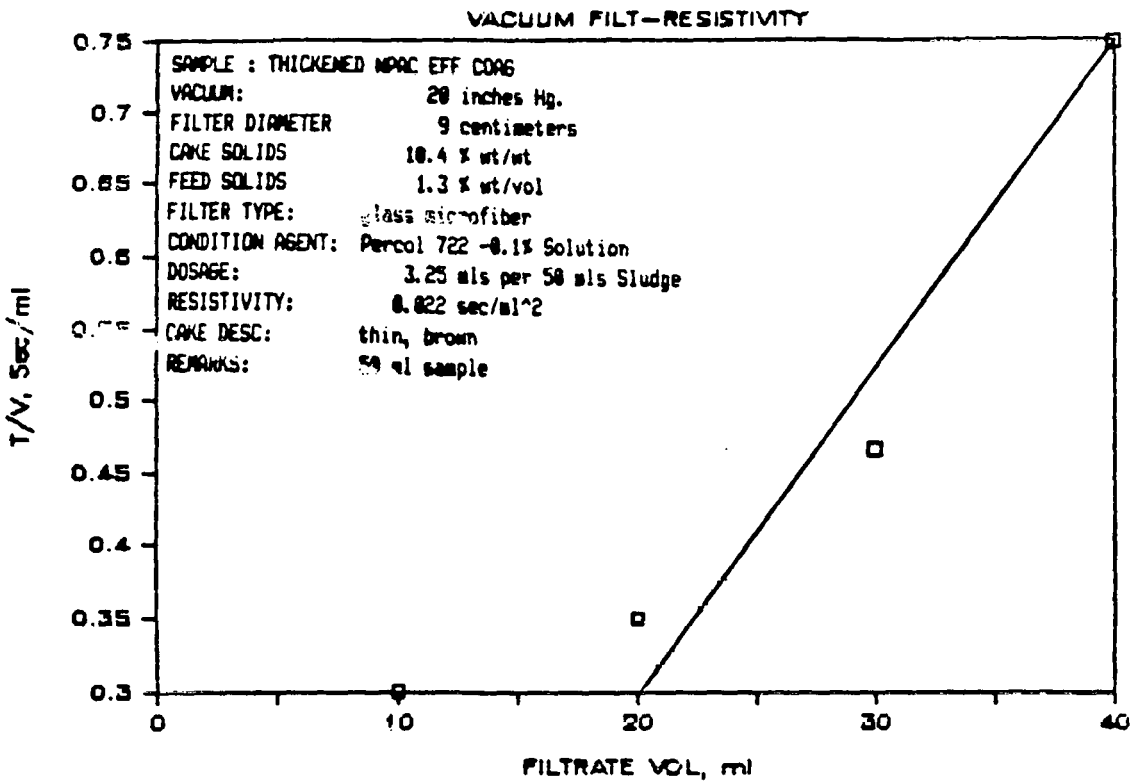


Figure A-29

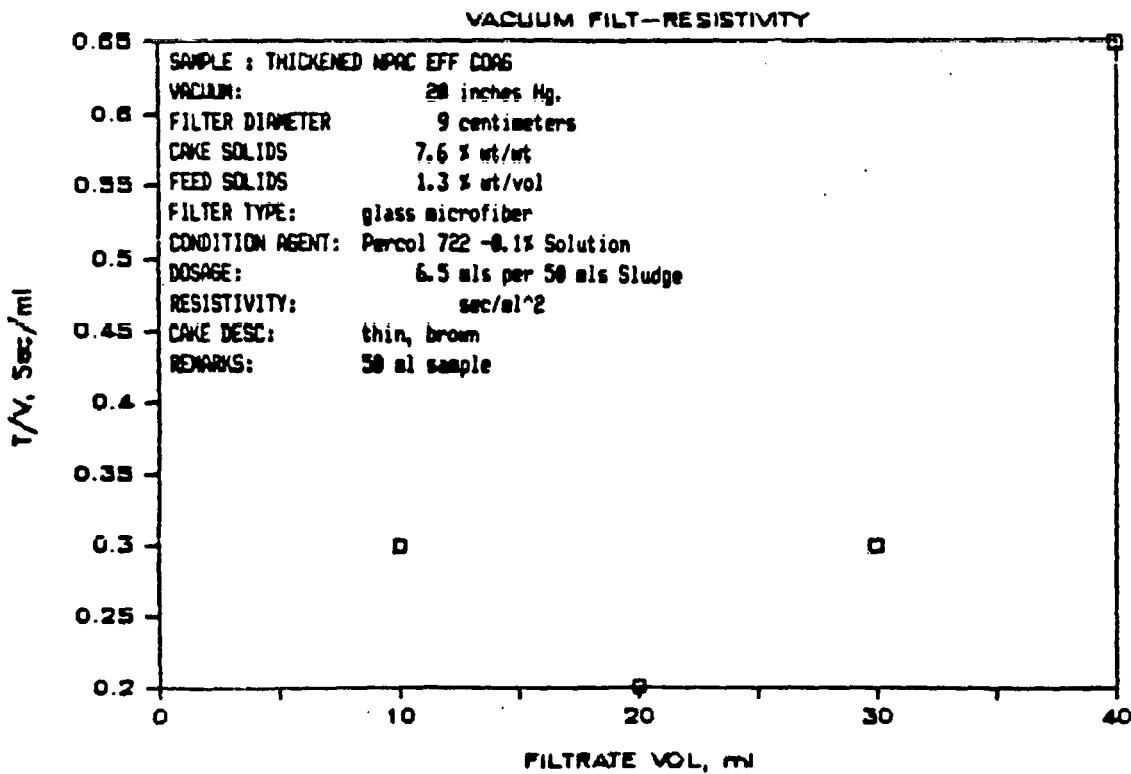


Figure A-30

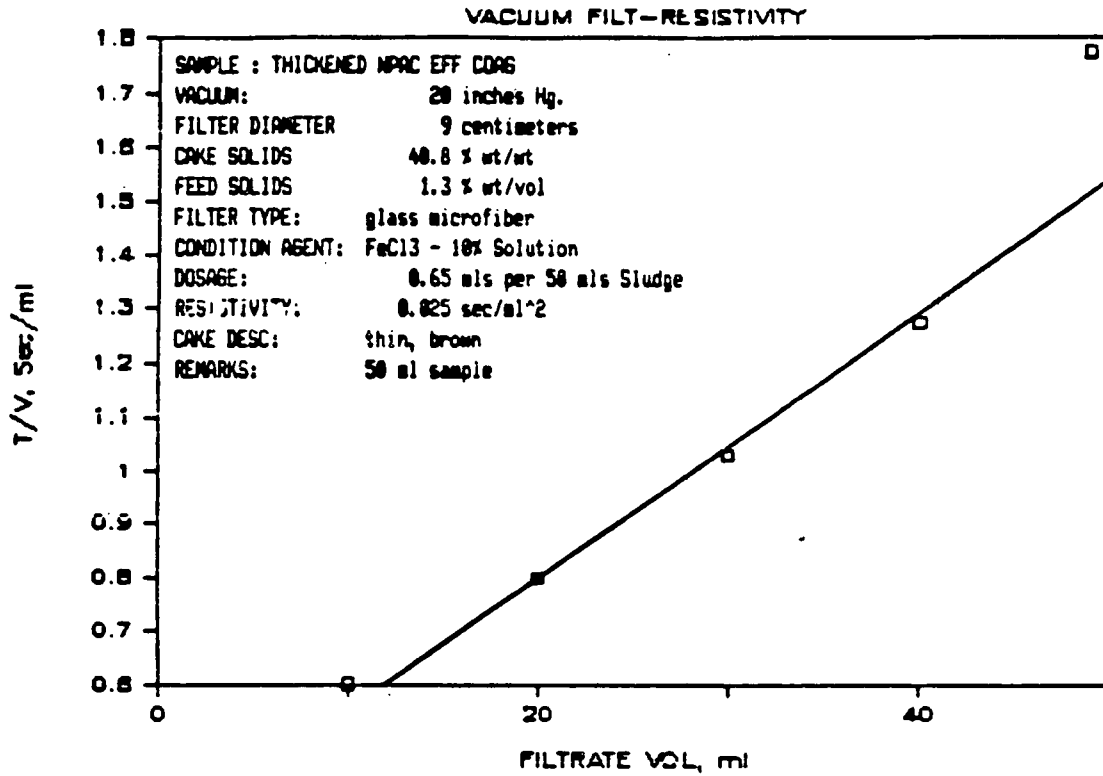


Figure A-31

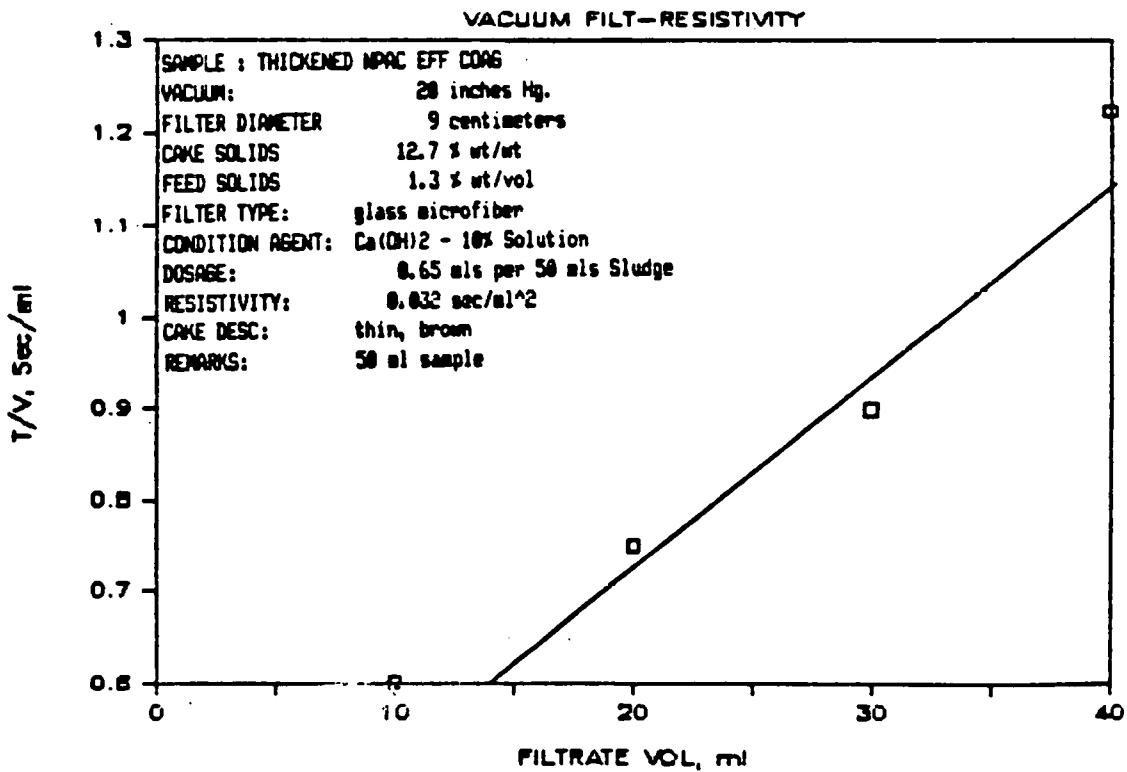


Figure A-32

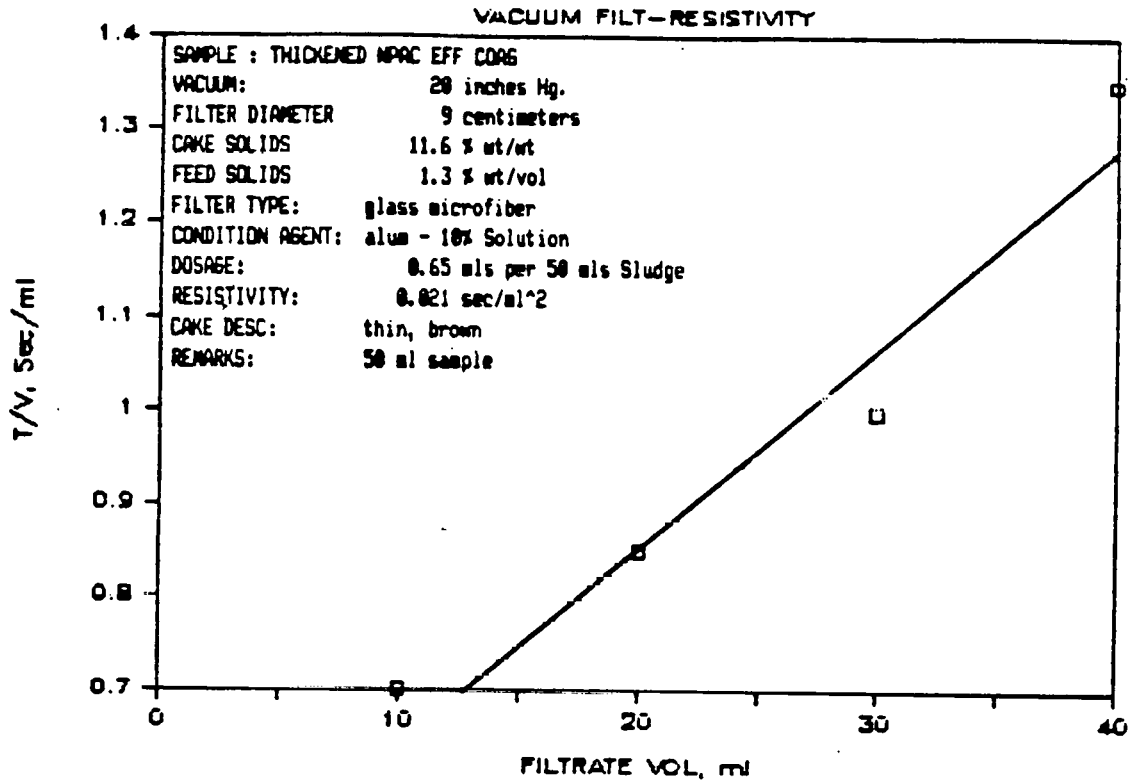


Figure A-33

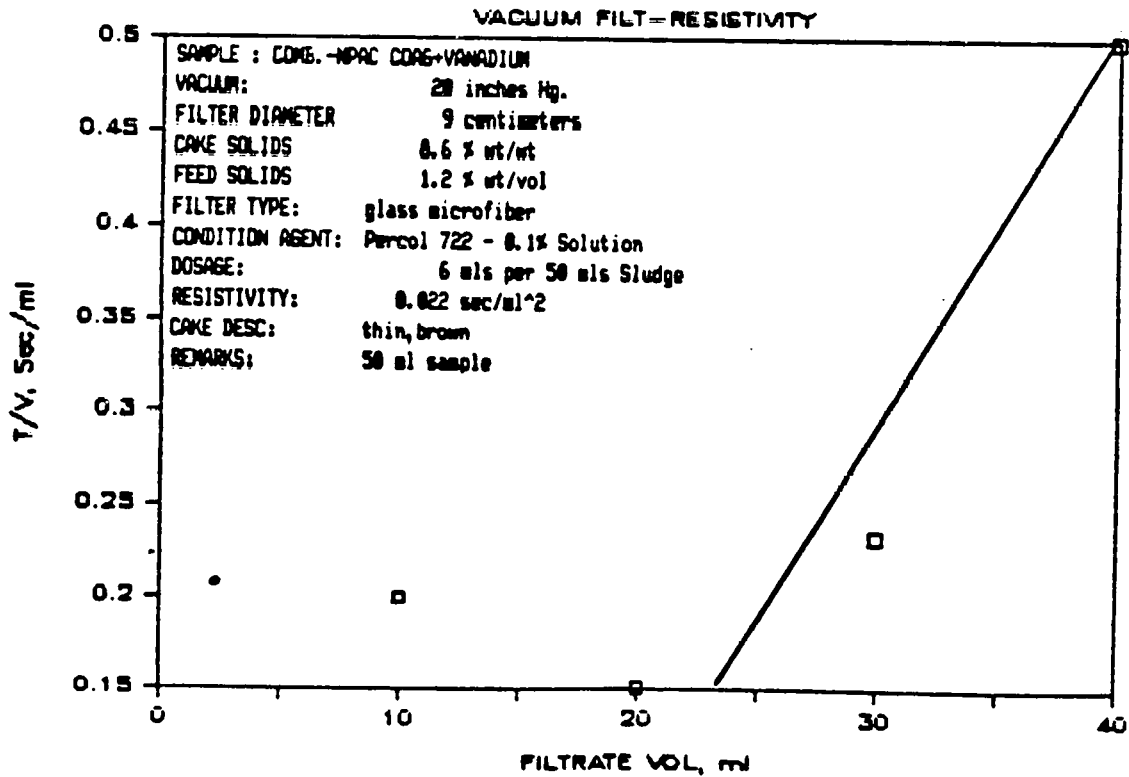


Figure A-34

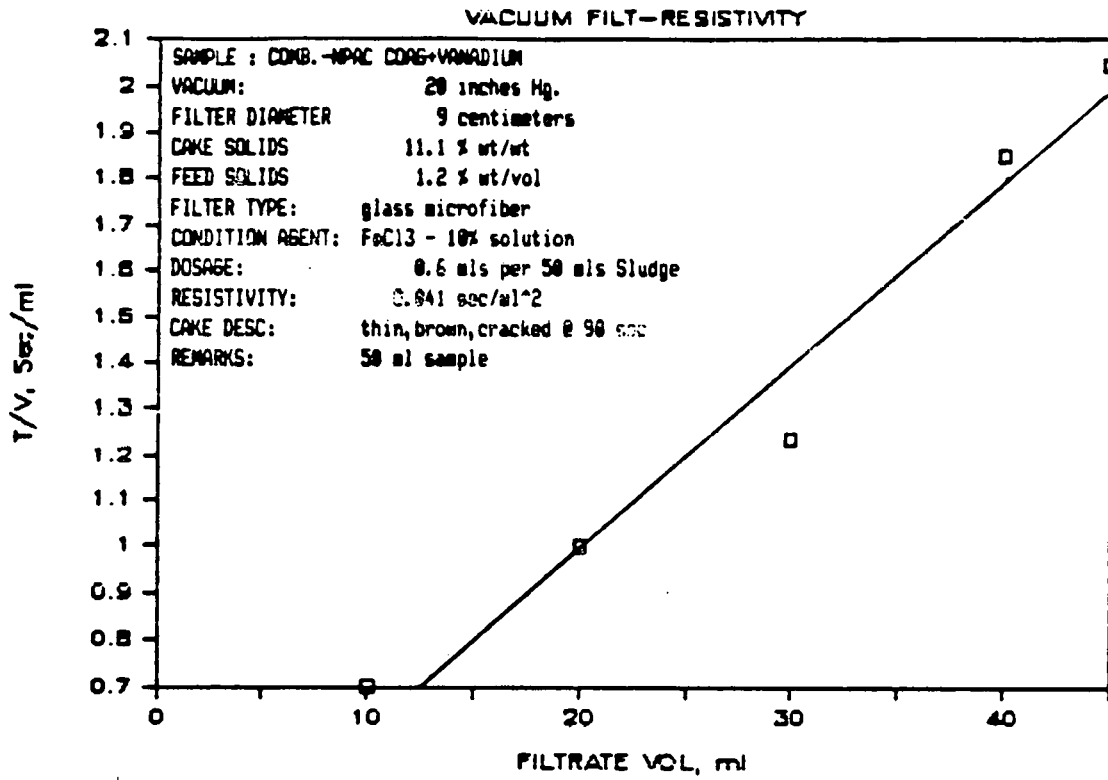


Figure A-35

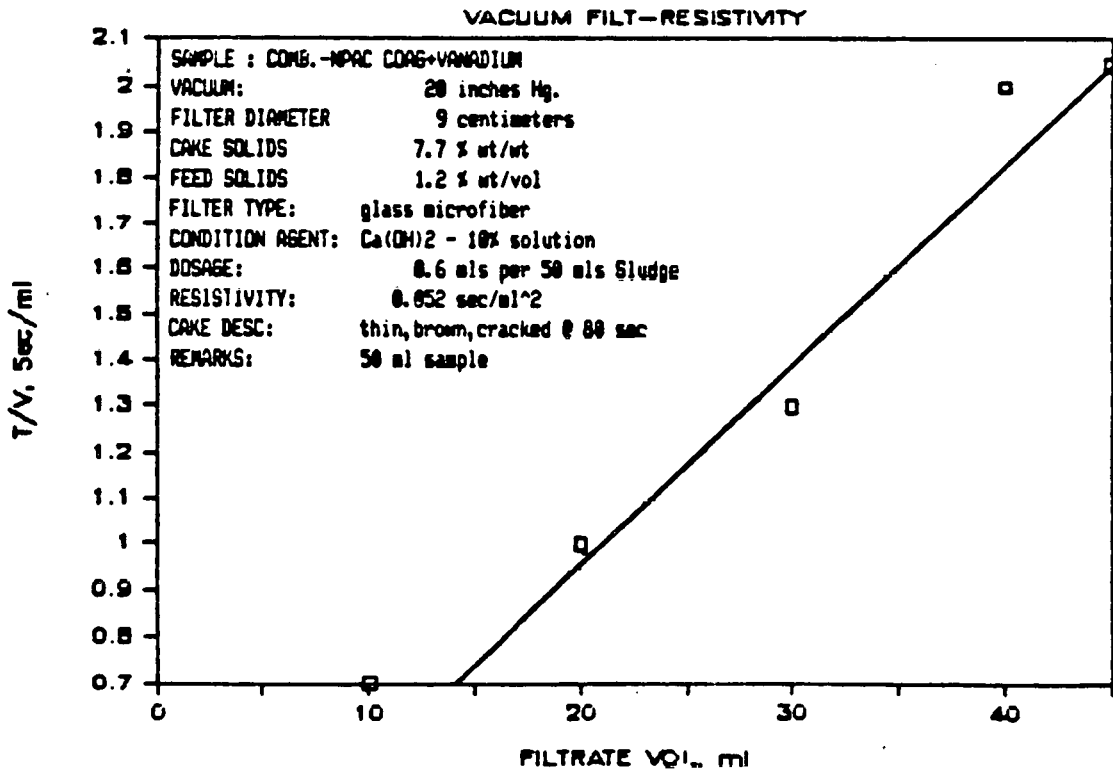


Figure A-36

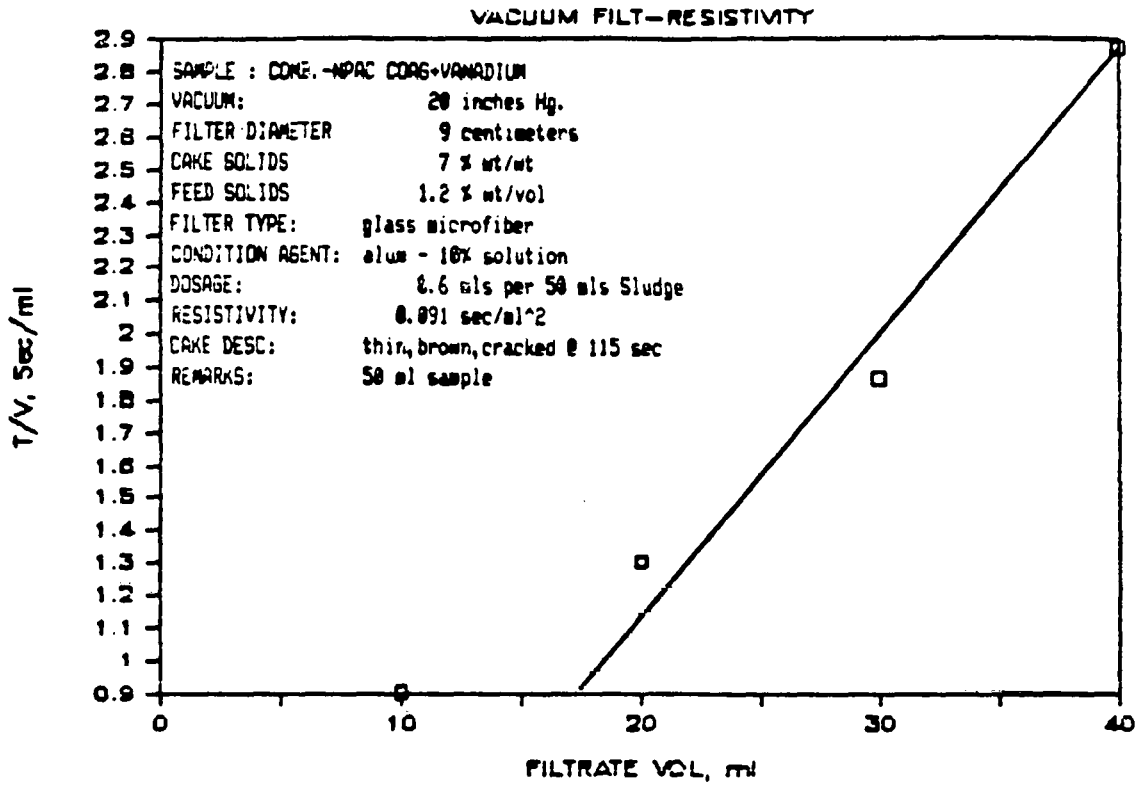


Figure A-37

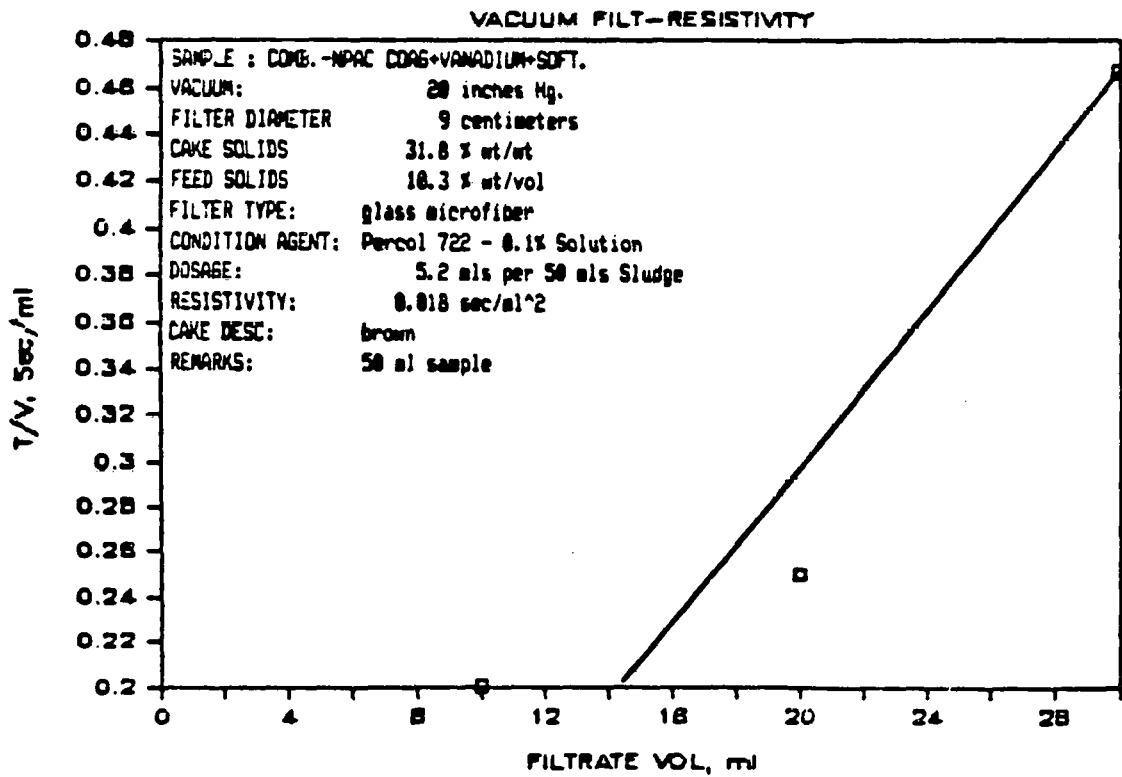


Figure A-38

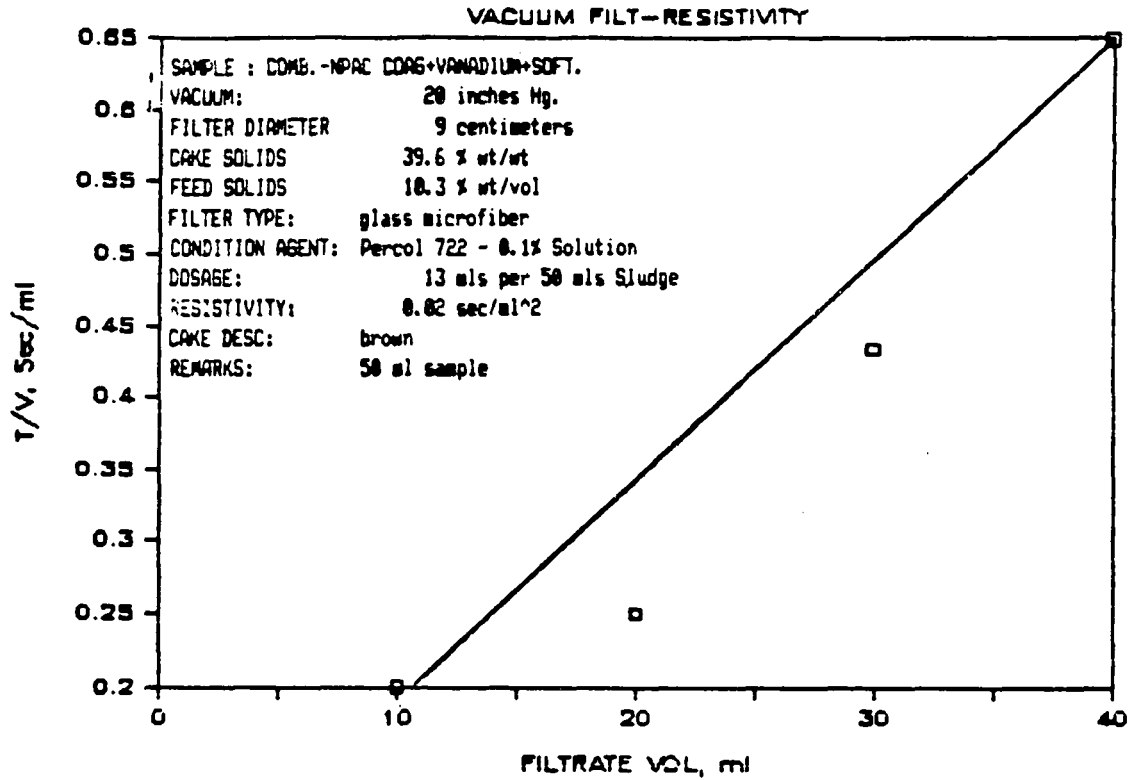


Figure A-39

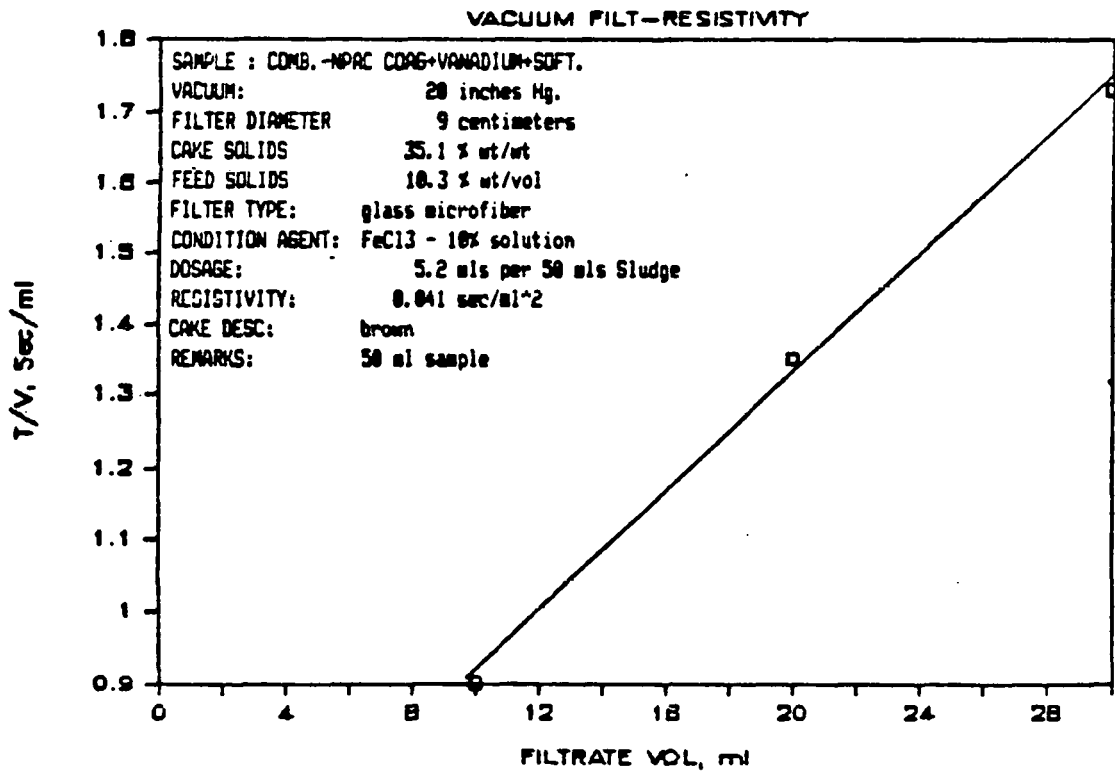


Figure A-40

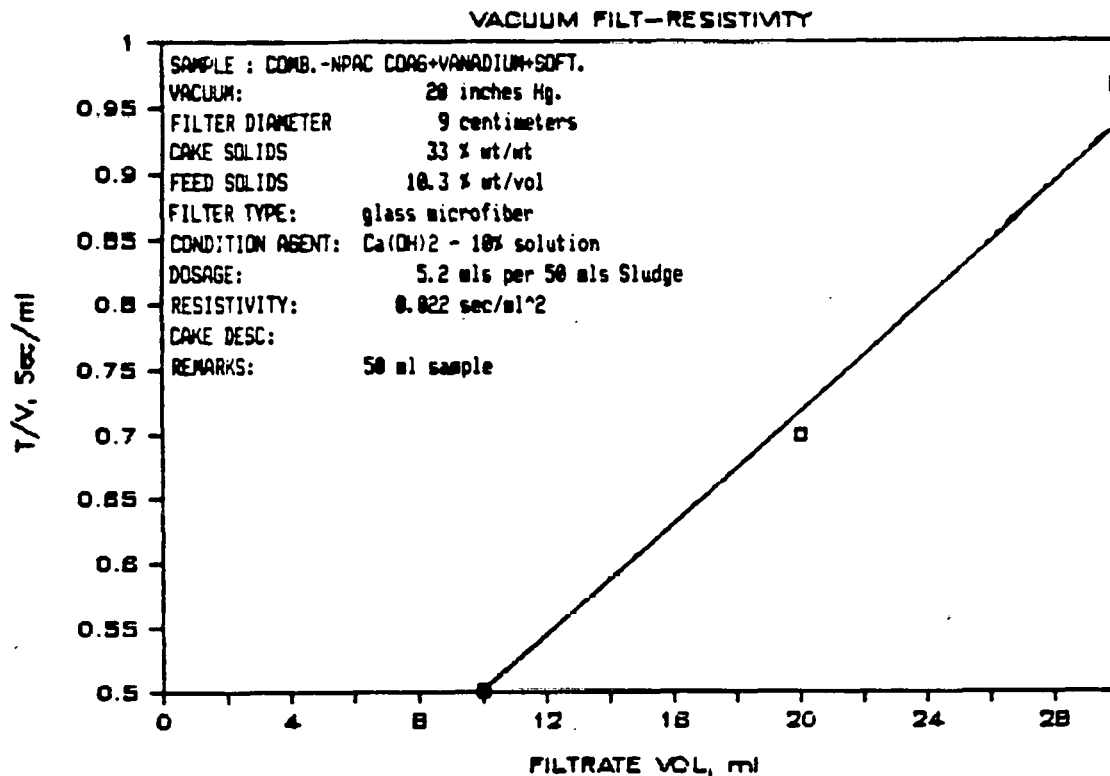


Figure A-41

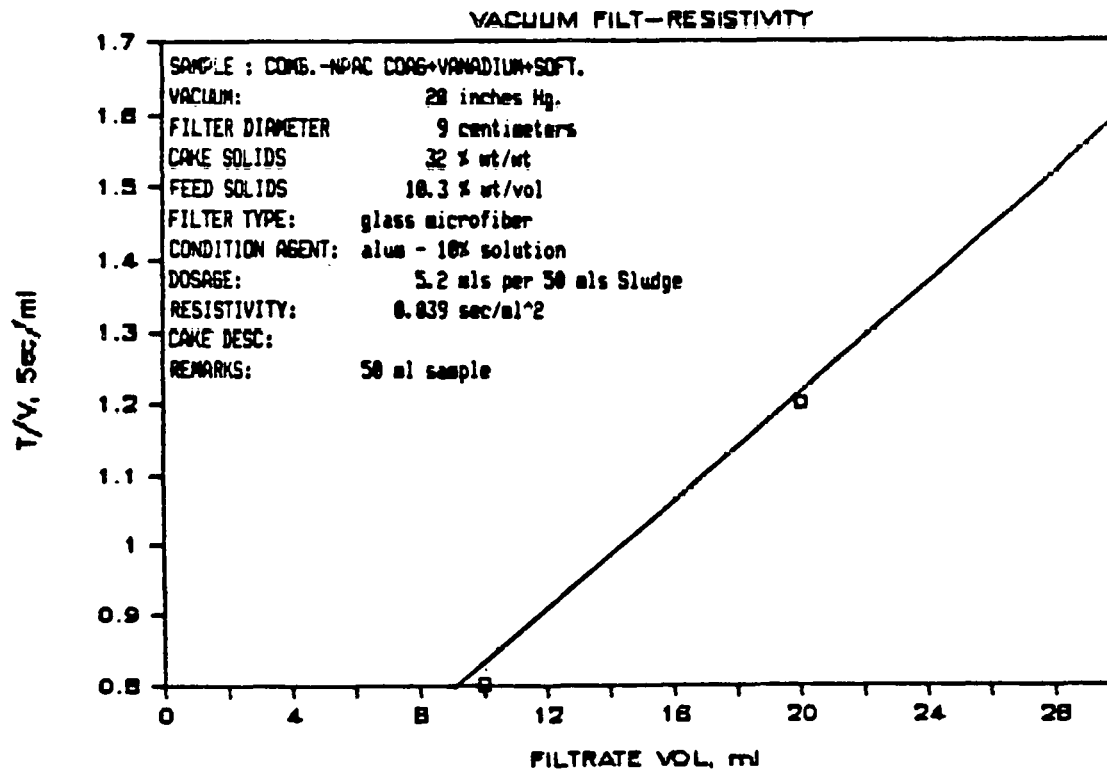


Figure A-42

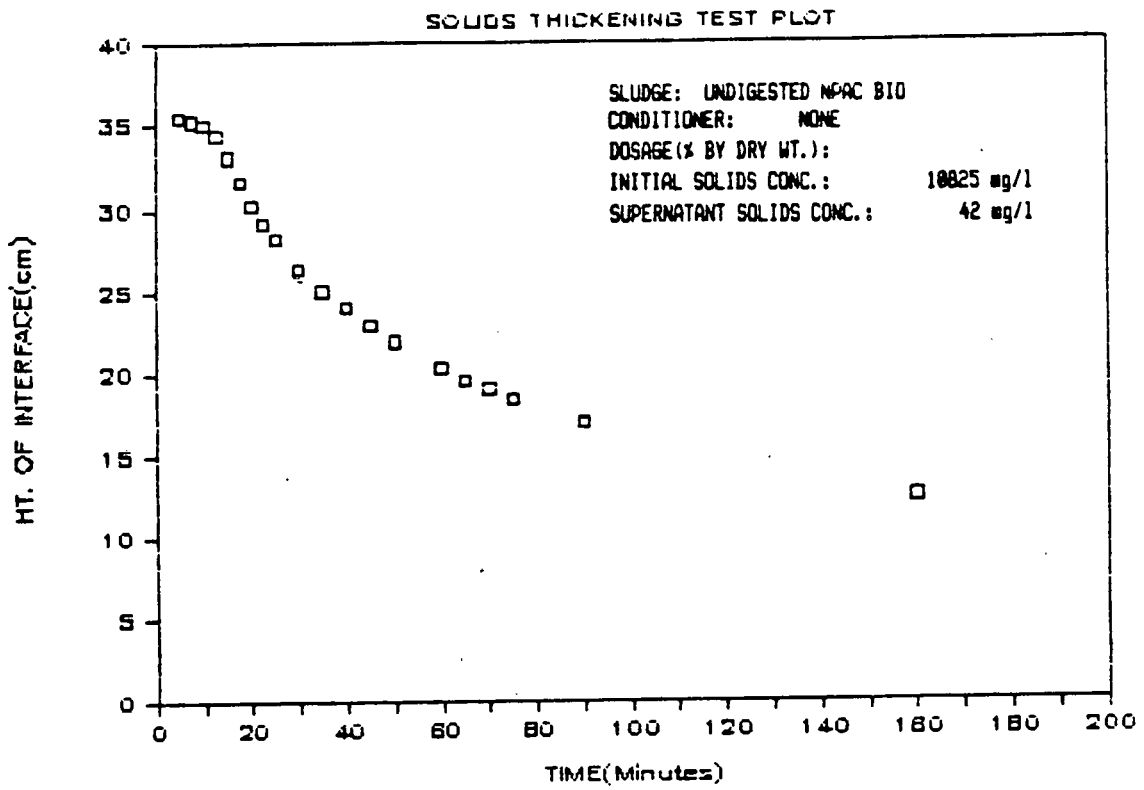


Figure A-43

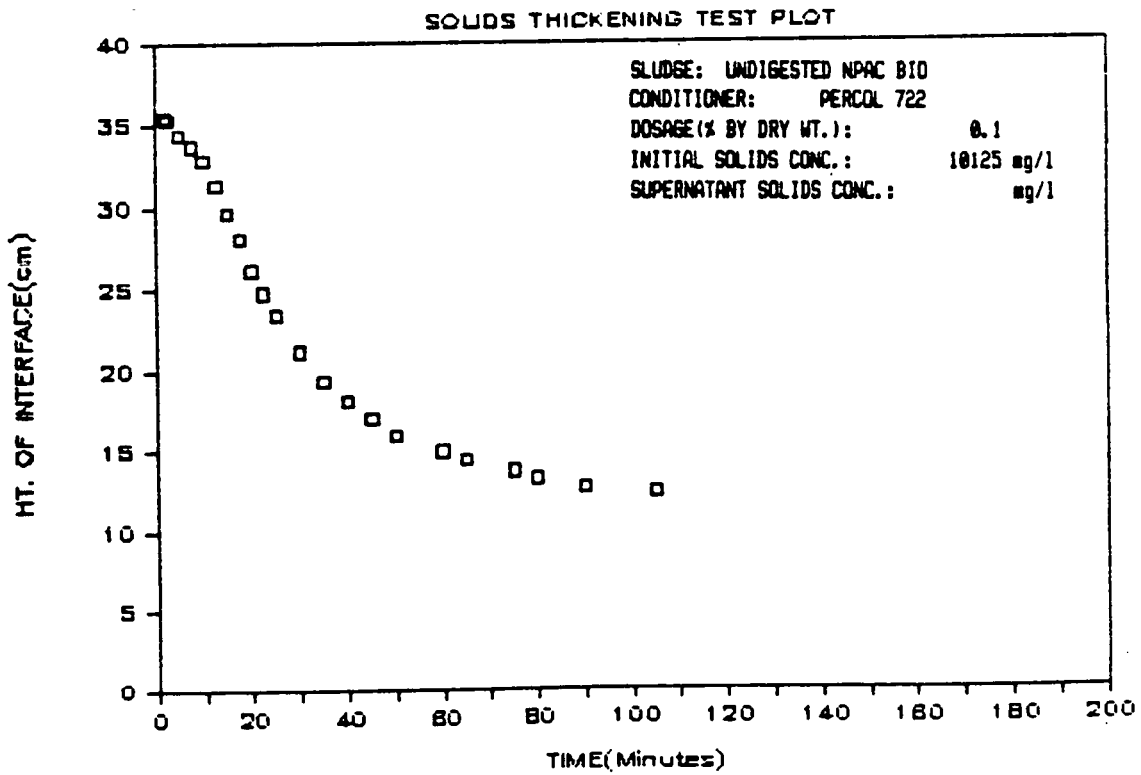


Figure A-44

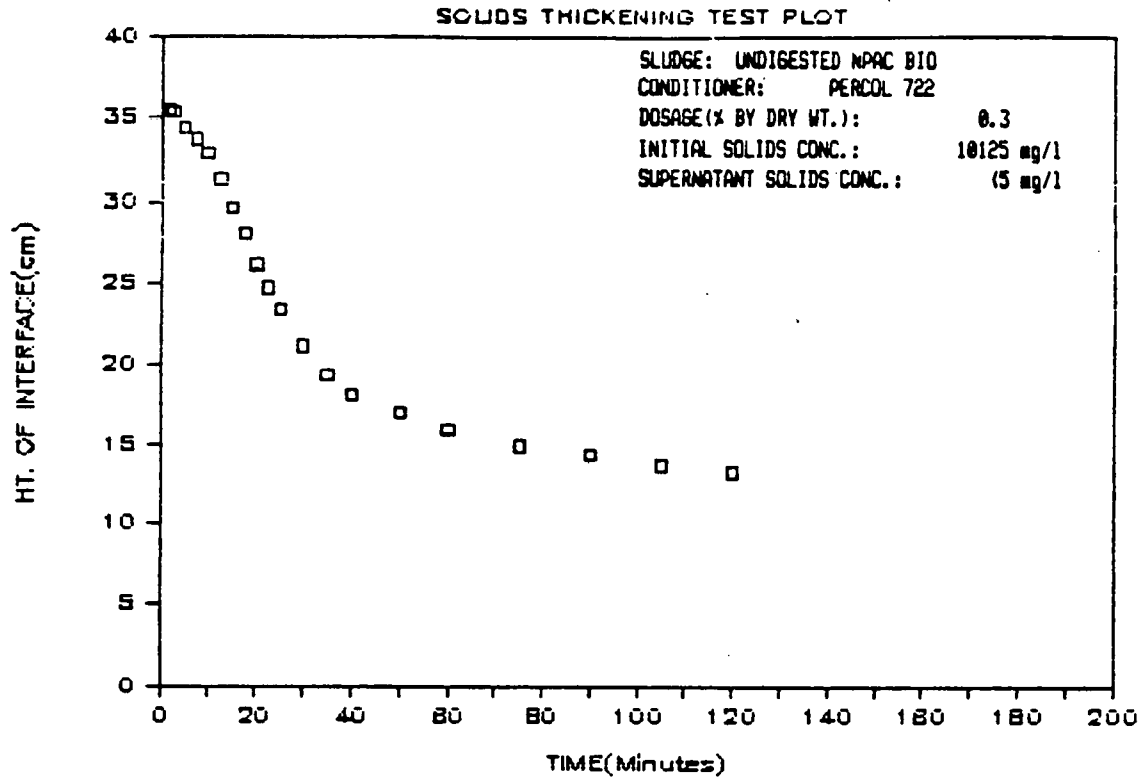


Figure A-45

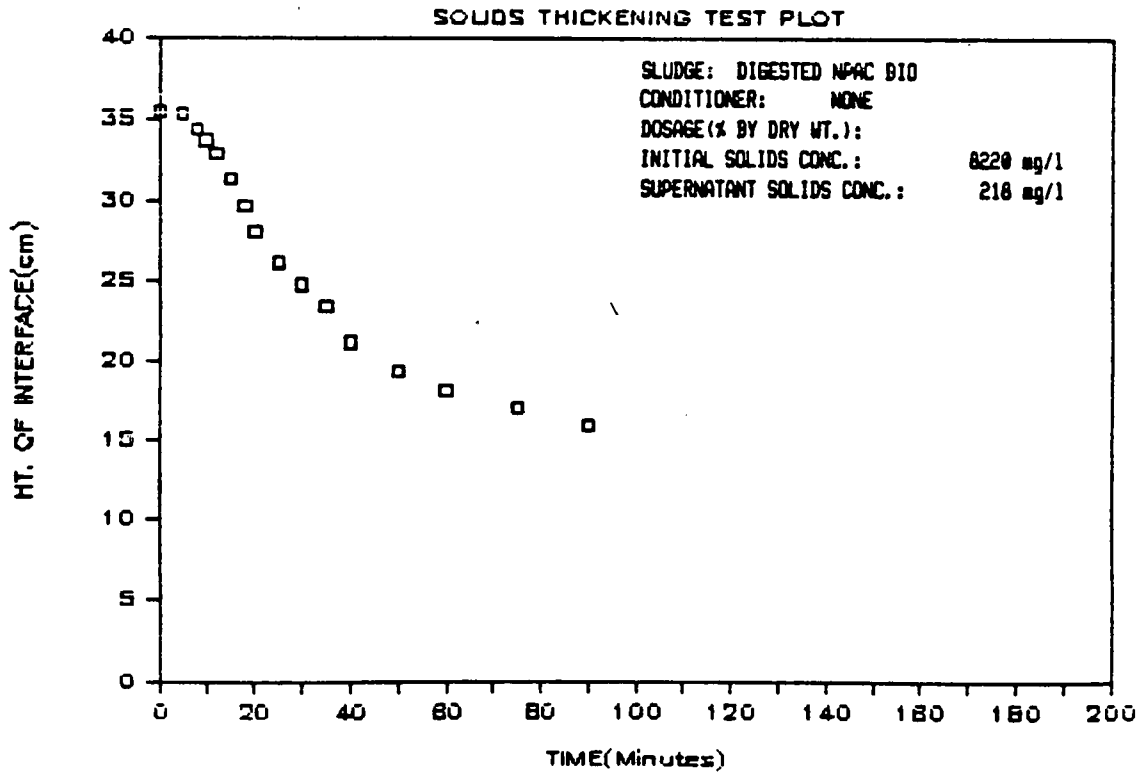


Figure A-46

SOLIDS THICKENING TEST PLOT

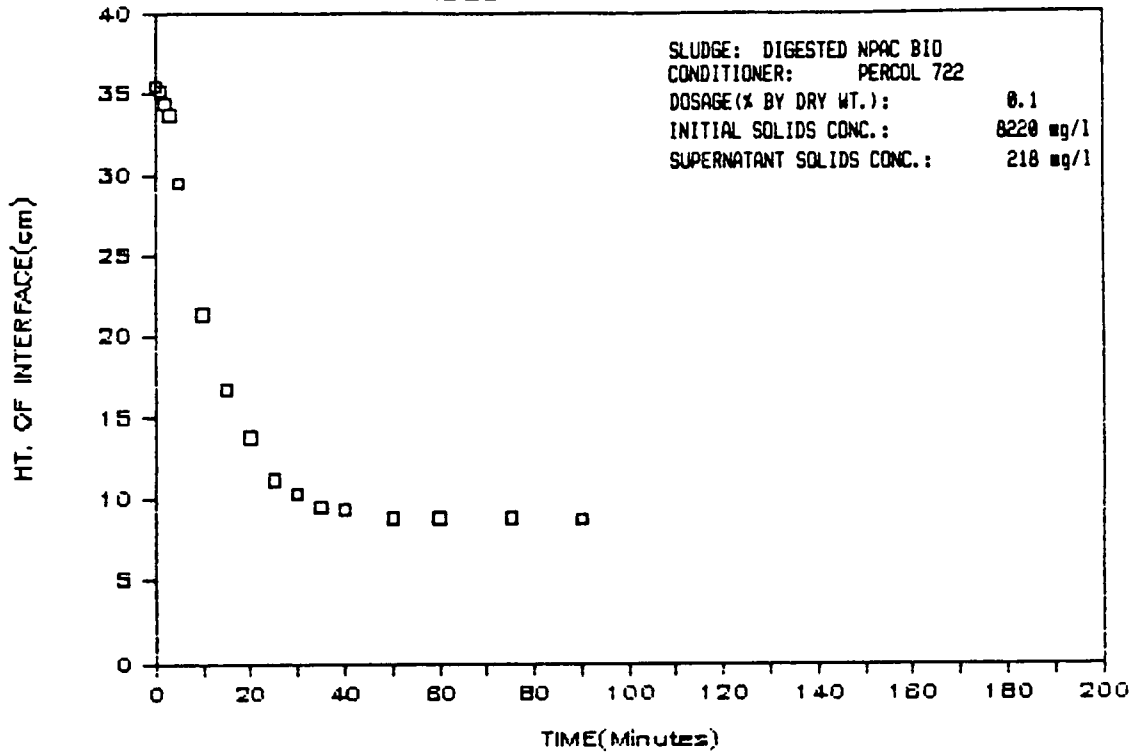


Figure A-47

SOLIDS THICKENING TEST PLOT

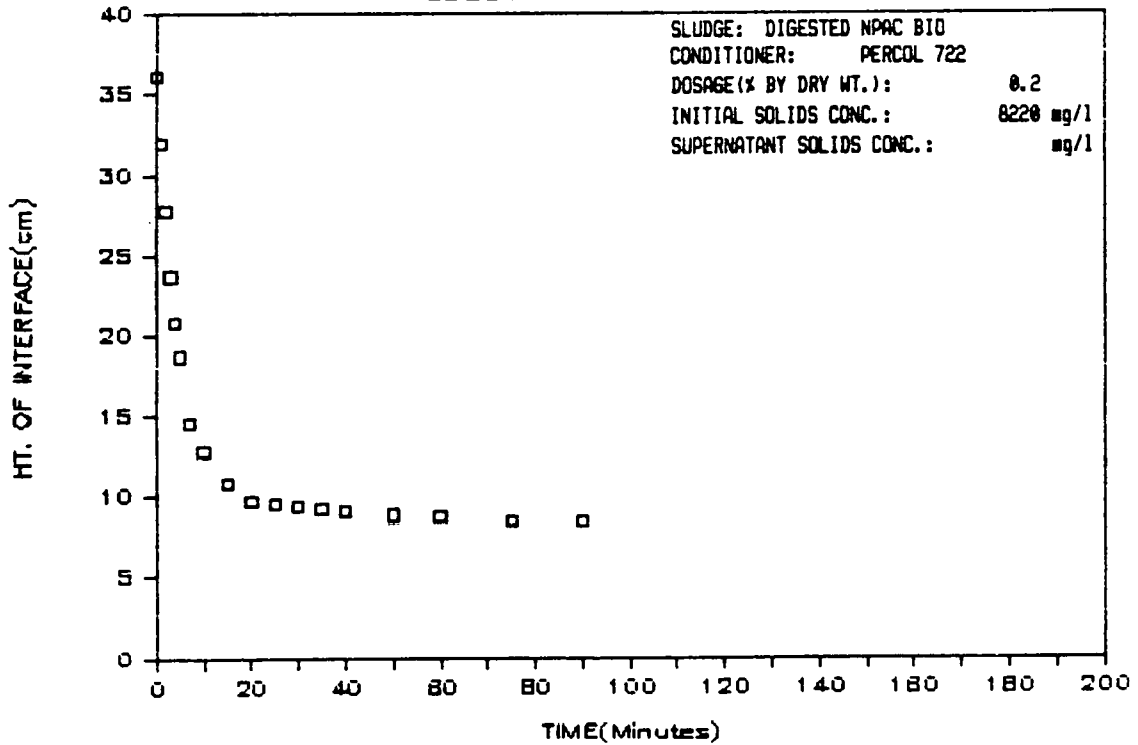


Figure A-48

SOLIDS THICKENING TEST PLOT

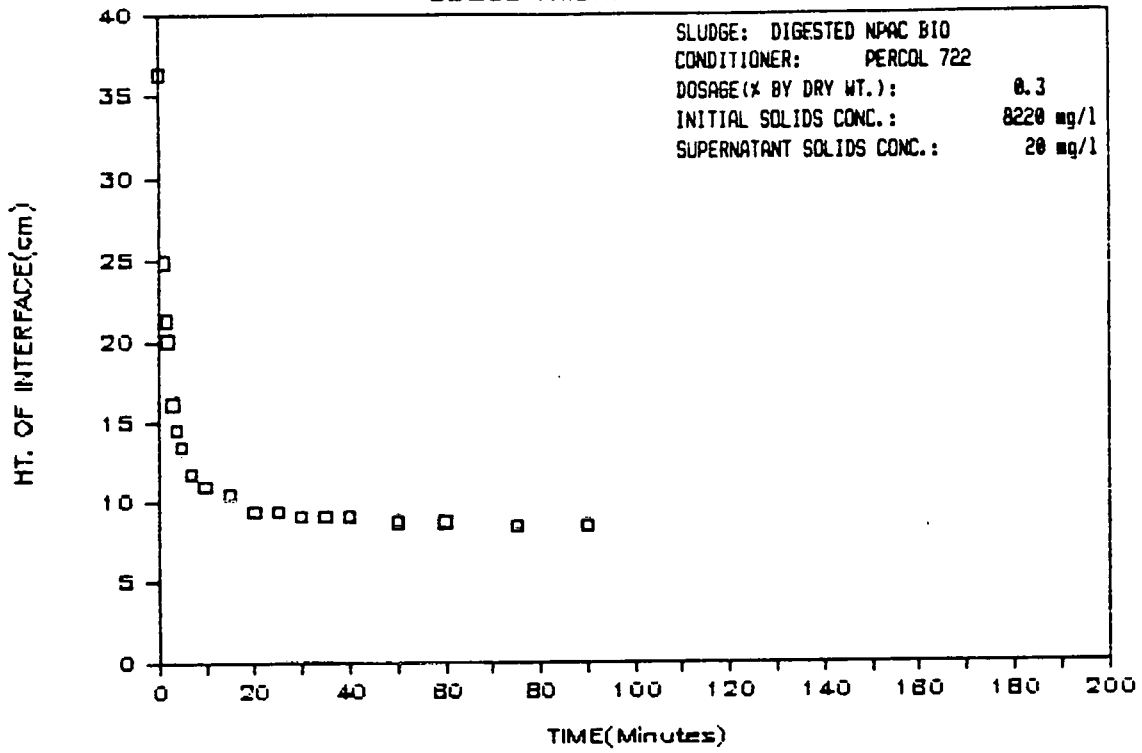


Figure A-49

SOLIDS THICKENING TEST PLOT

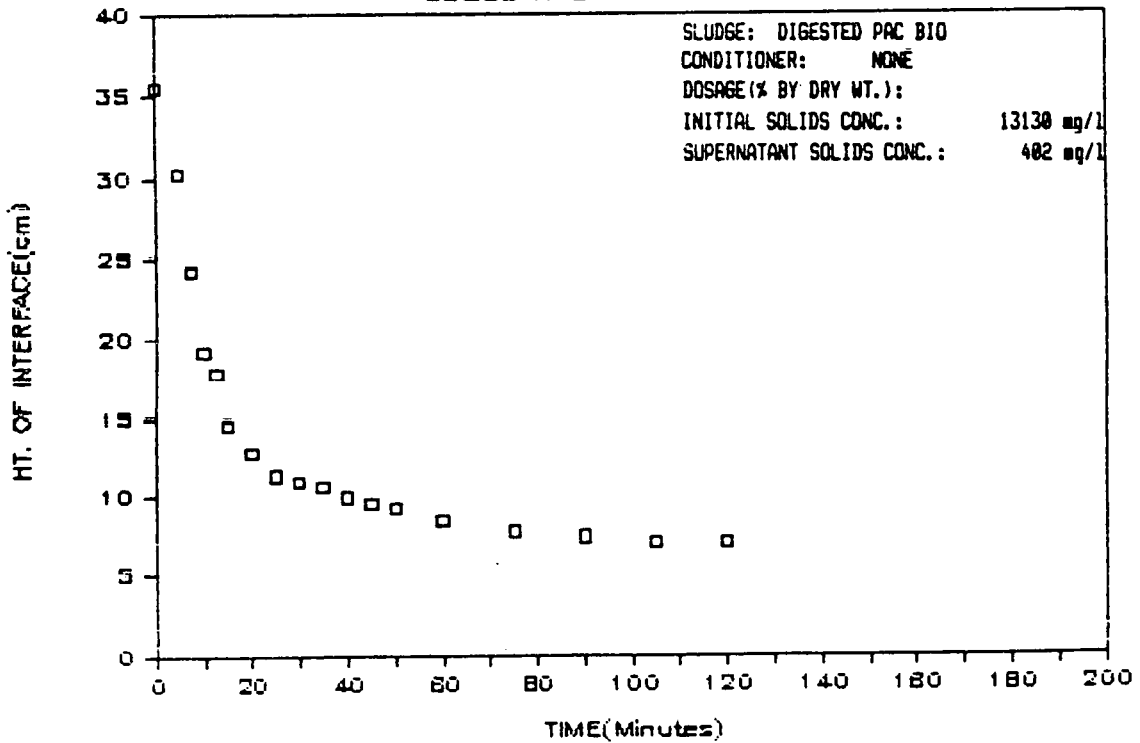


Figure A-50

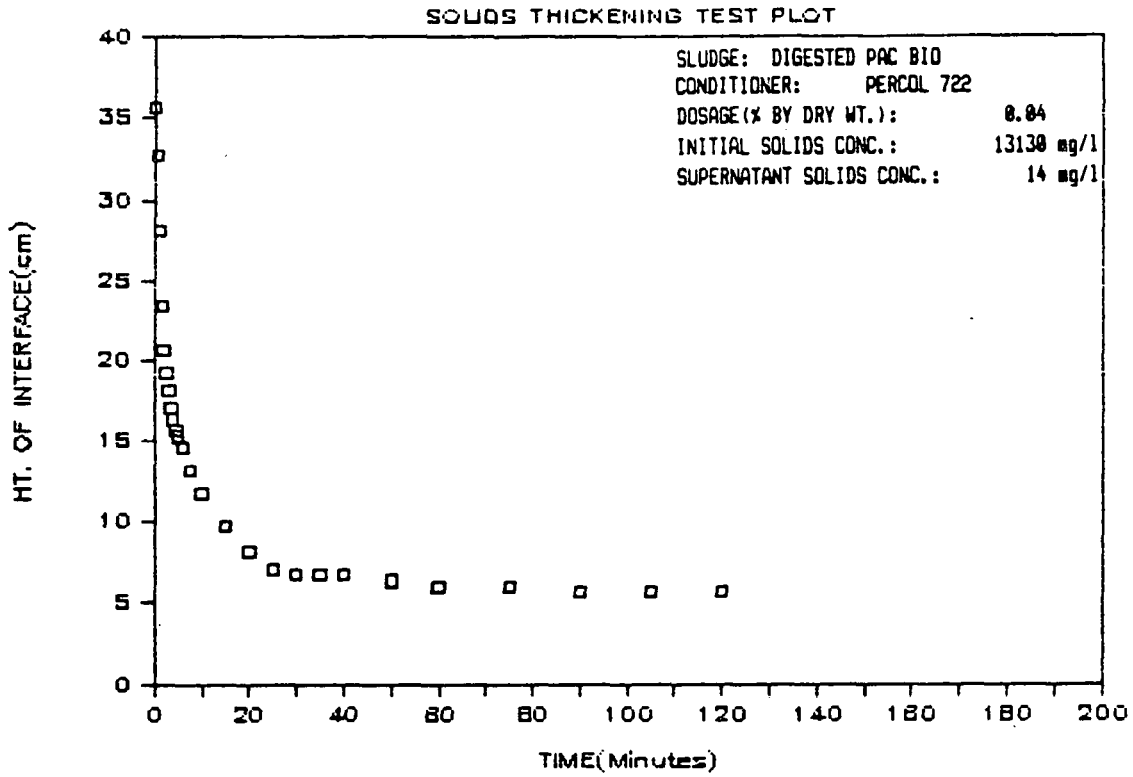


Figure A-51

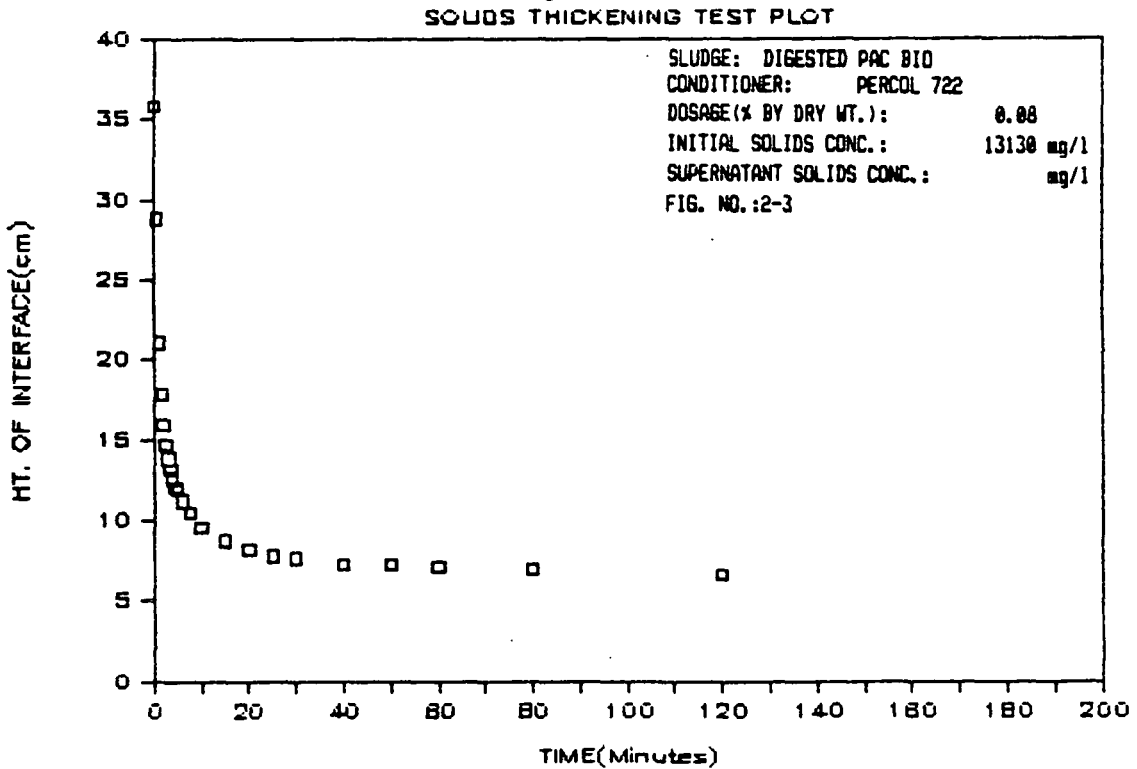


Figure A-52

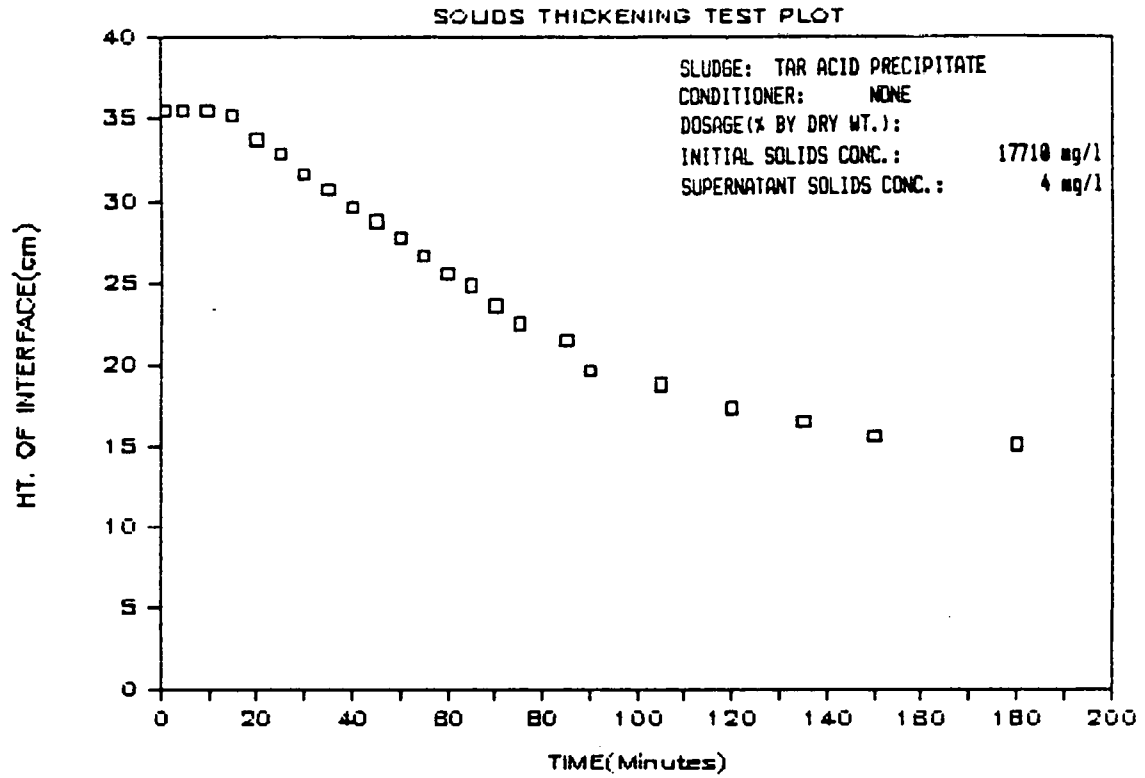


Figure A-53

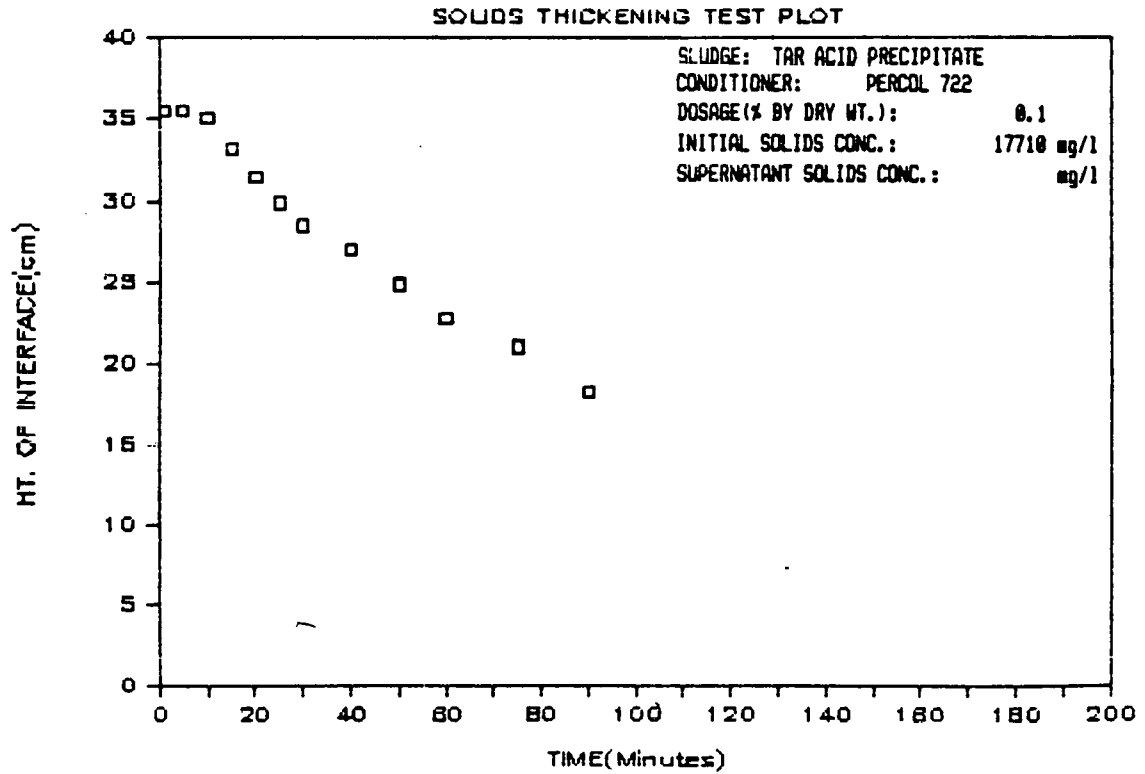


Figure A-54

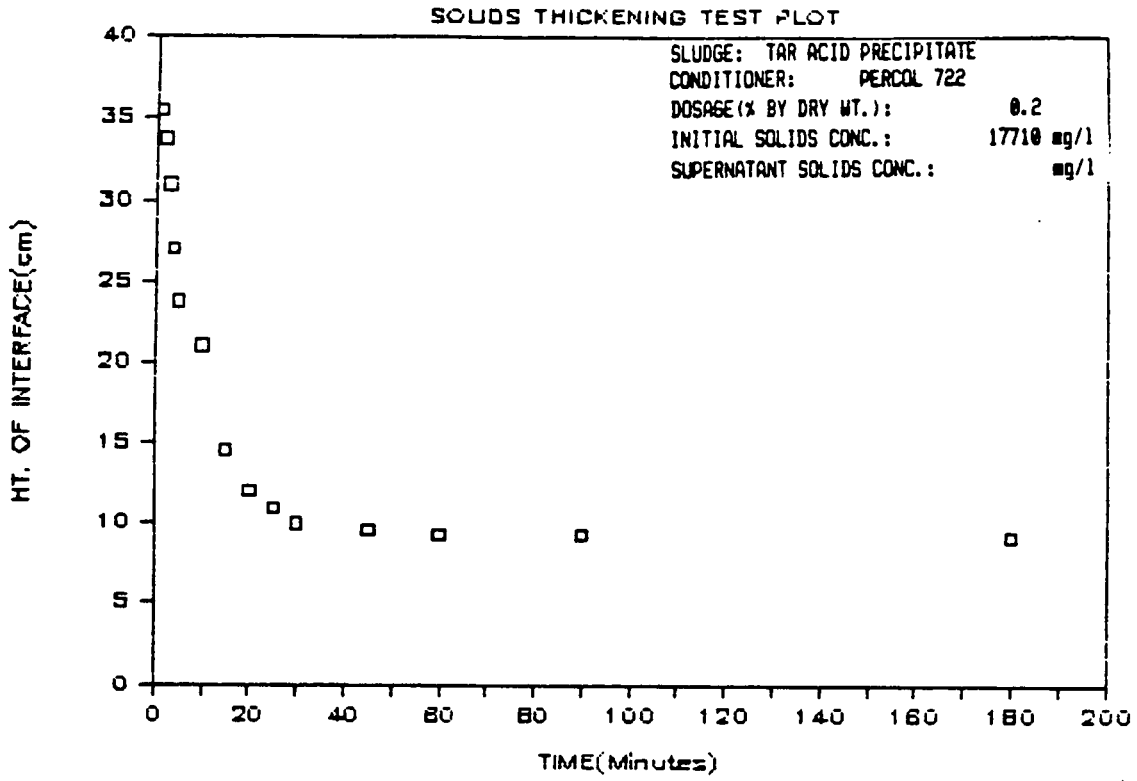


Figure A-55

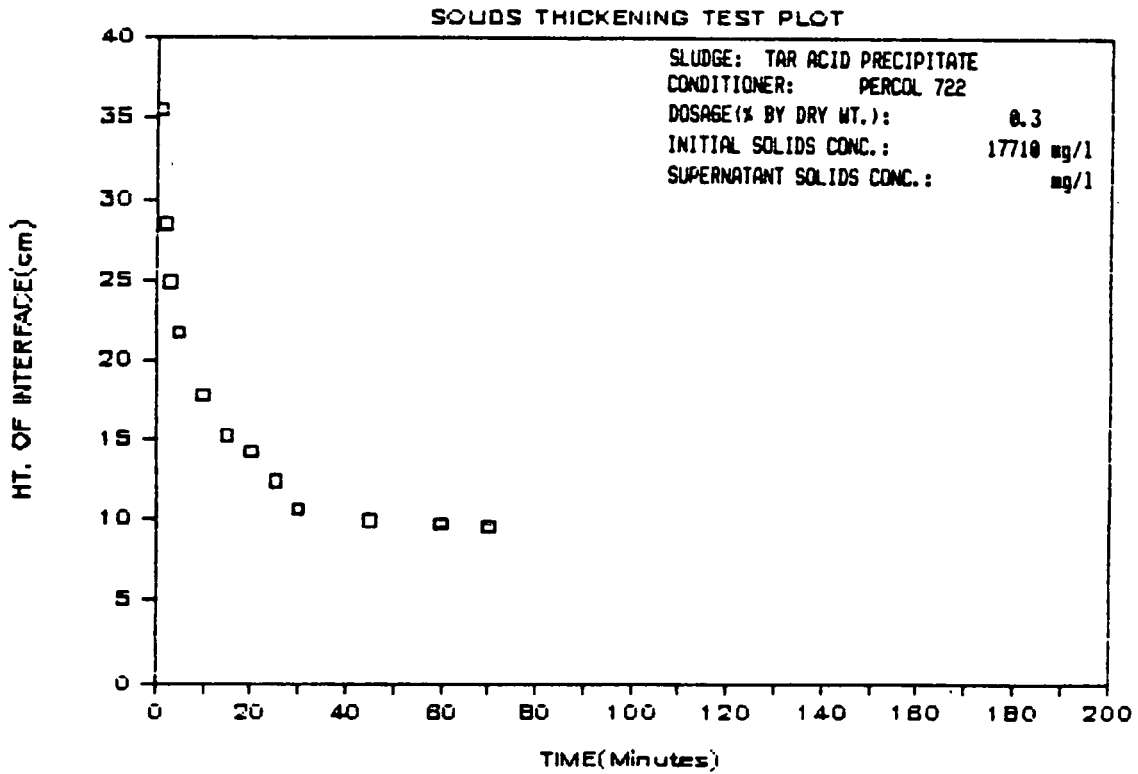


Figure A-56

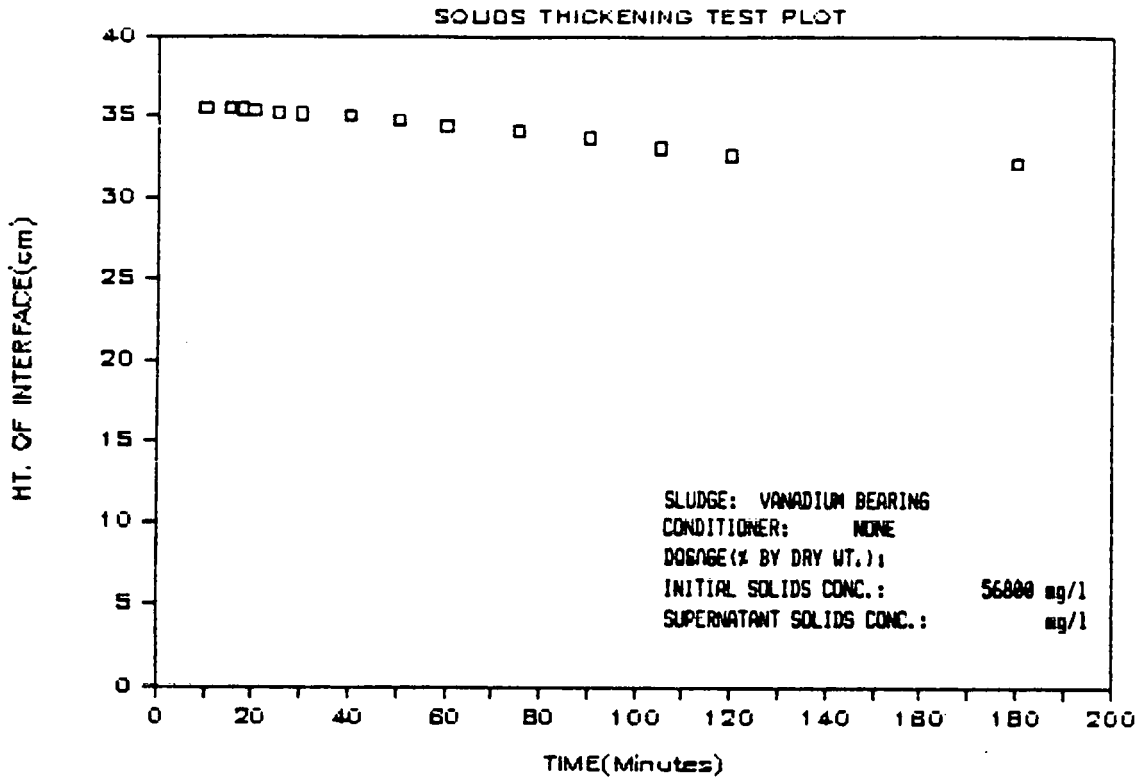


Figure A-57

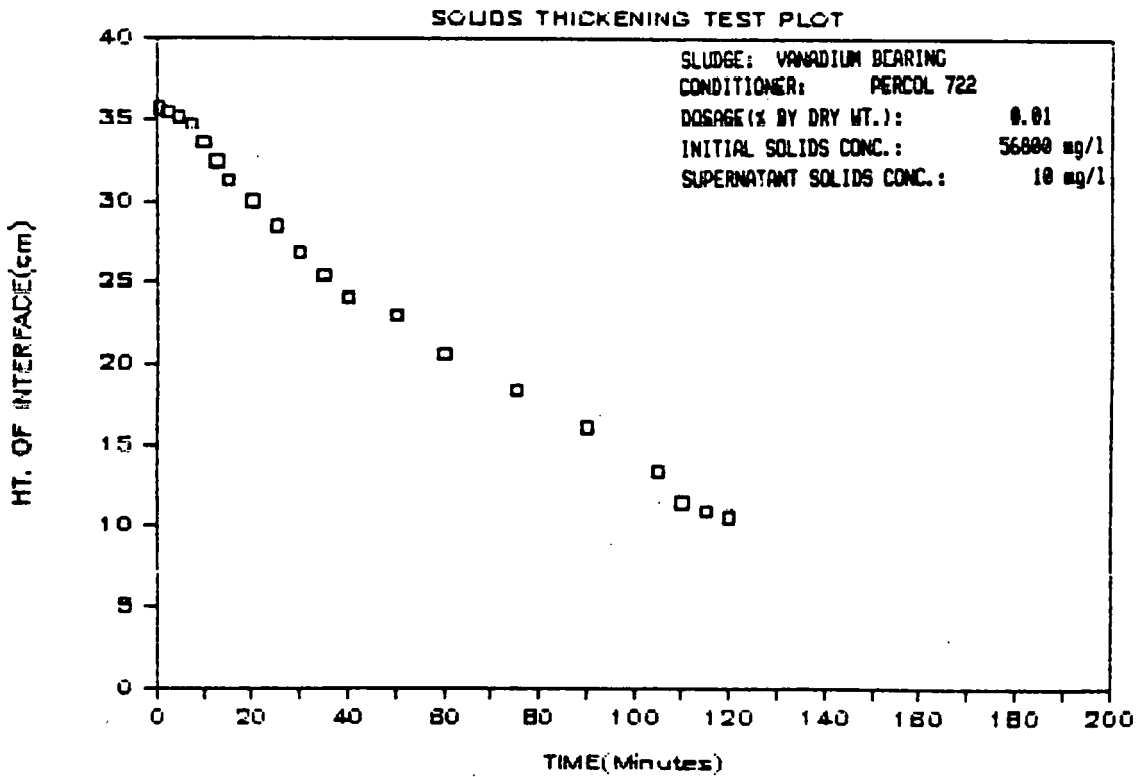


Figure A-58

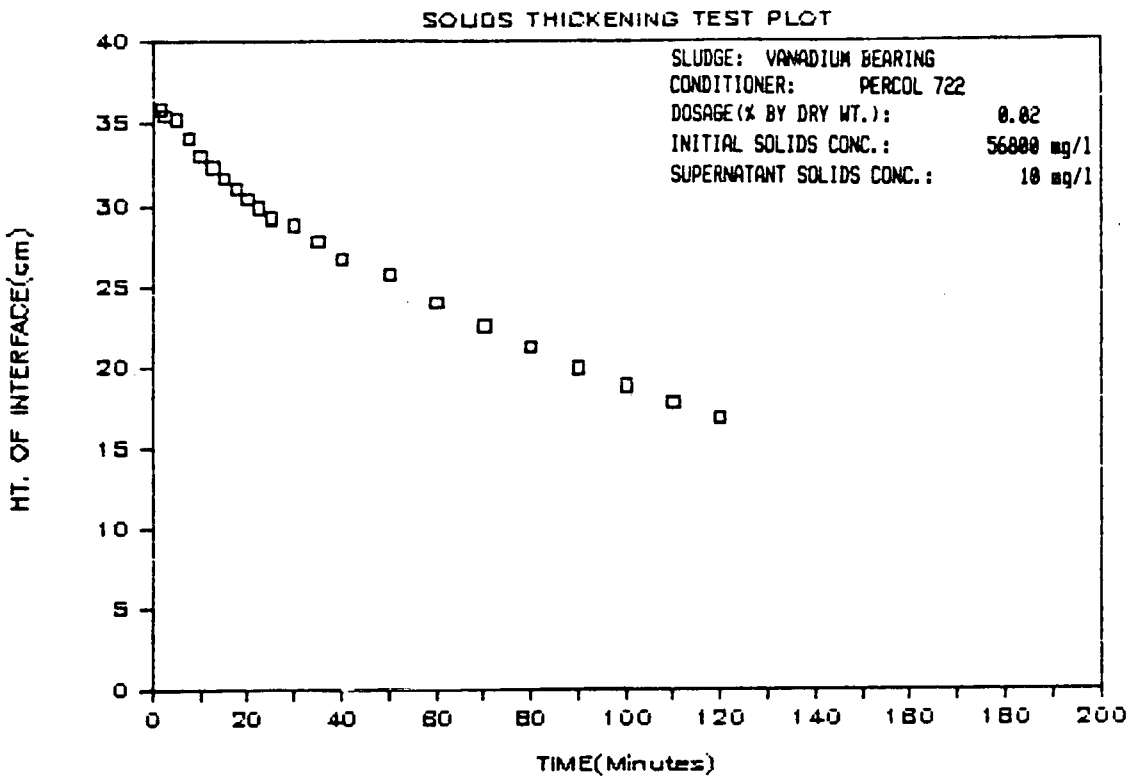


Figure A-59

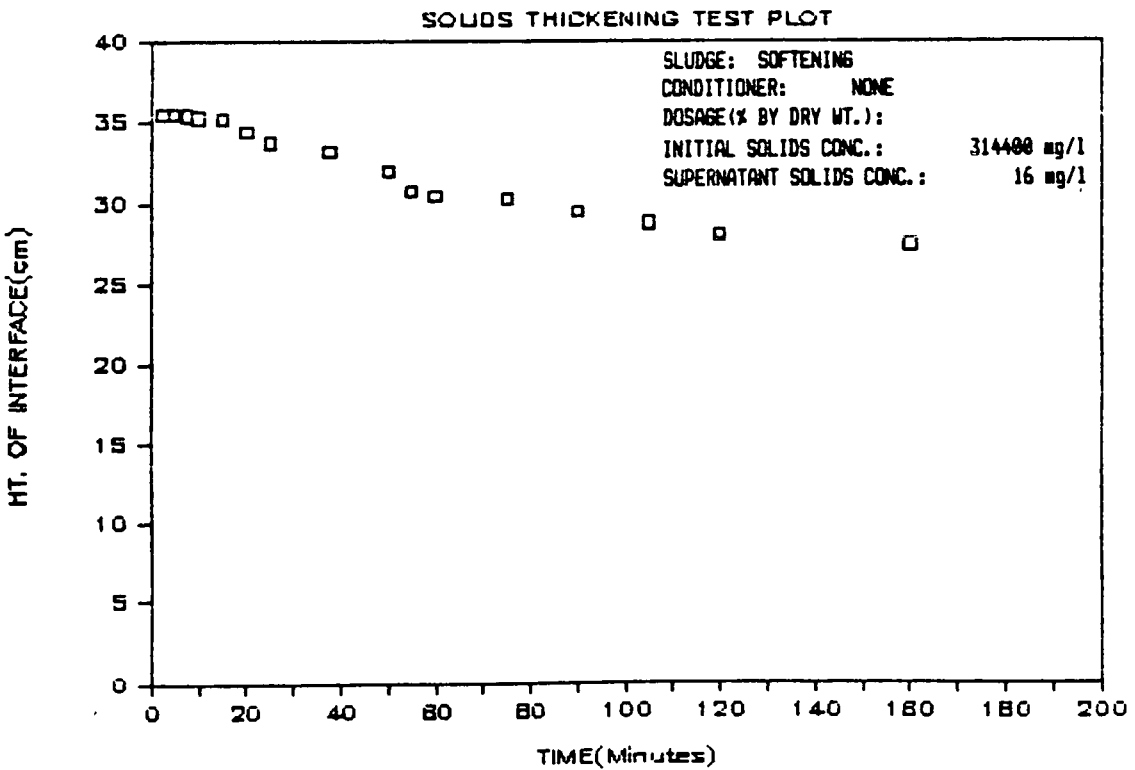


Figure A-60

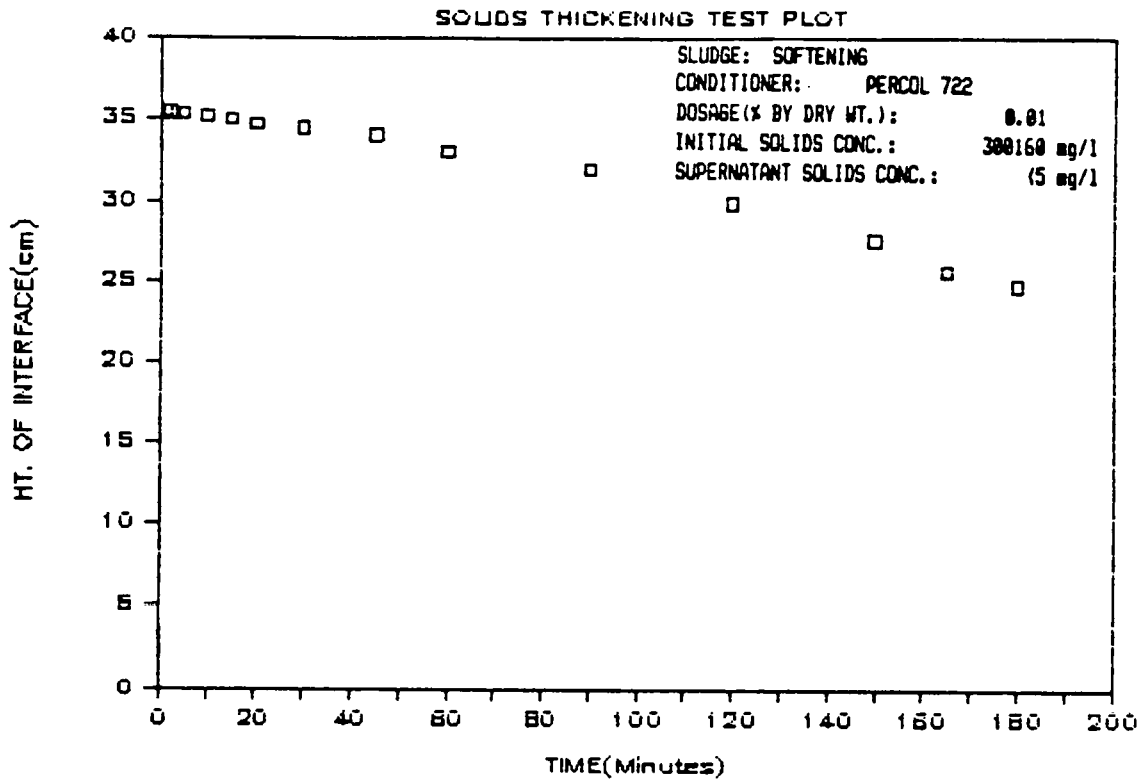


Figure A-61

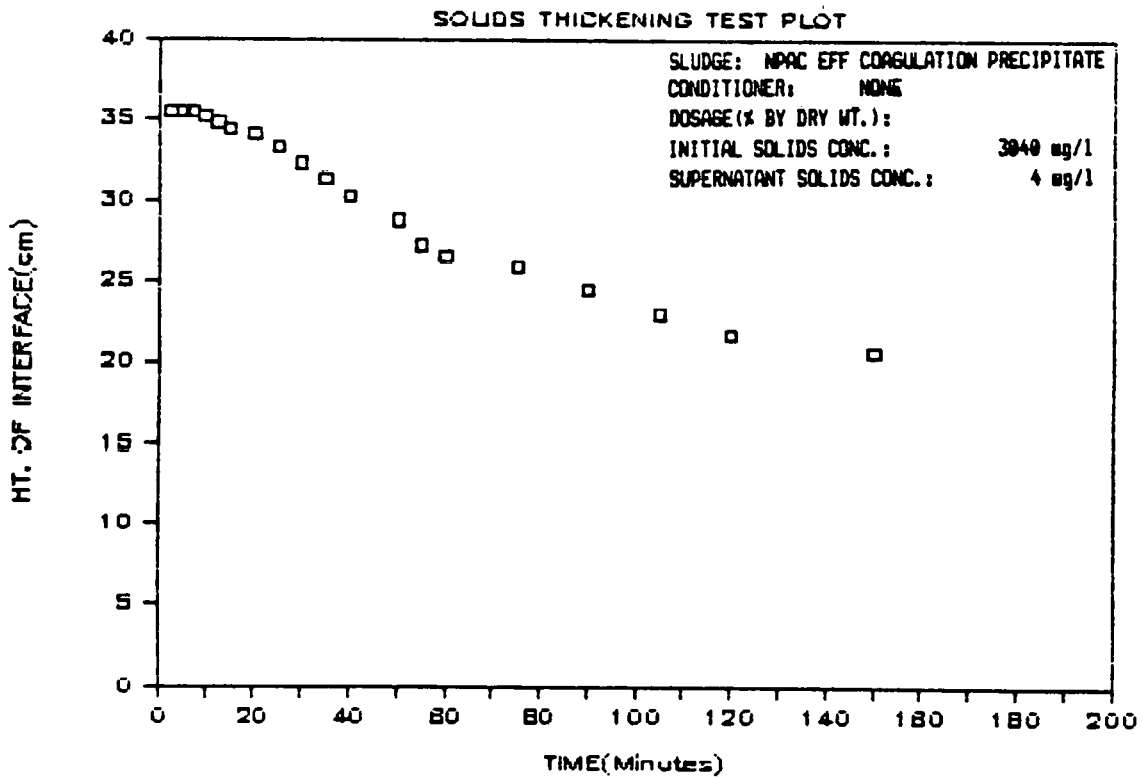


Figure A-62

SOLIDS THICKENING TEST PLOT

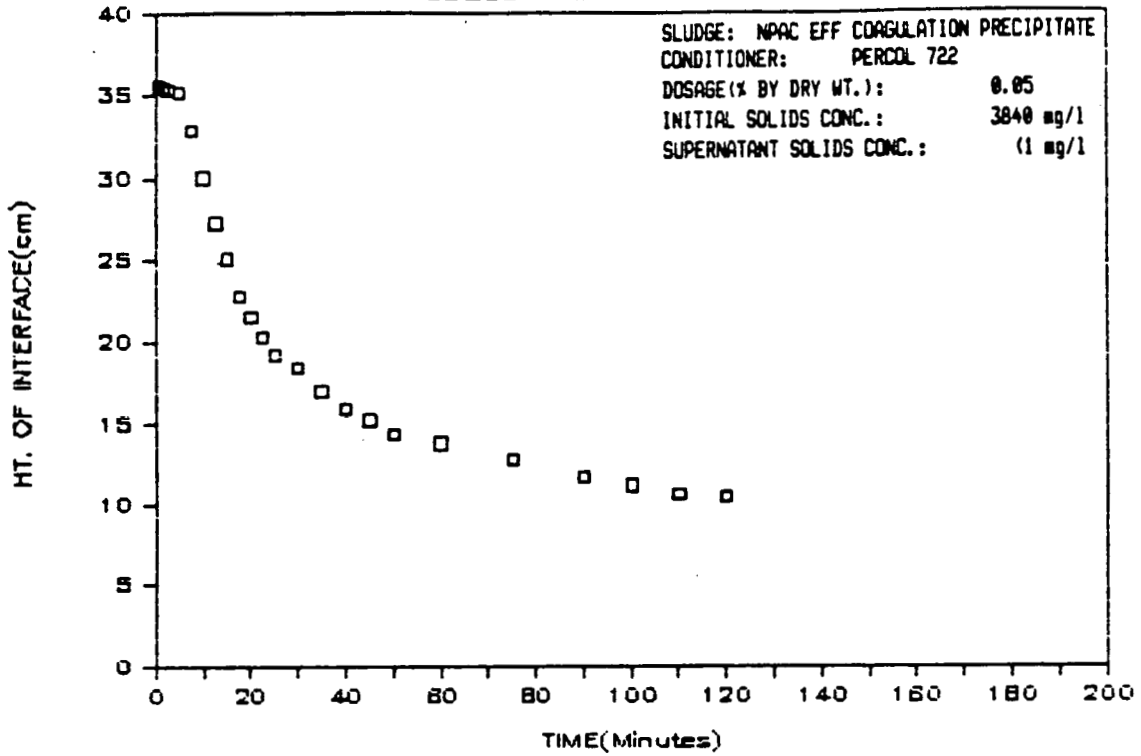


Figure A-63

SOLIDS THICKENING TEST PLOT

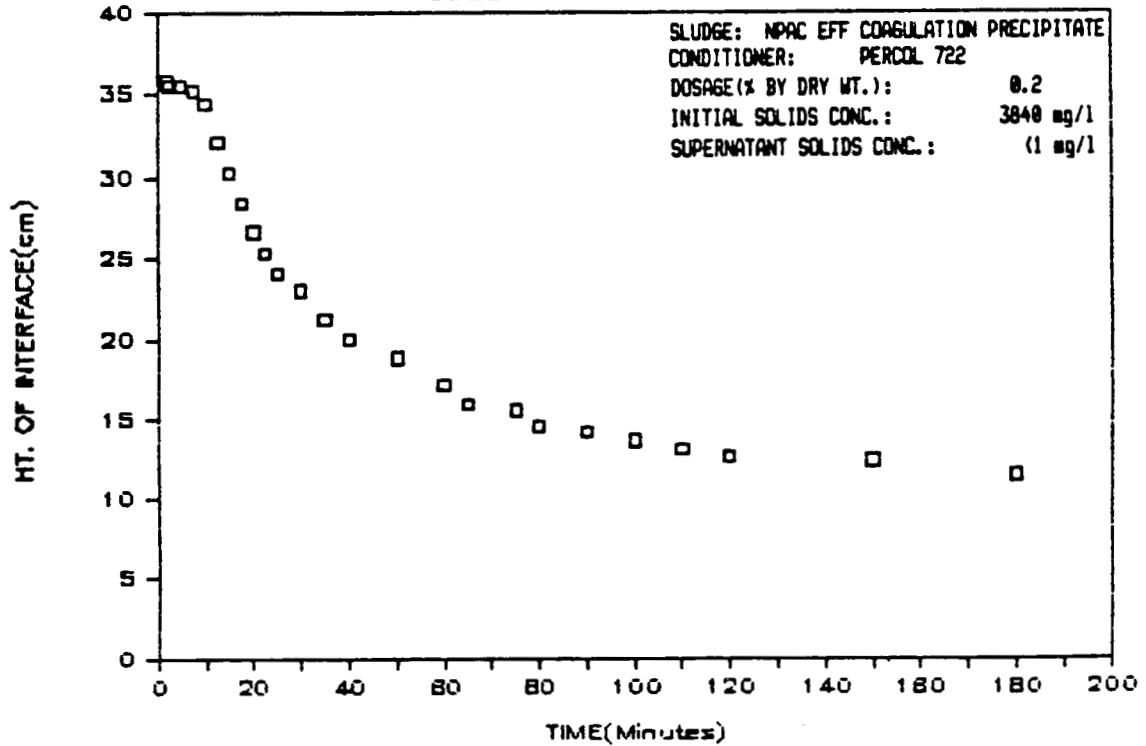


Figure A-64

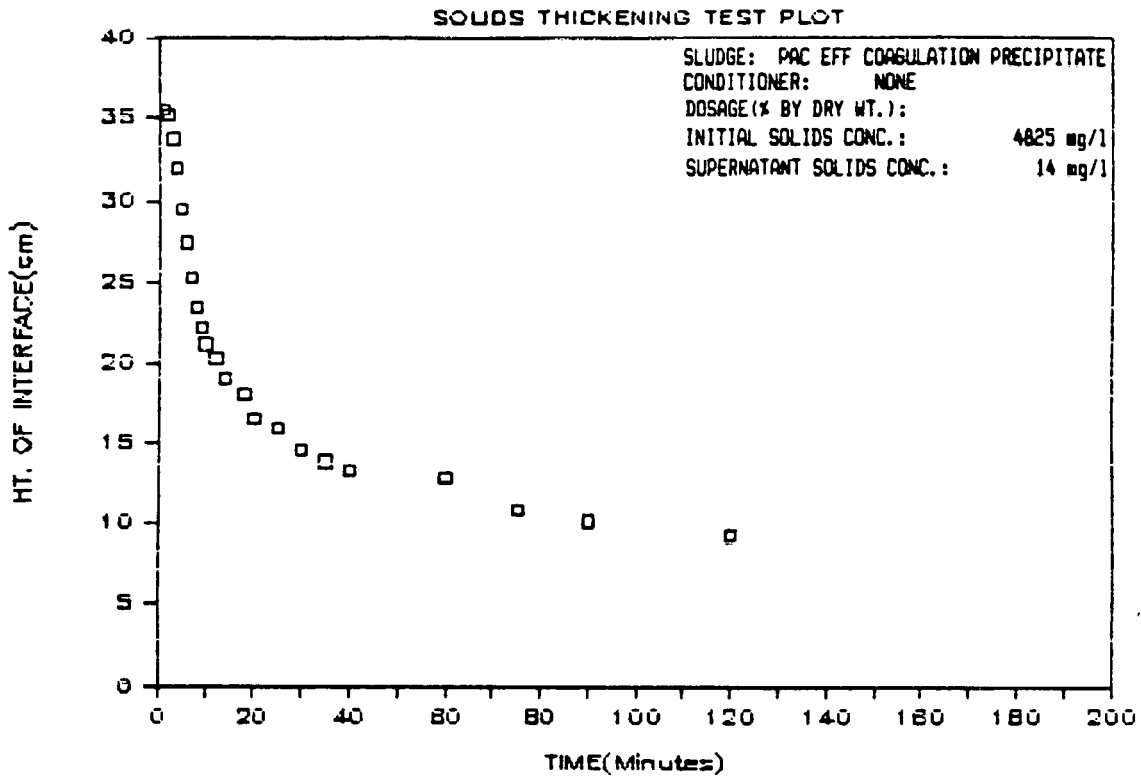


Figure A-65

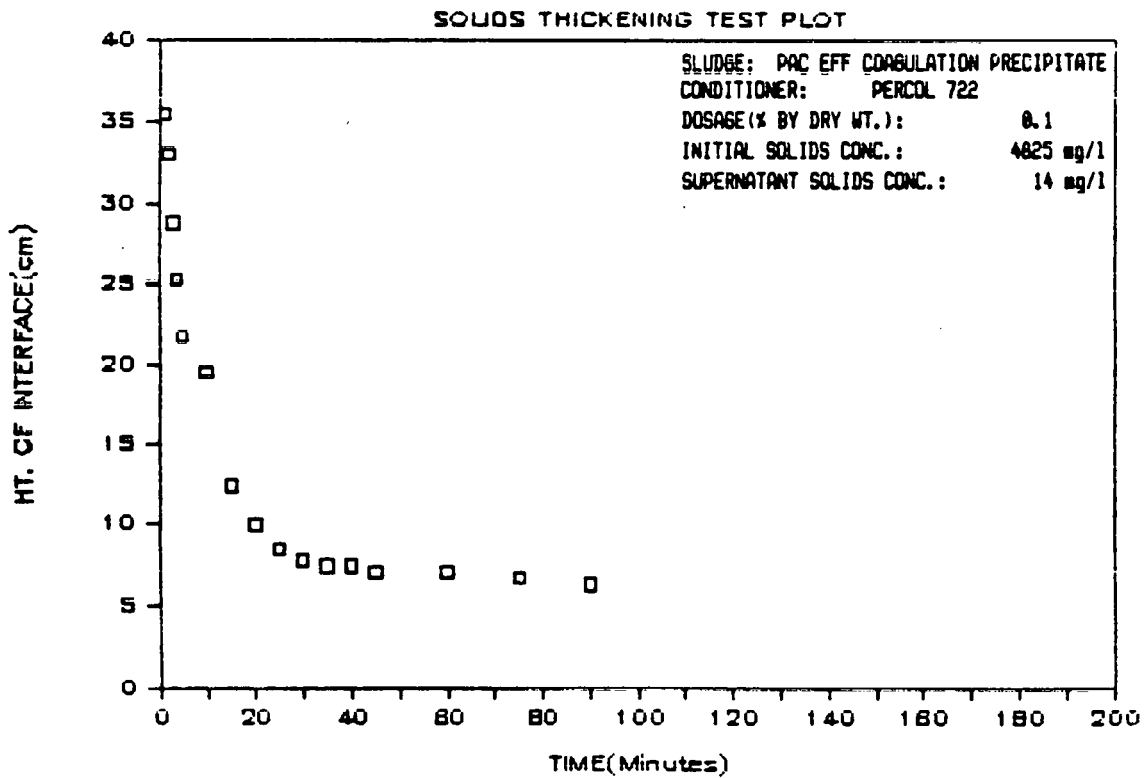


Figure A-66

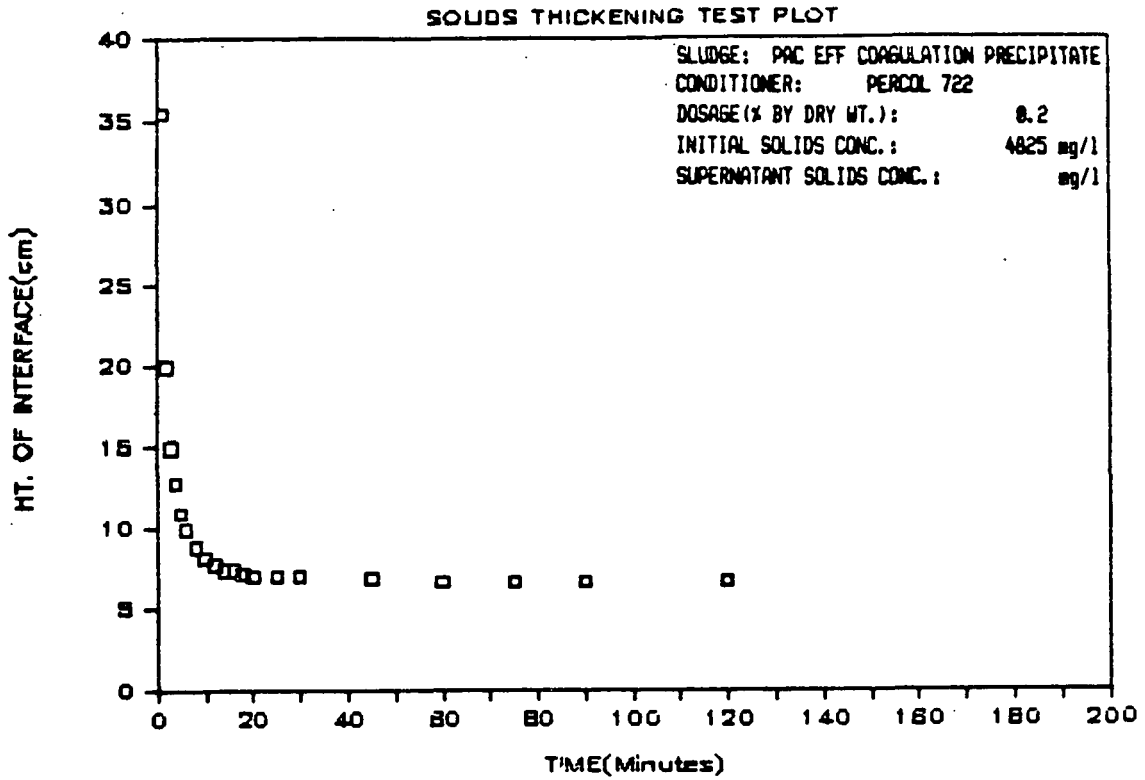


Figure A-67

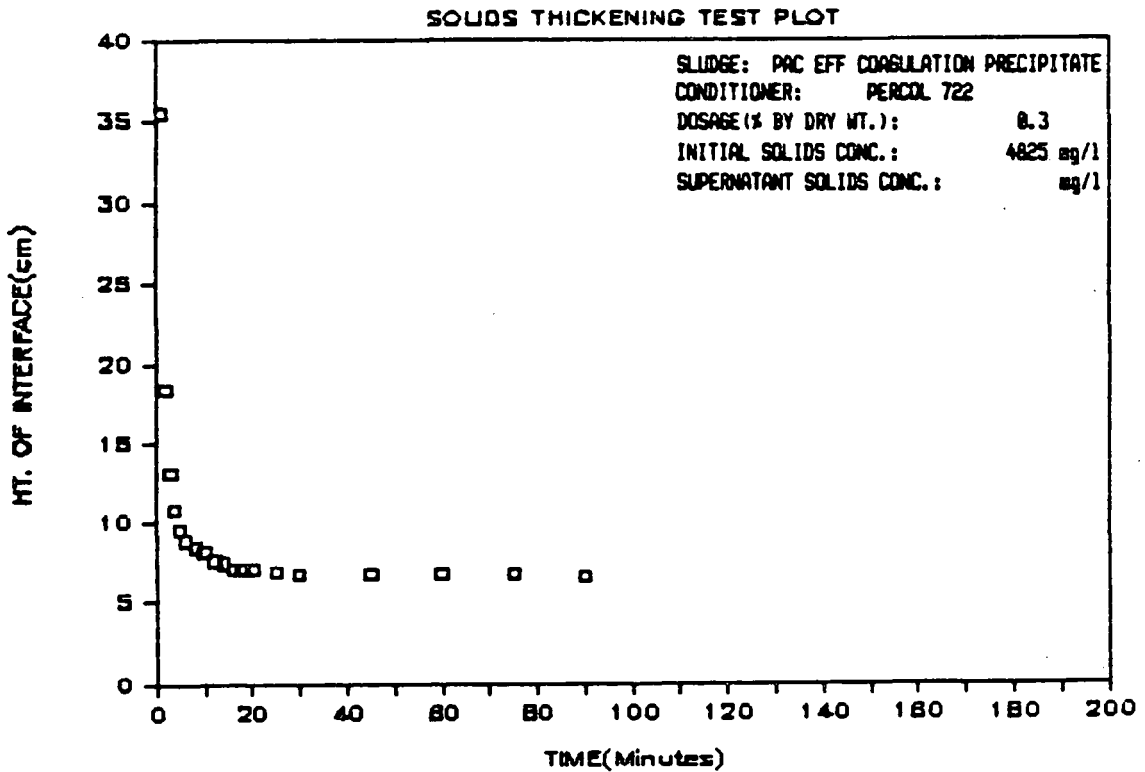


Figure A-68

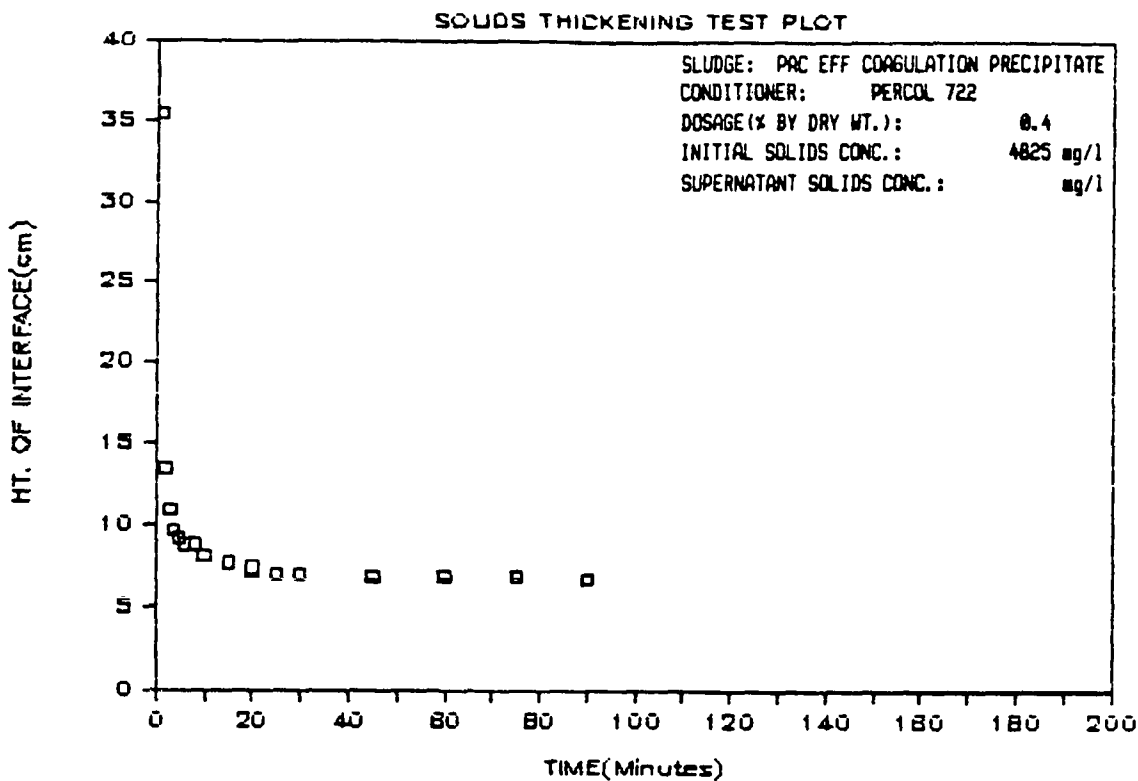


Figure A-69

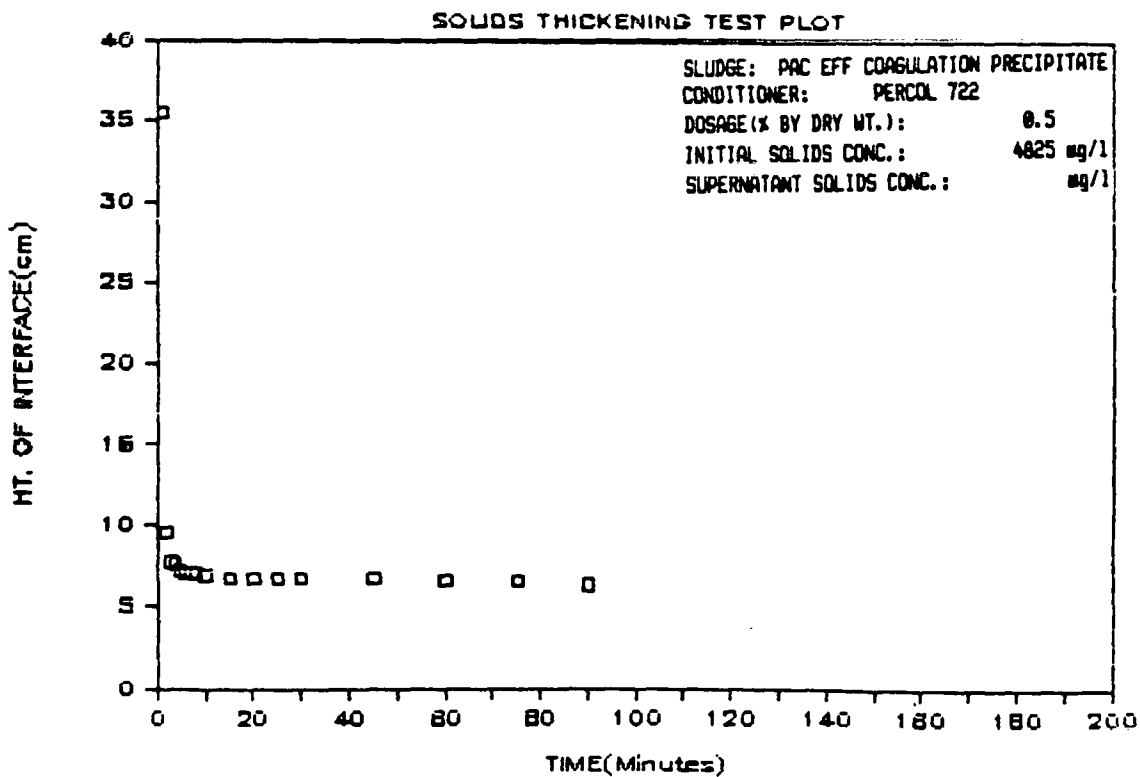


Figure A-70

SOLIDS THICKENING TEST PLOT

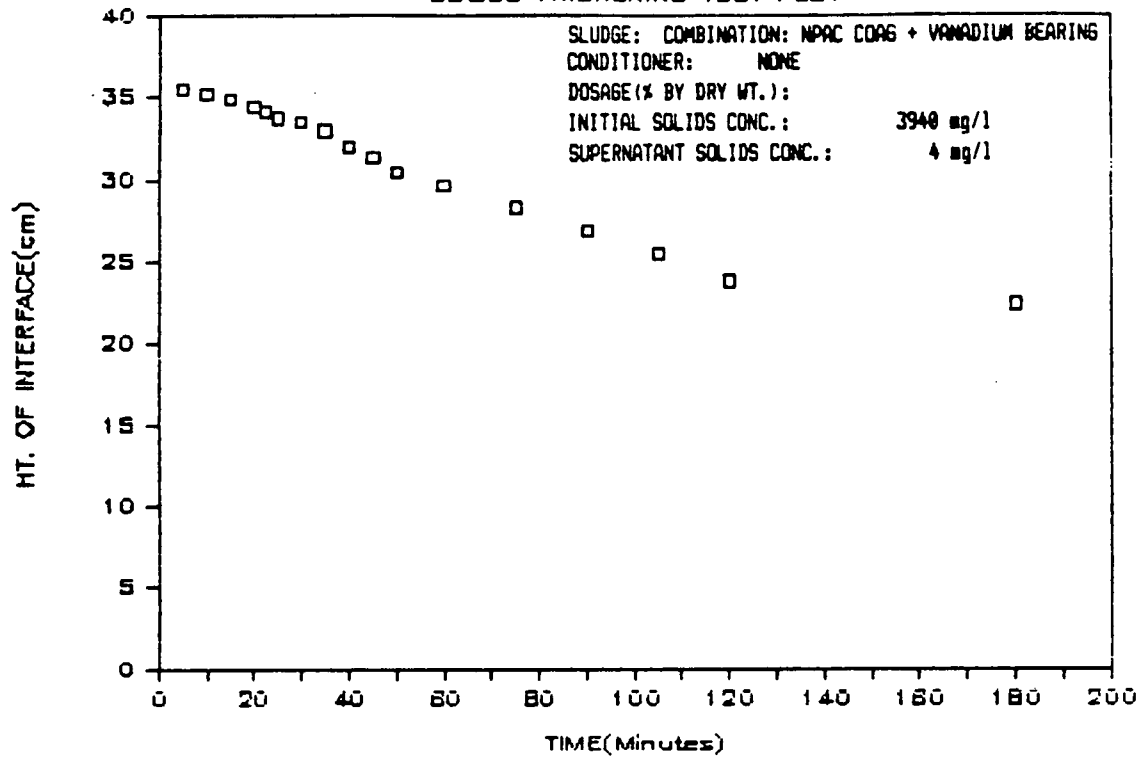


Figure A-71

SOLIDS THICKENING TEST PLOT

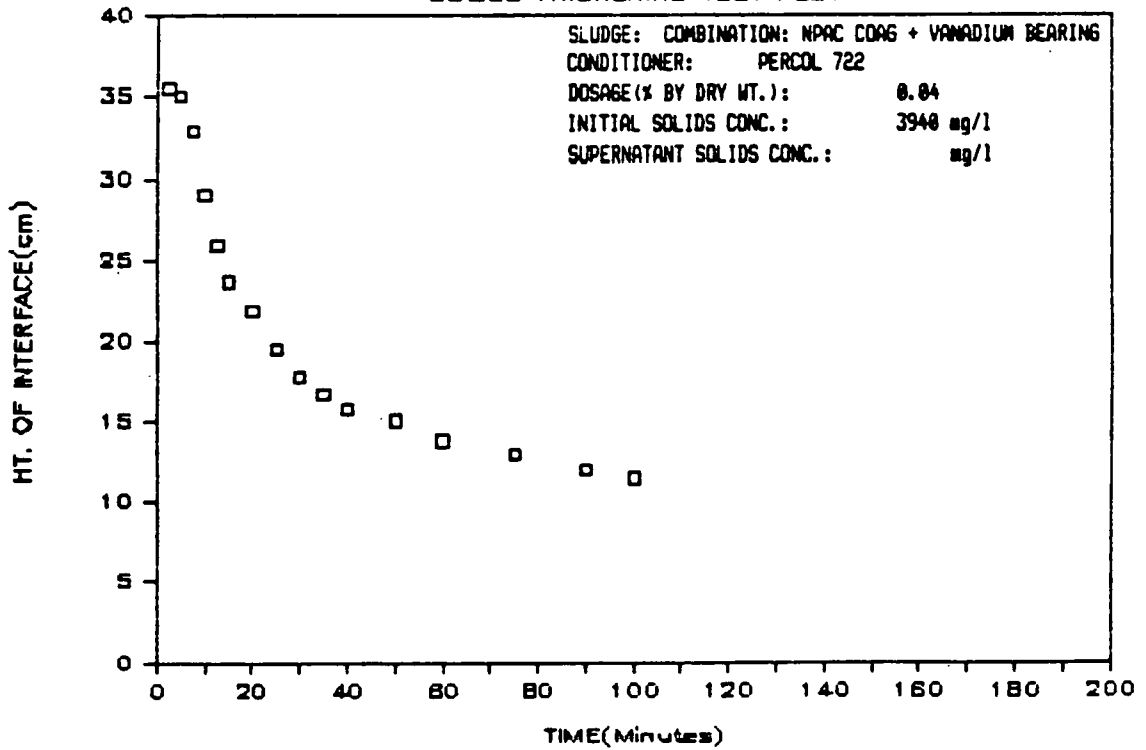


Figure A-72

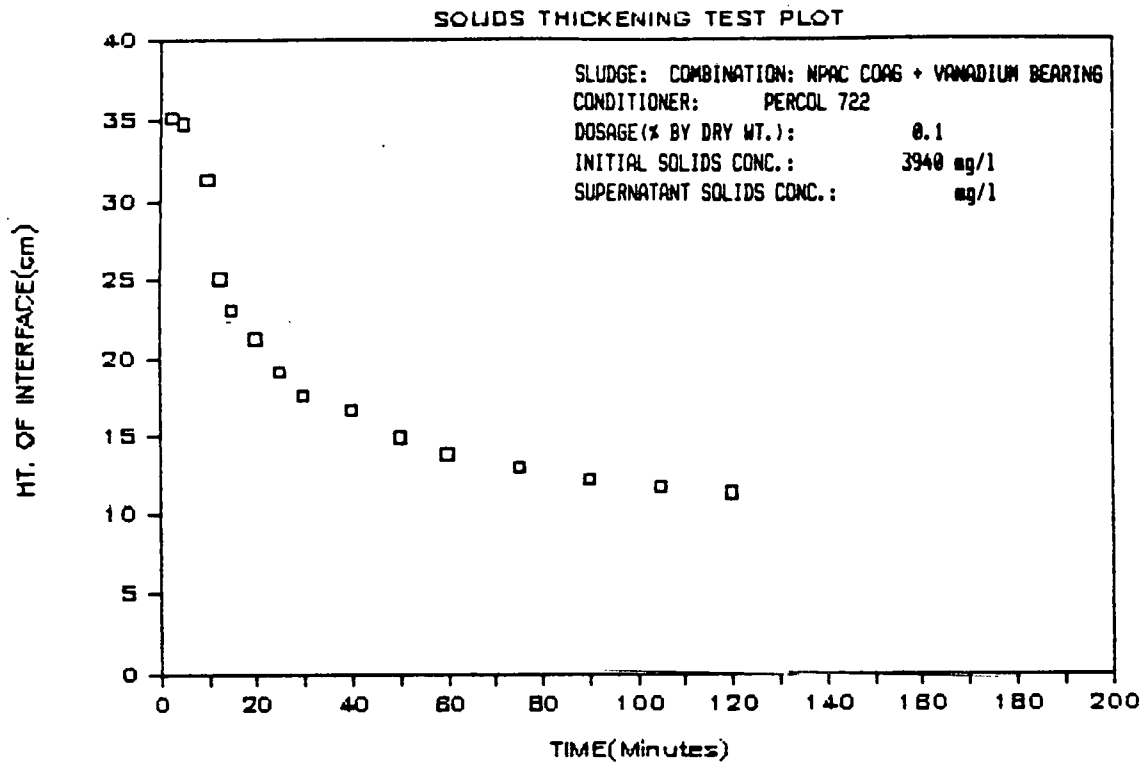


Figure A-73

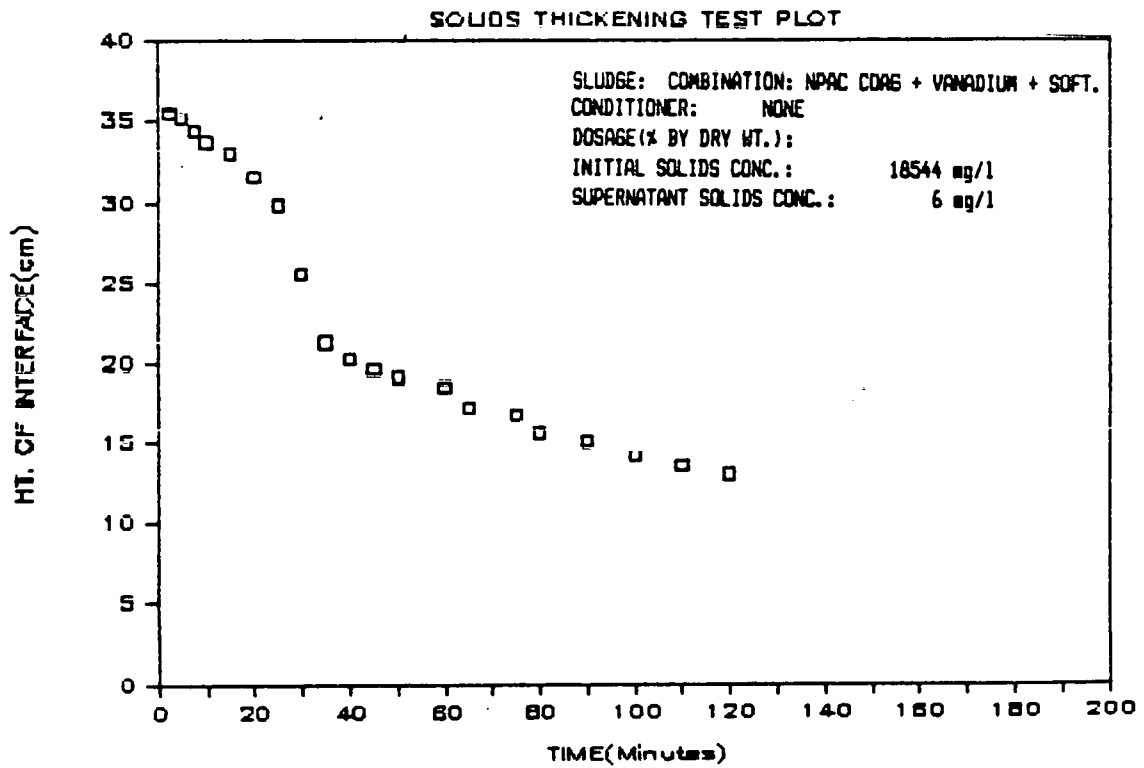


Figure A-74

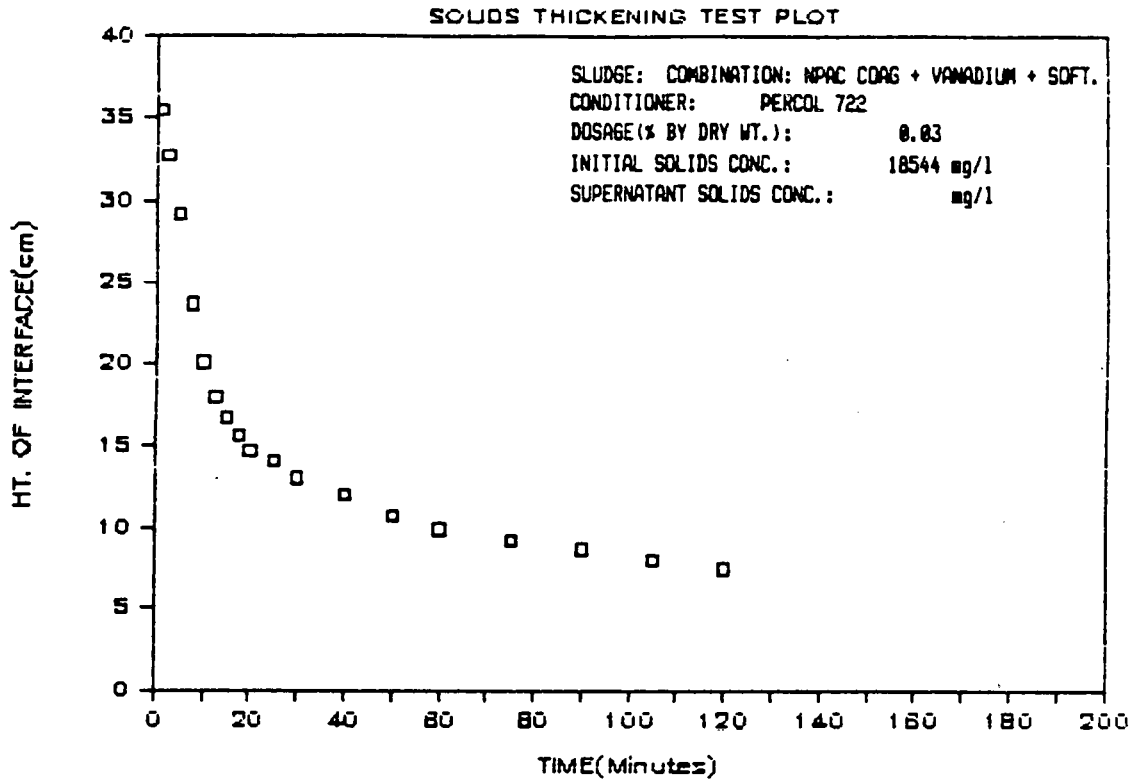


Figure A-75

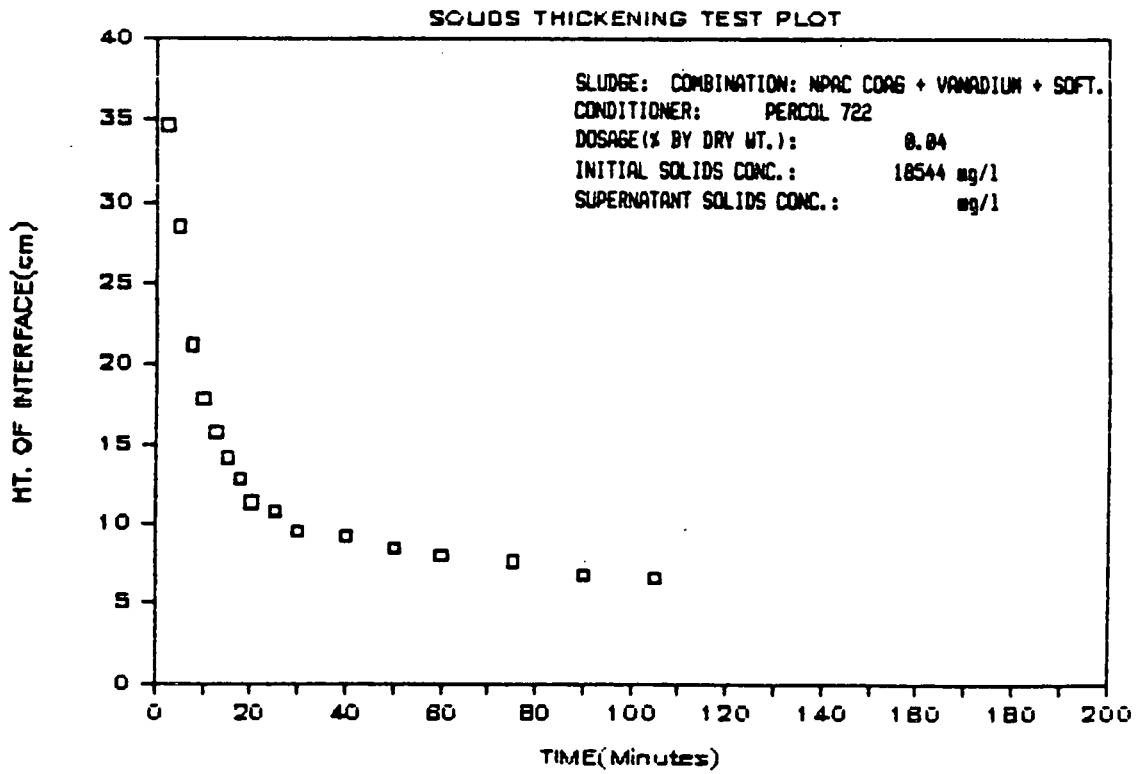


Figure A-76

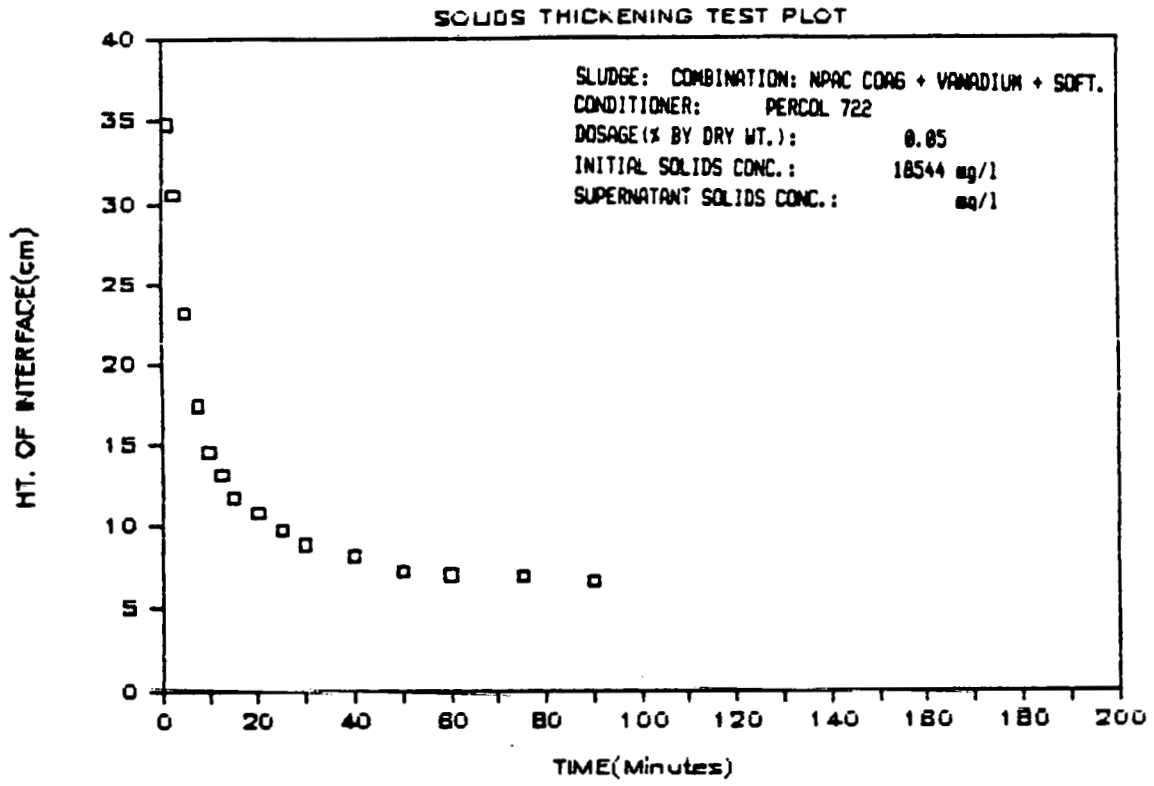


Figure A-77

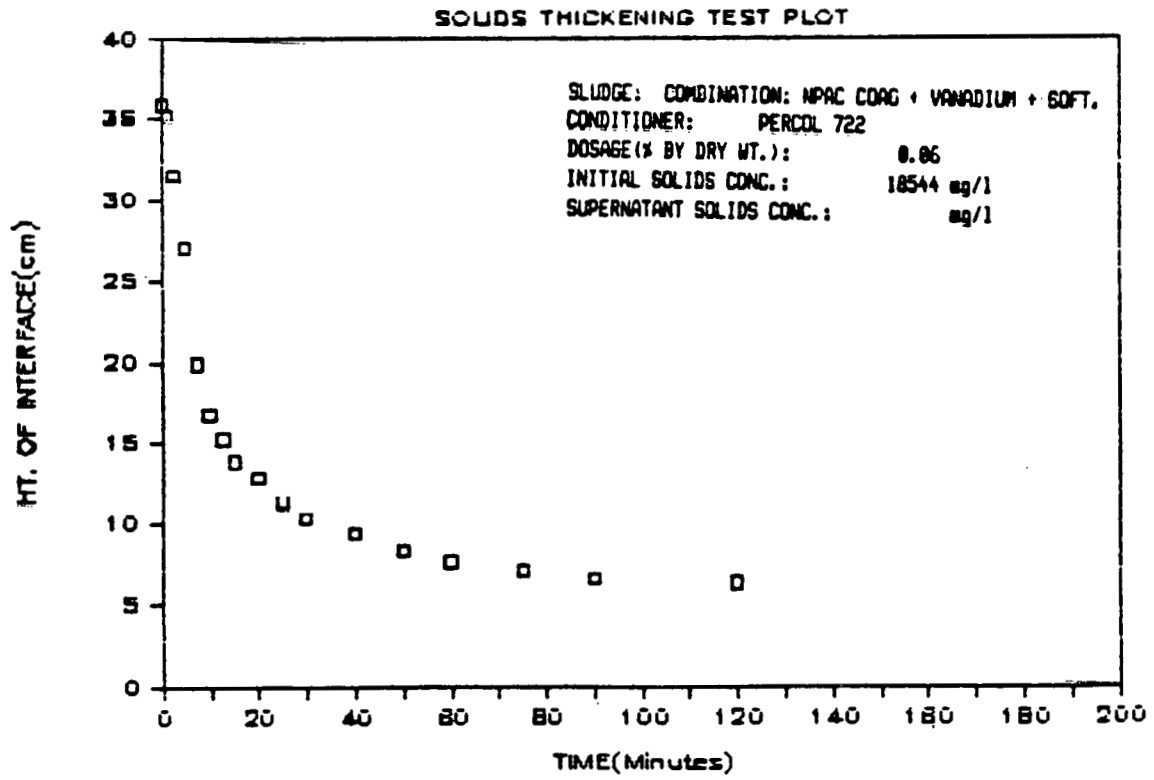


Figure A-78

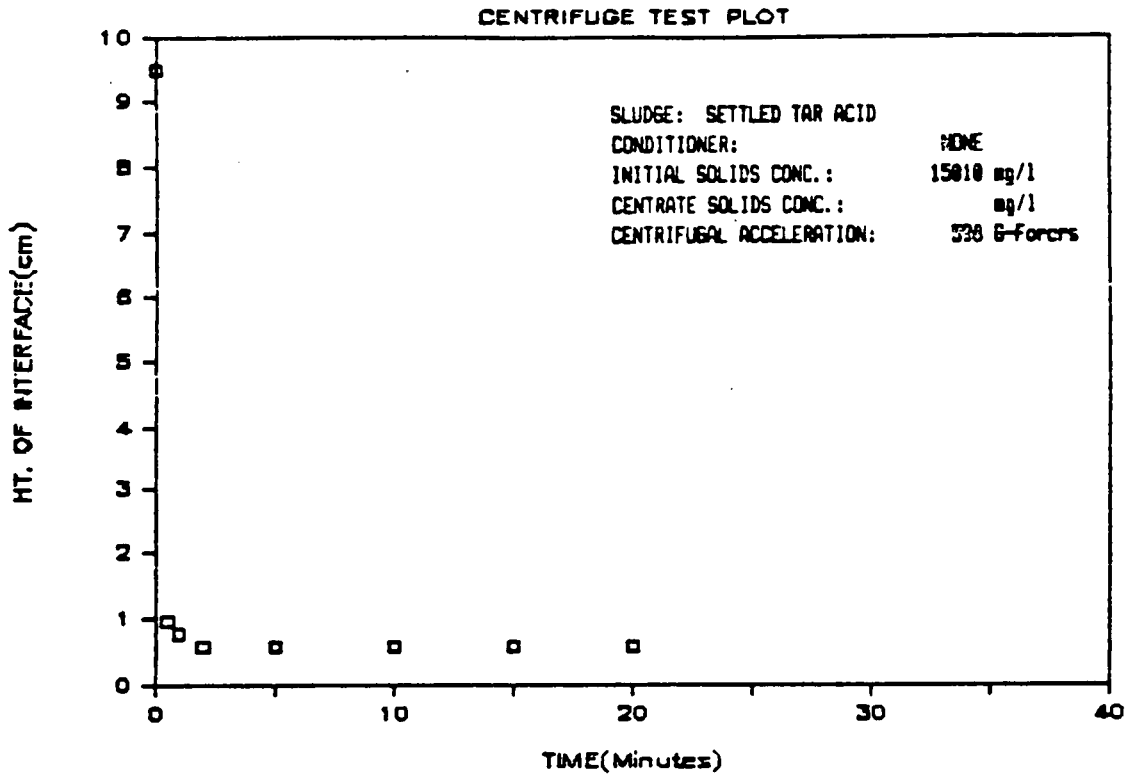


Figure A-79

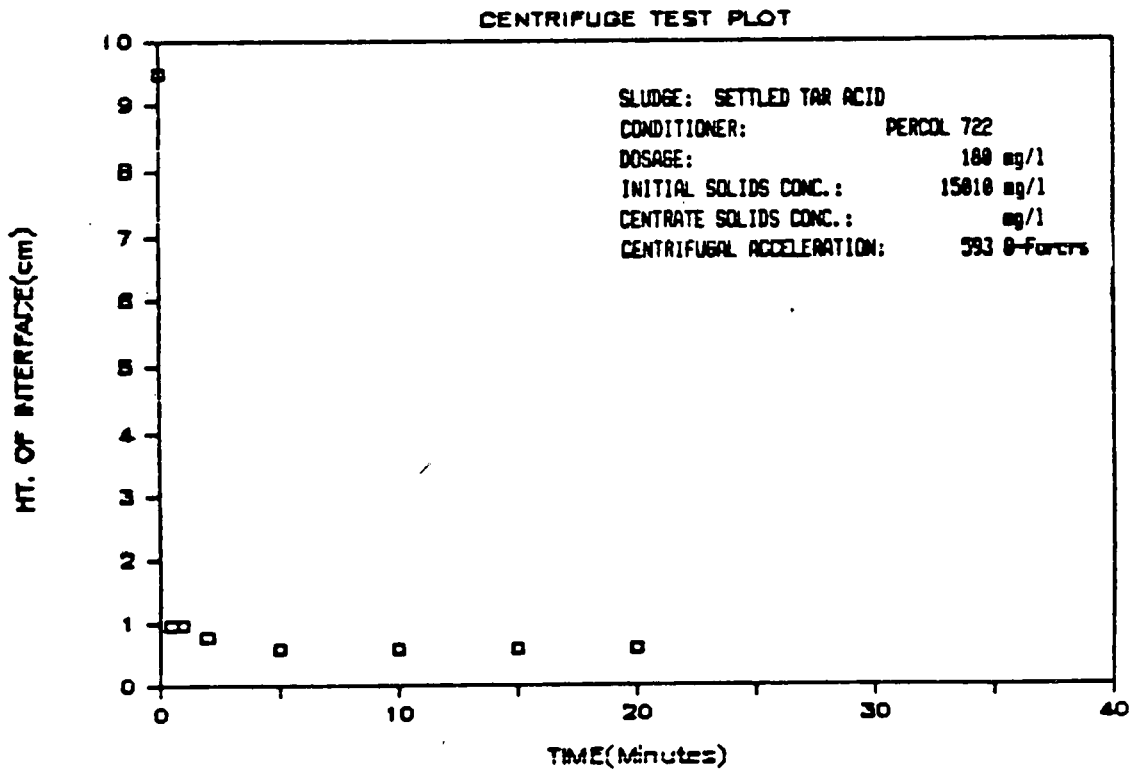


Figure A-80

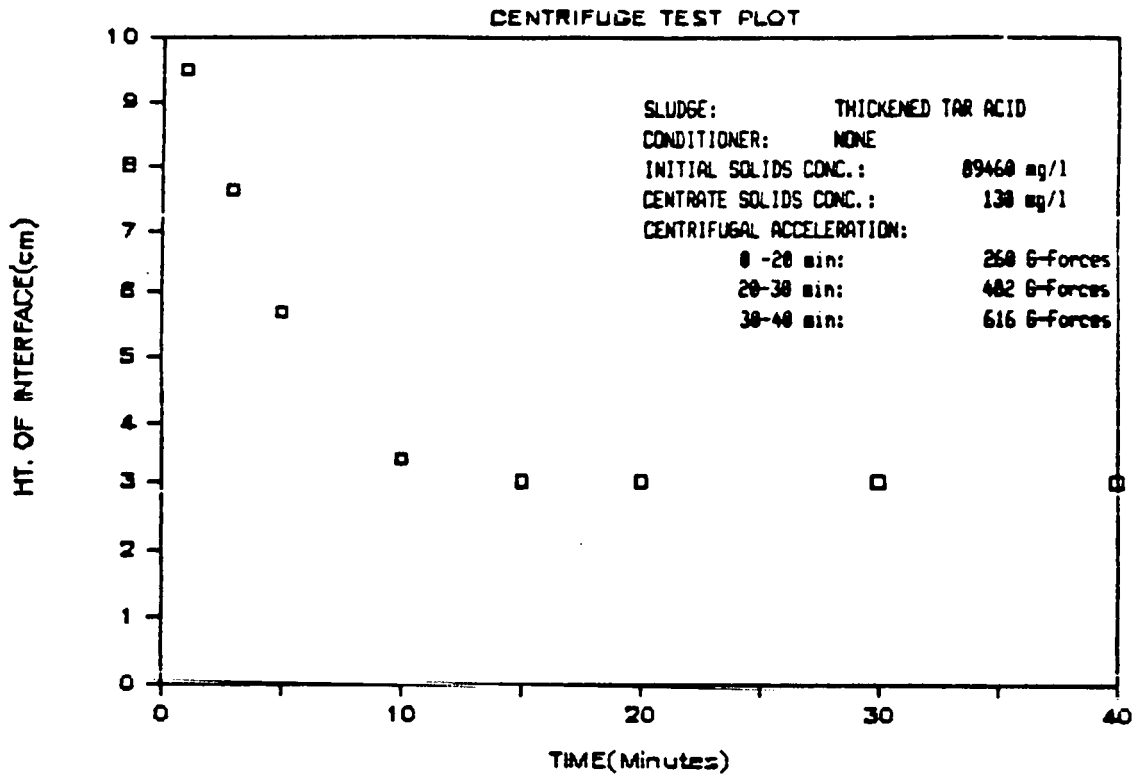


Figure A-81

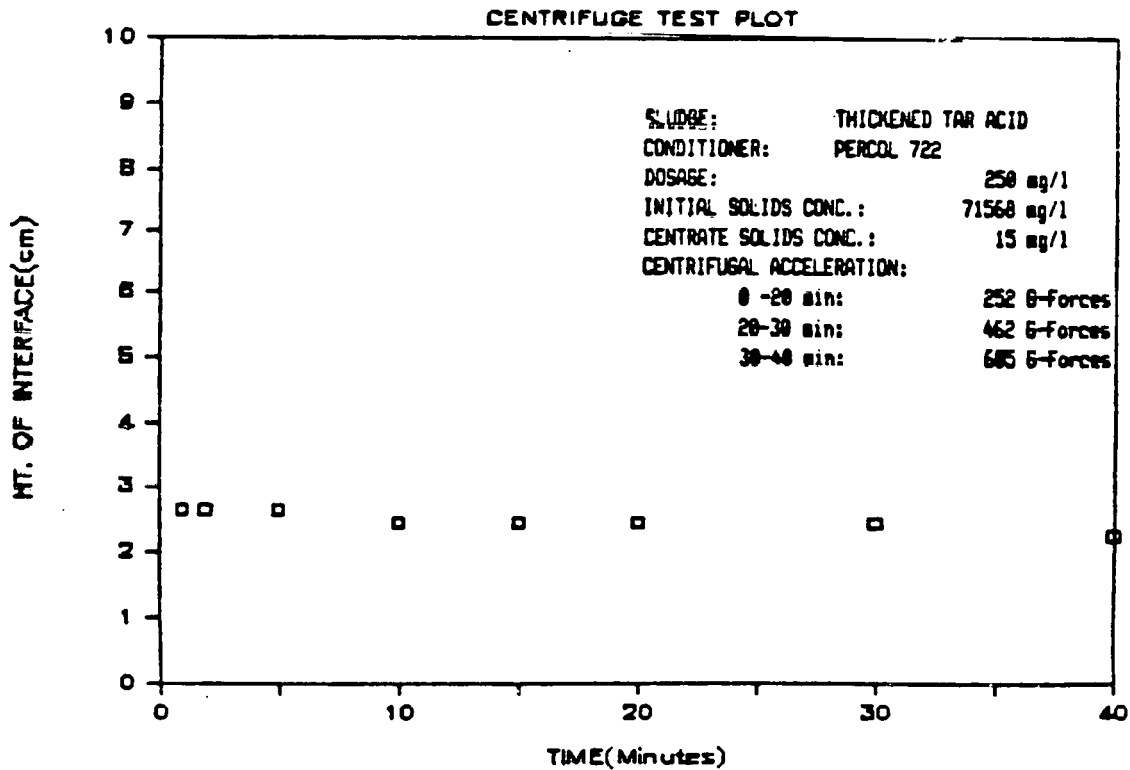


Figure A-82

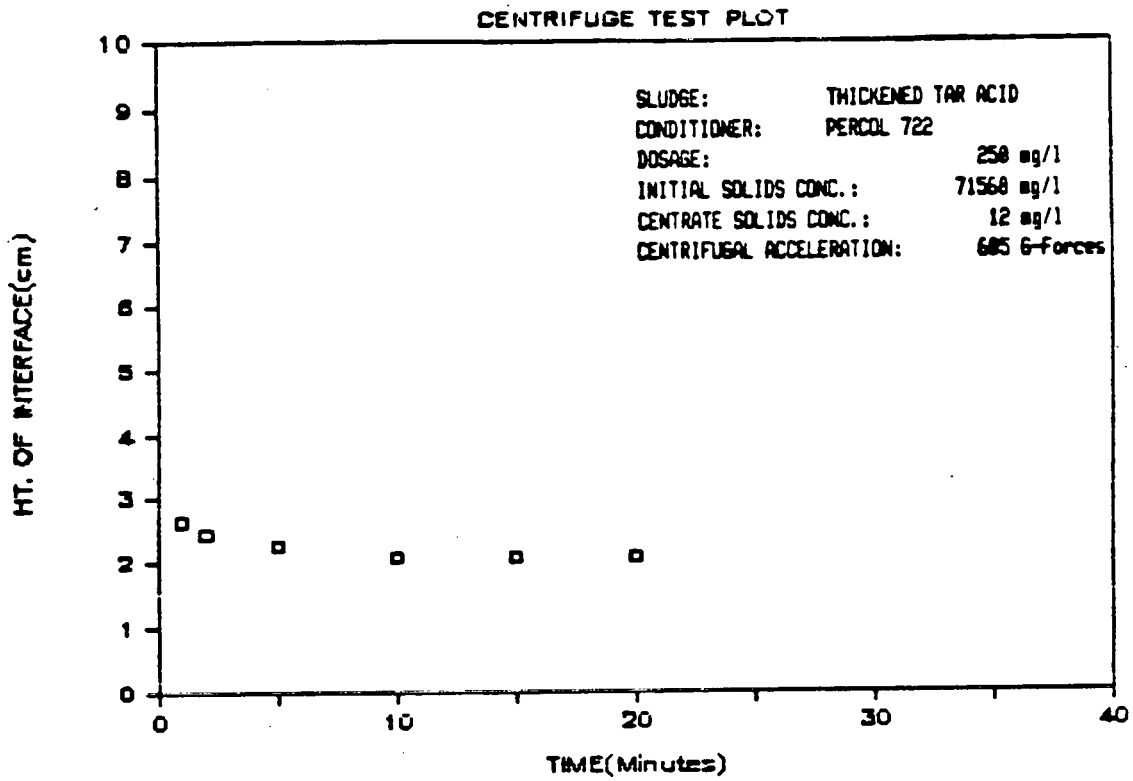


Figure A-83

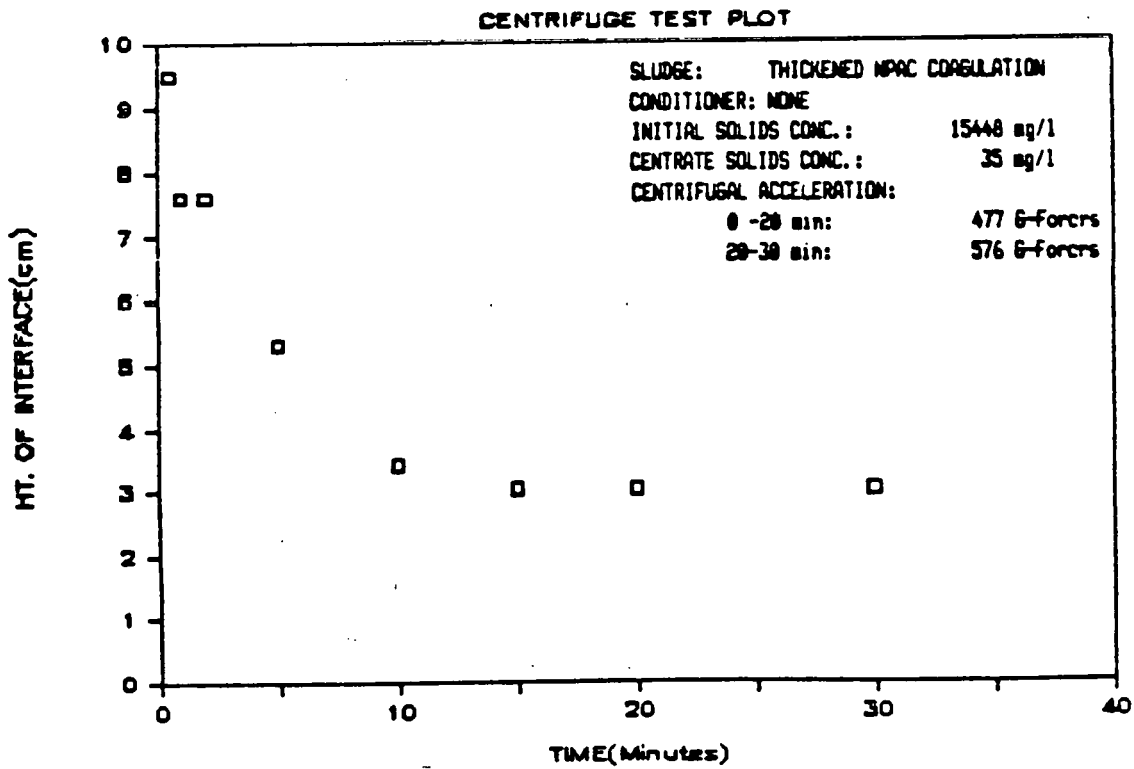


Figure A-84

CENTRIFUGE TEST PLOT

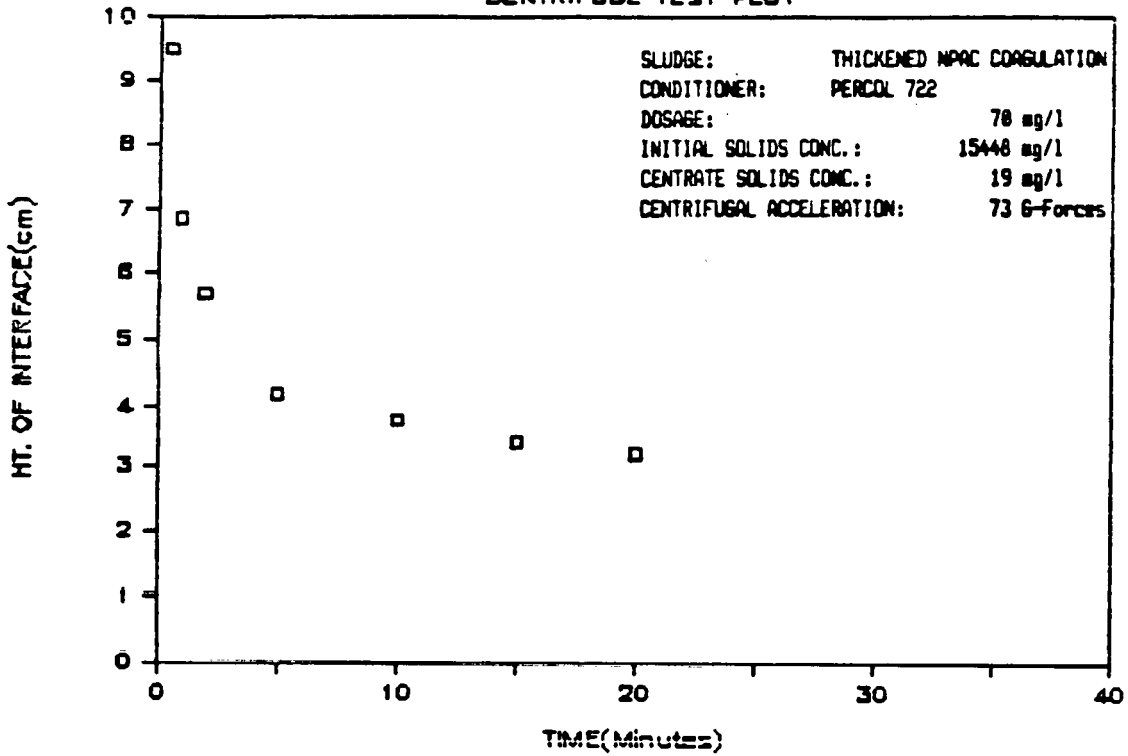


Figure A-85

CENTRIFUGE TEST PLOT

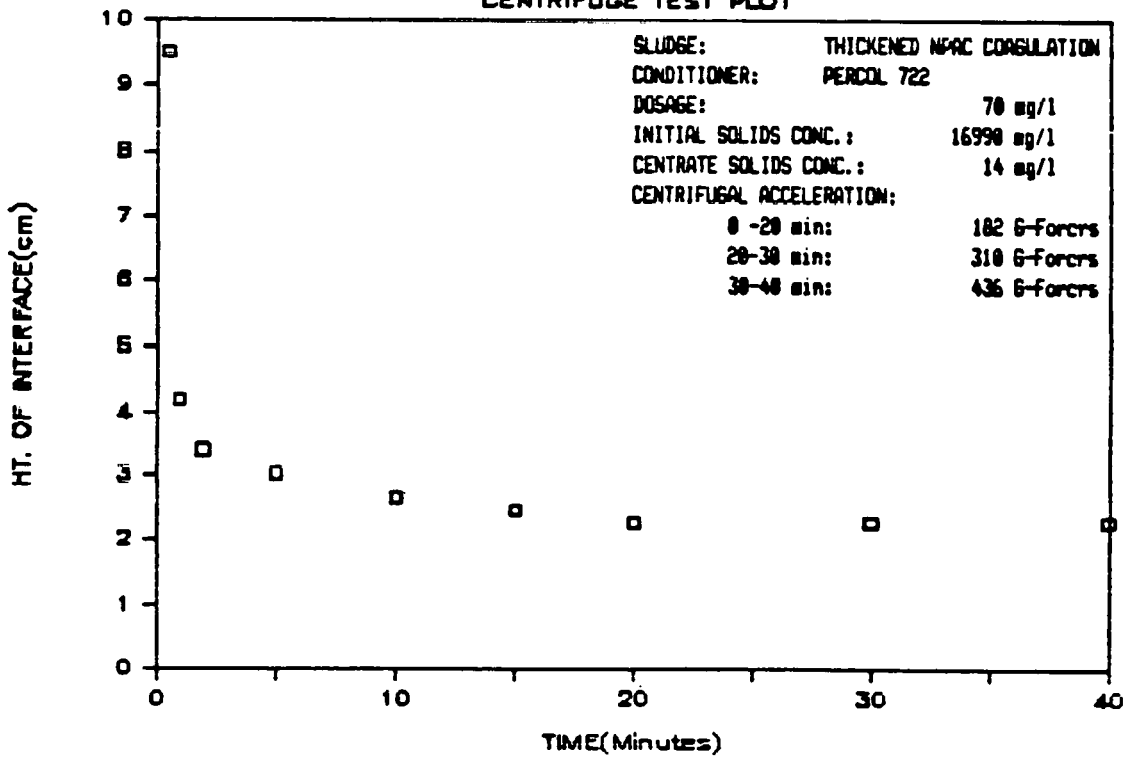


Figure A-86

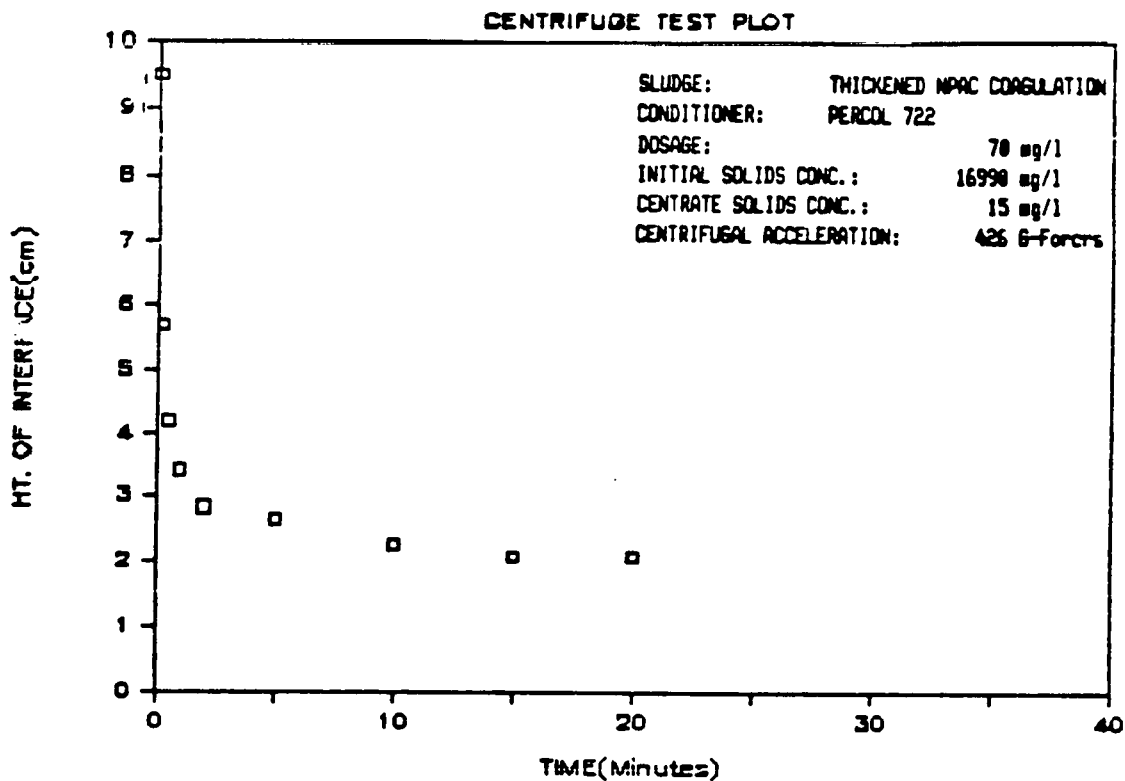


Figure A-87

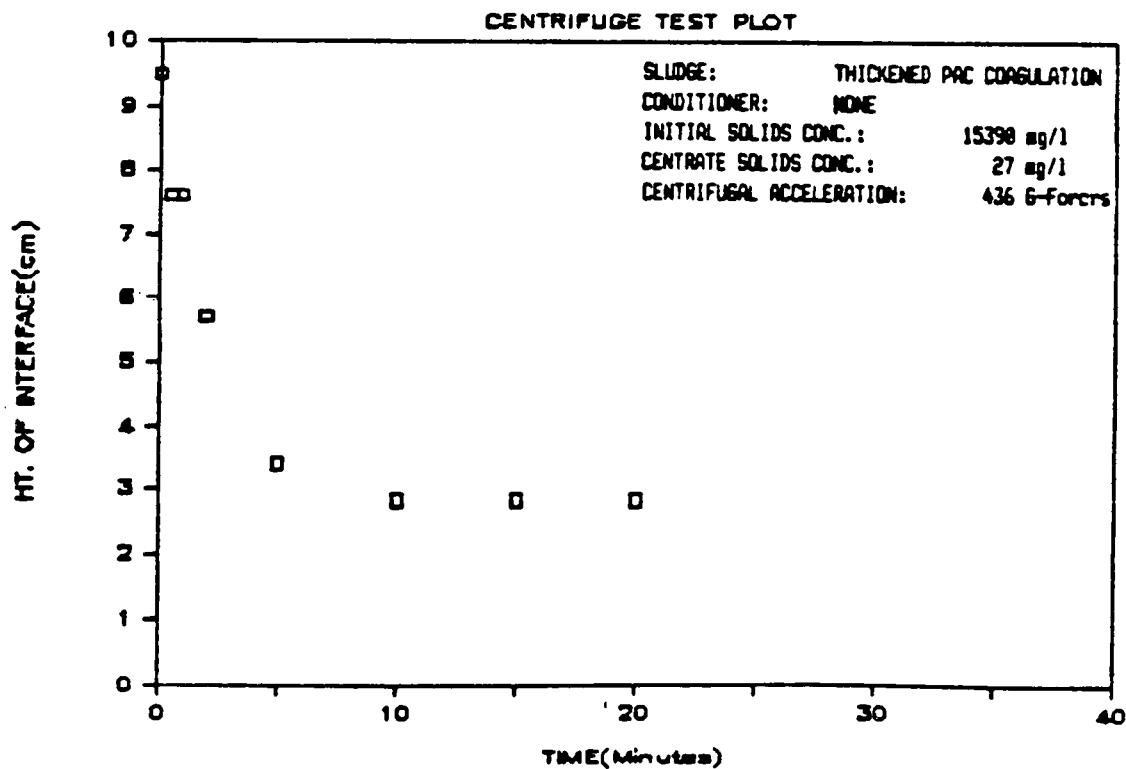


Figure A-88

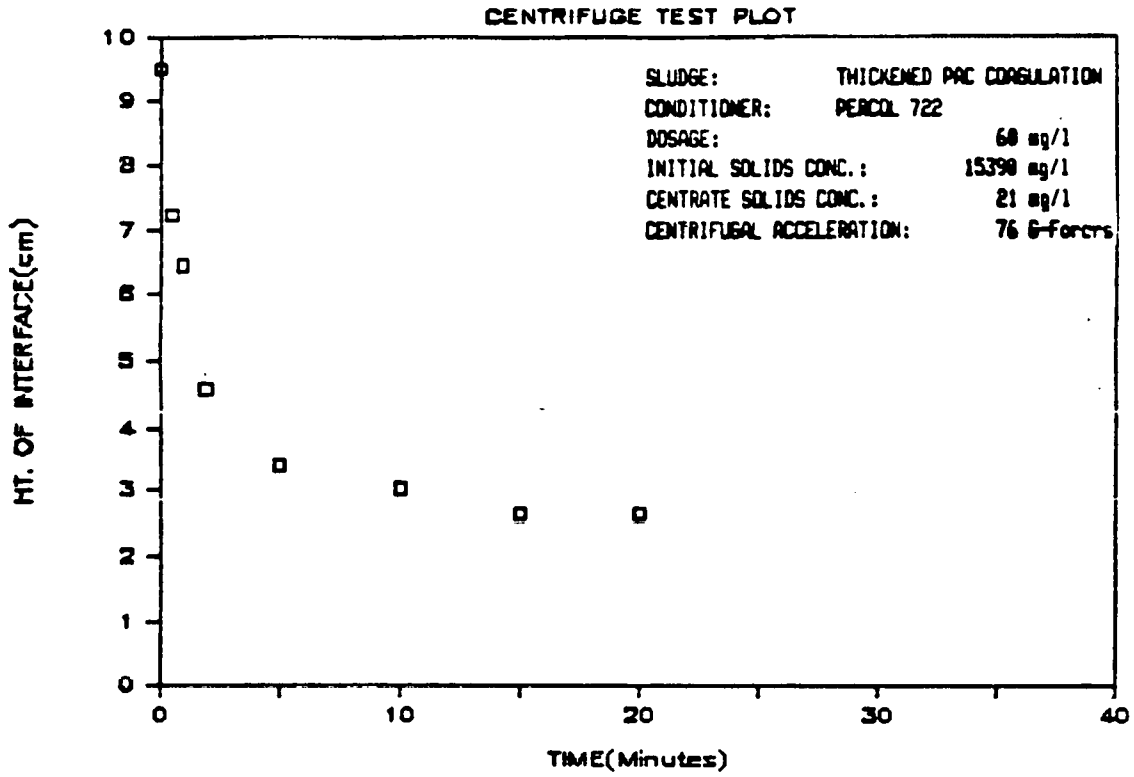


Figure A-89

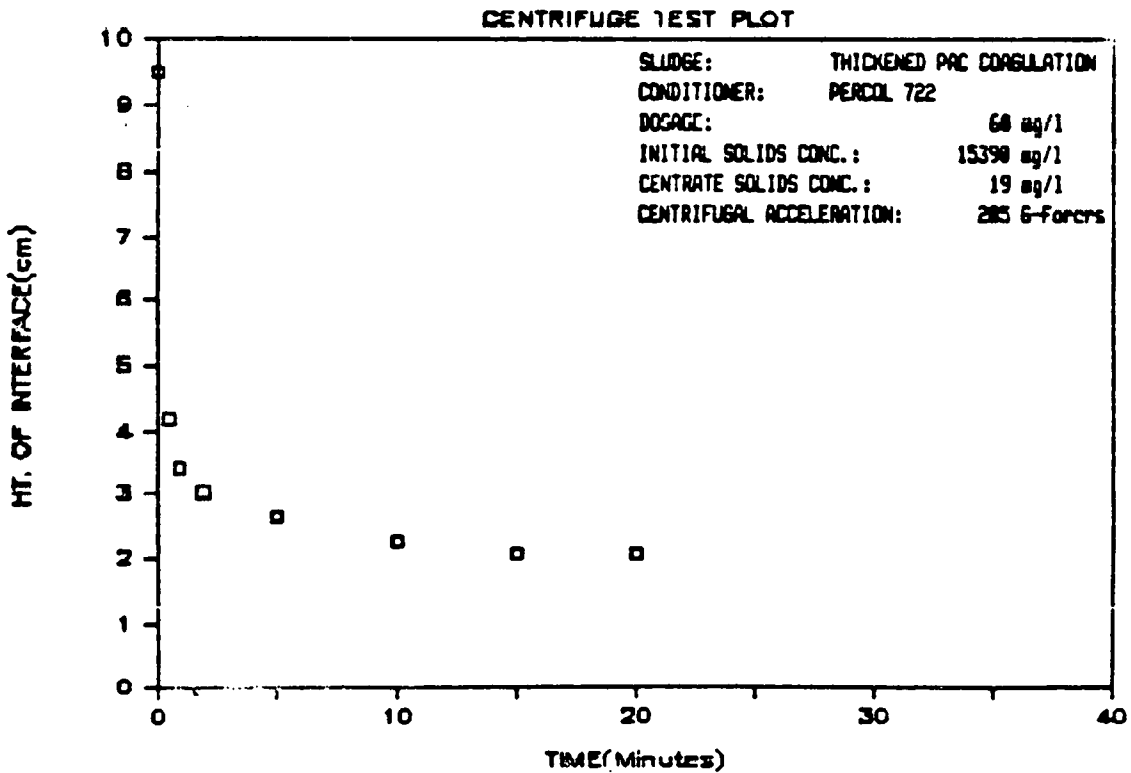


Figure A-90

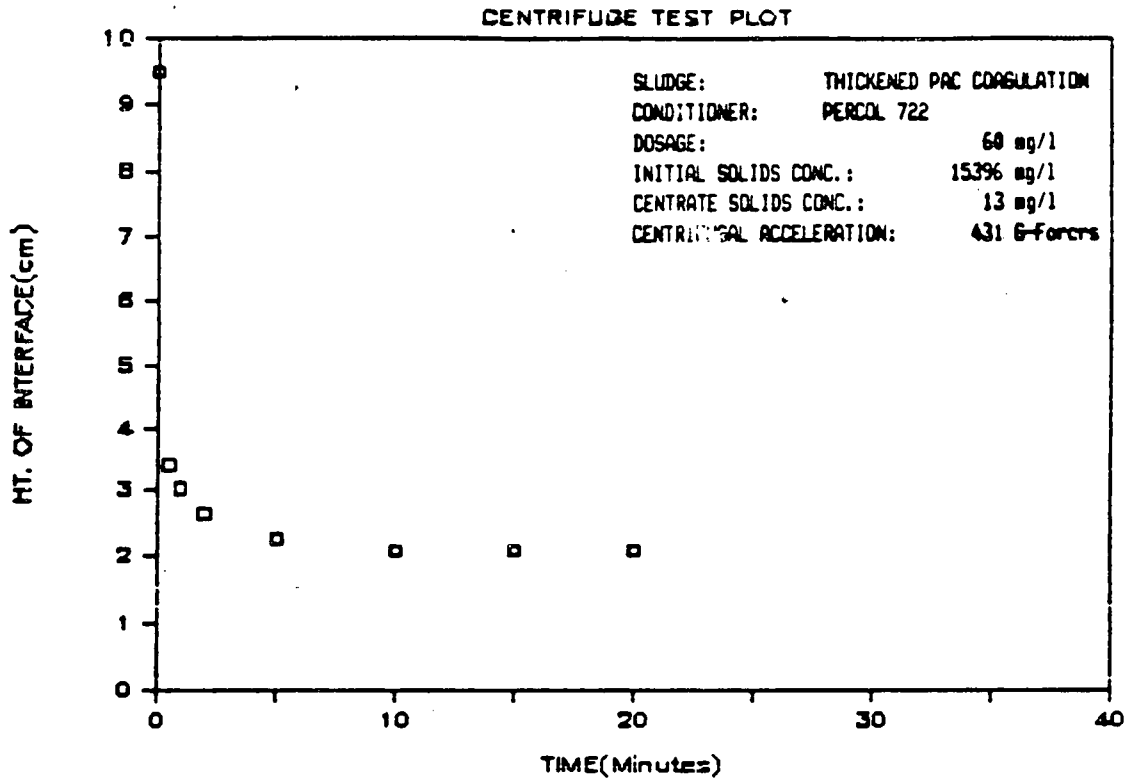


Figure A-91

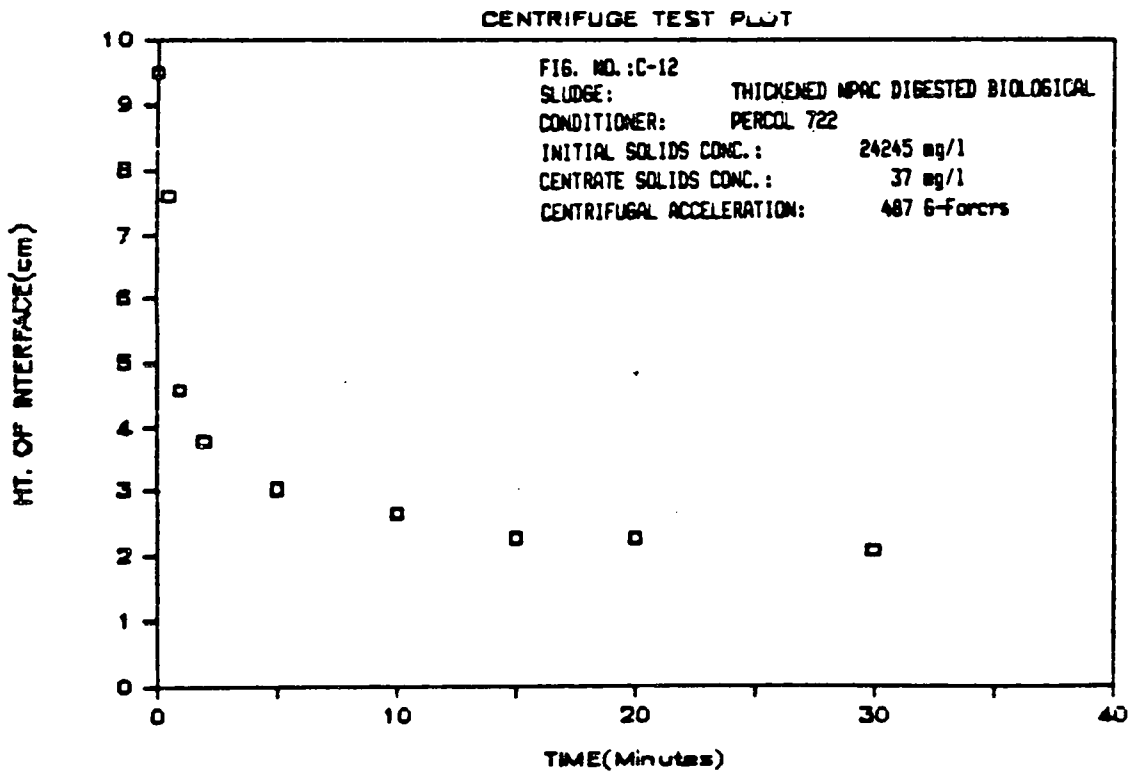


Figure A-92

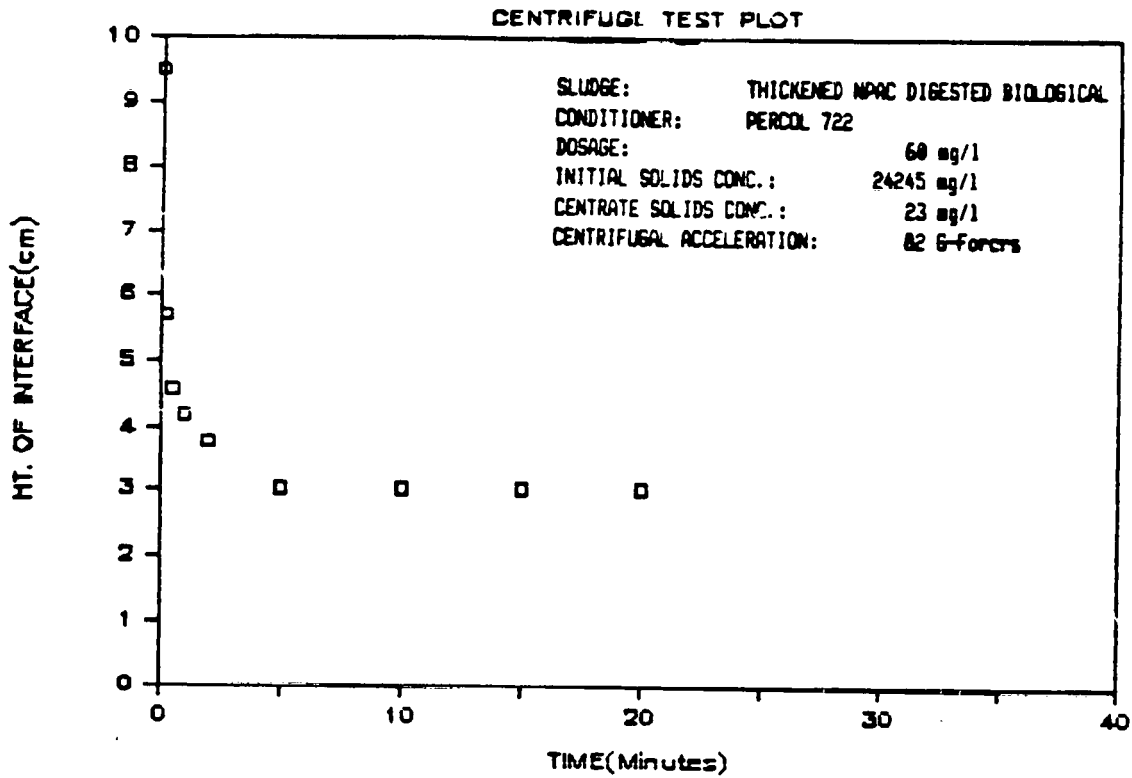


Figure A-93

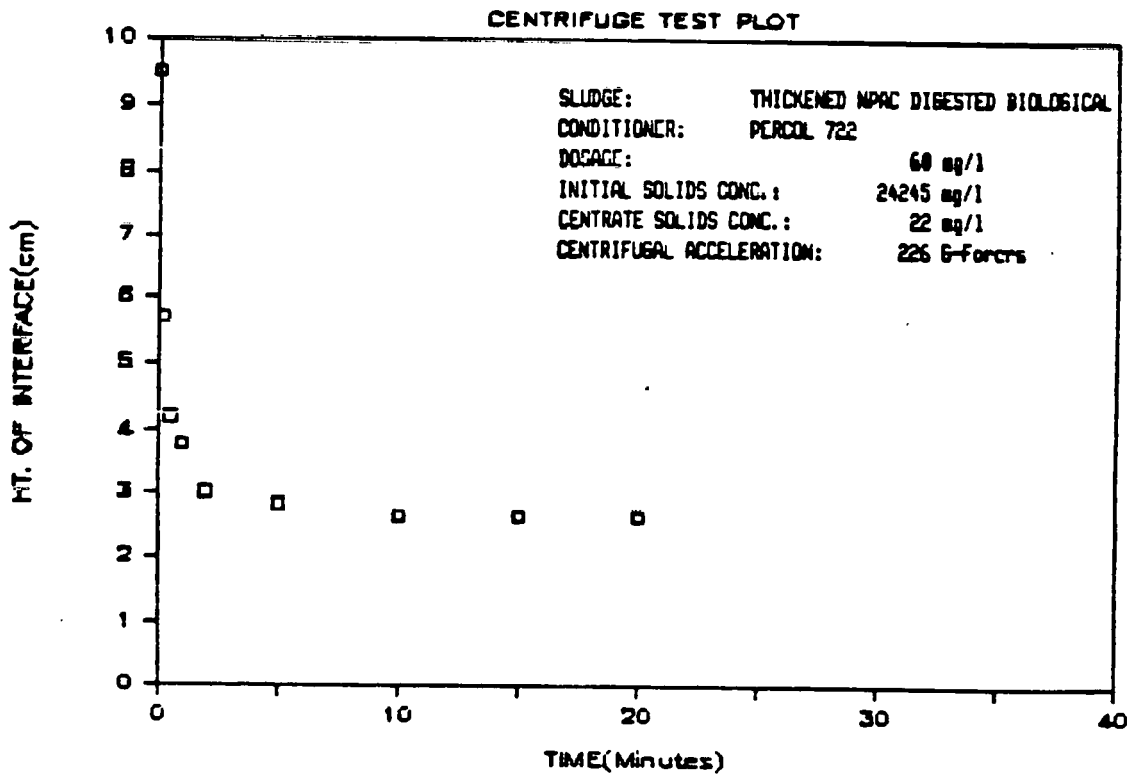


Figure A-94

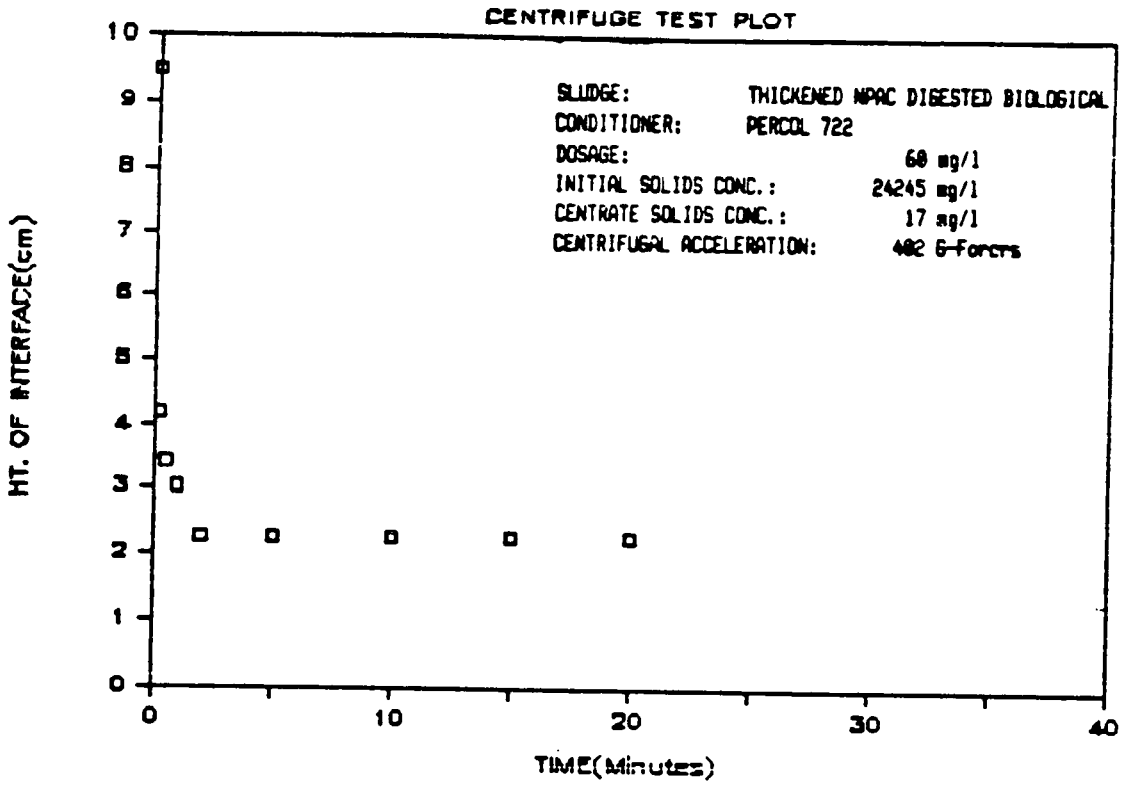


Figure A-95

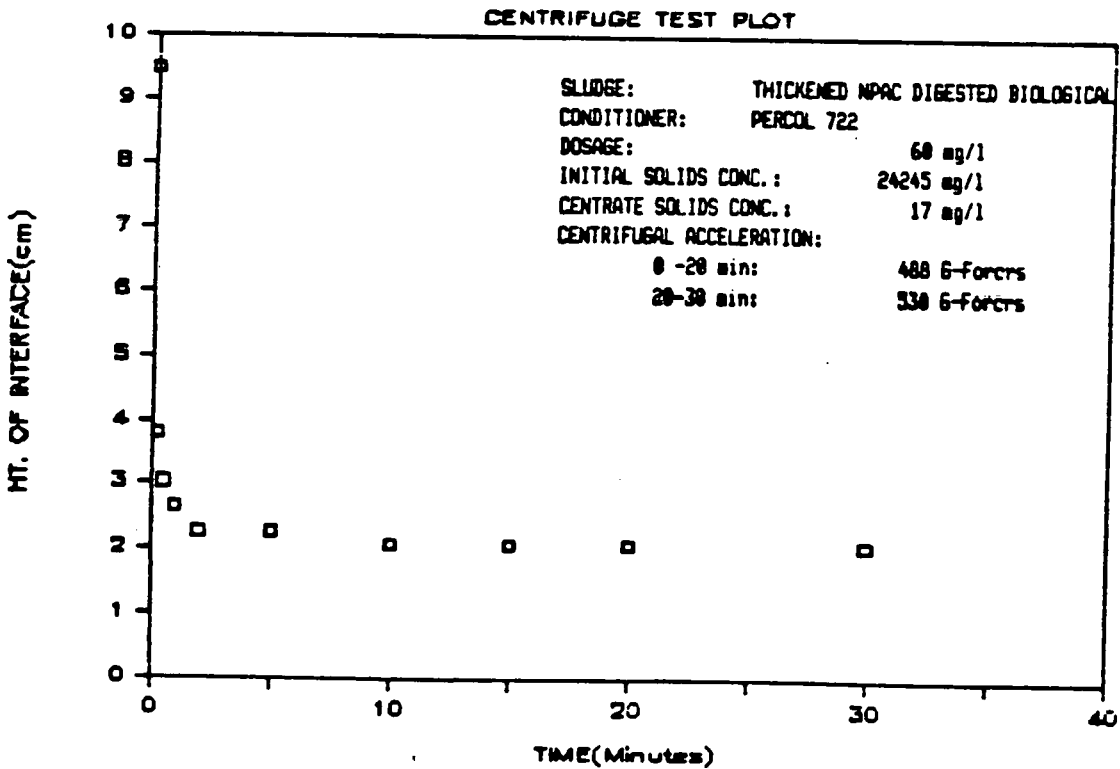


Figure A-96

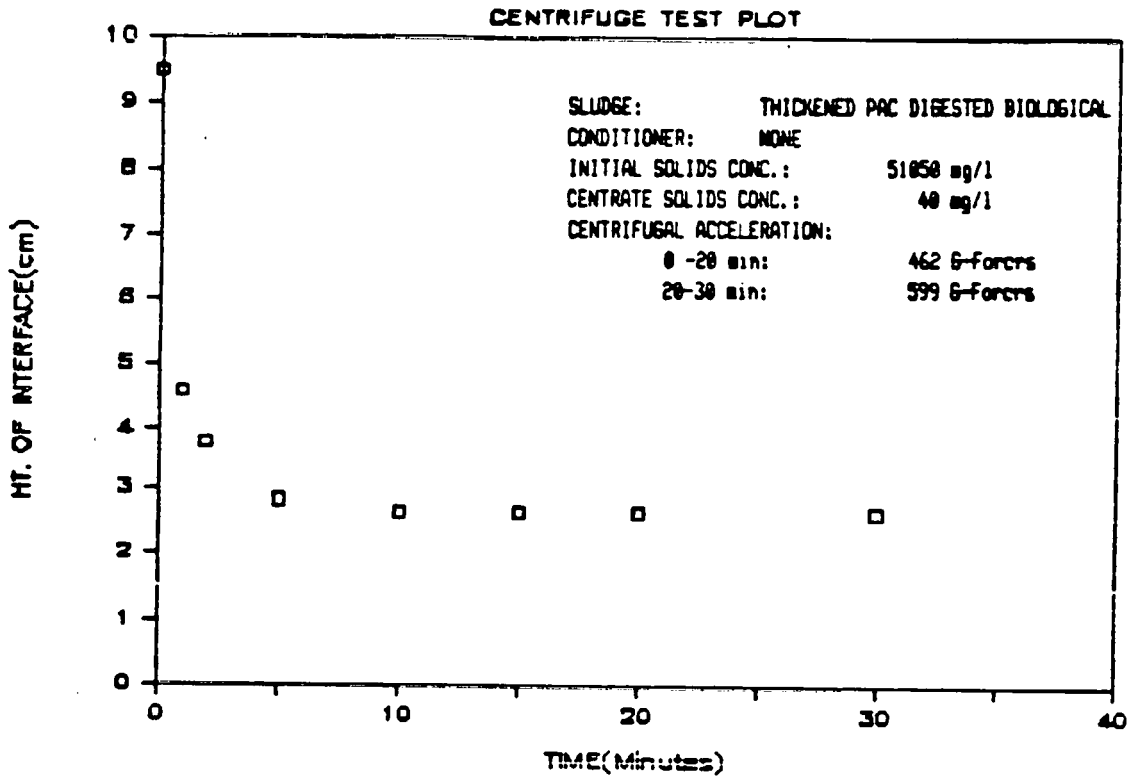


Figure A-97

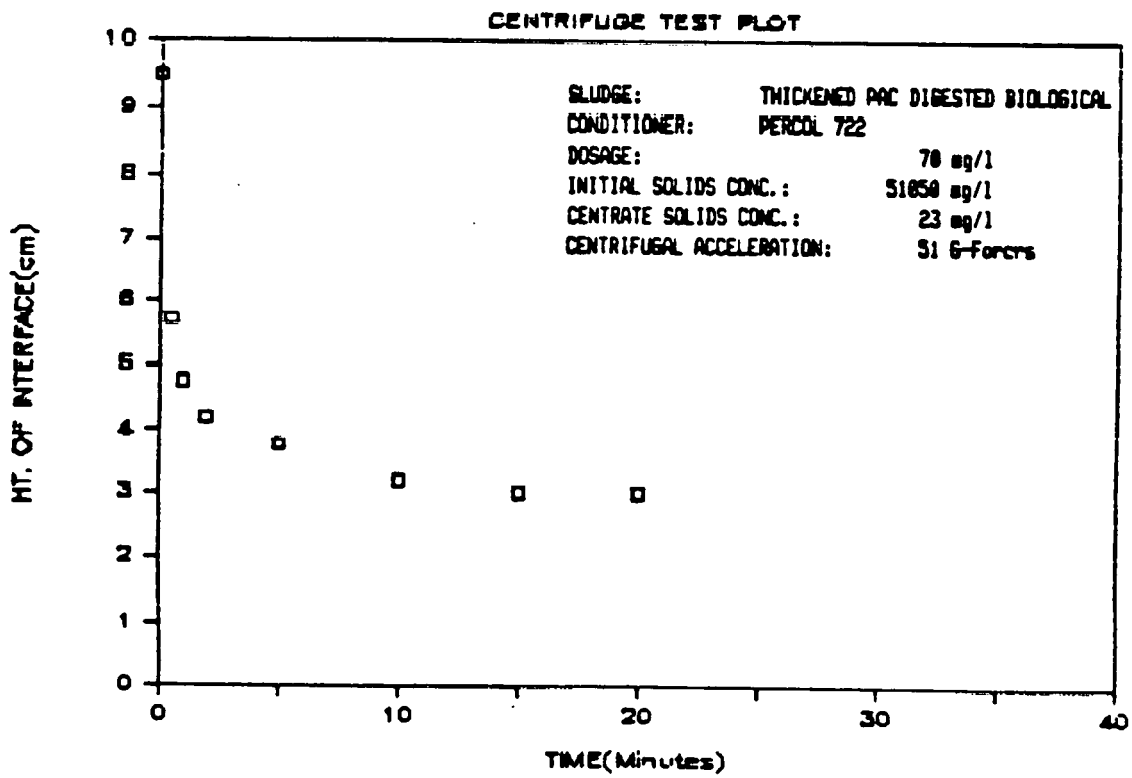


Figure A-98

CENTRIFUGE TEST PLOT

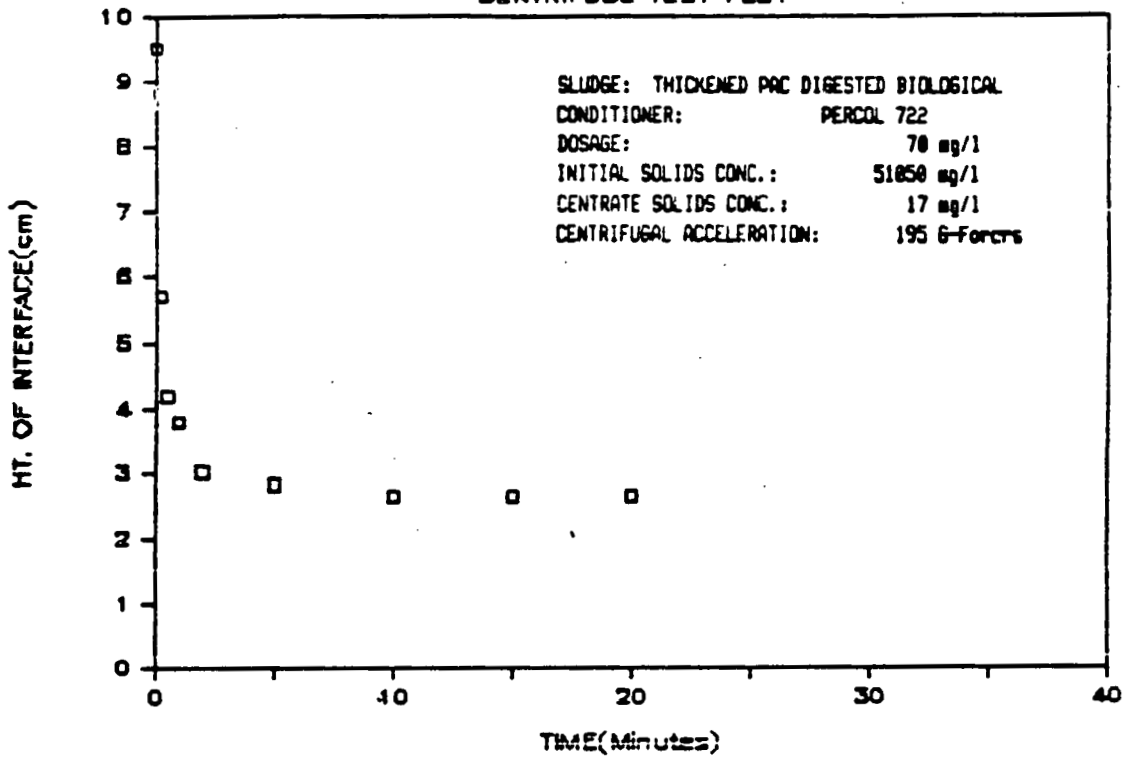


Figure A-99

CENTRIFUGE TEST PLOT

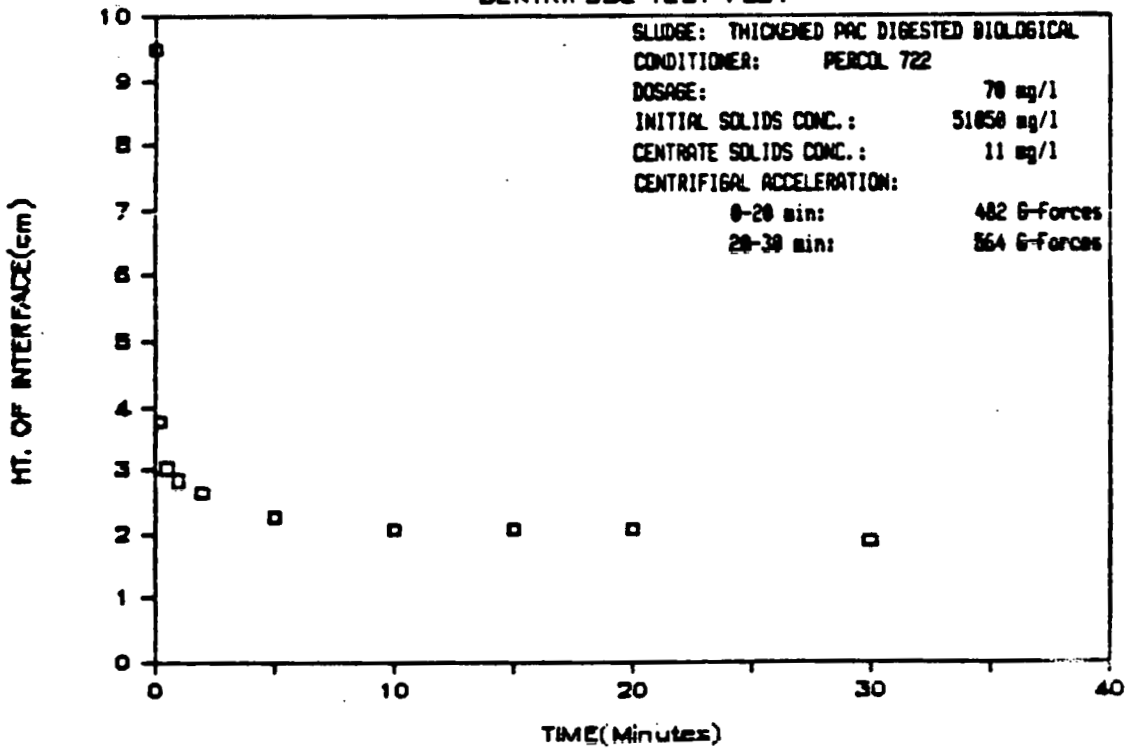


Figure A-100

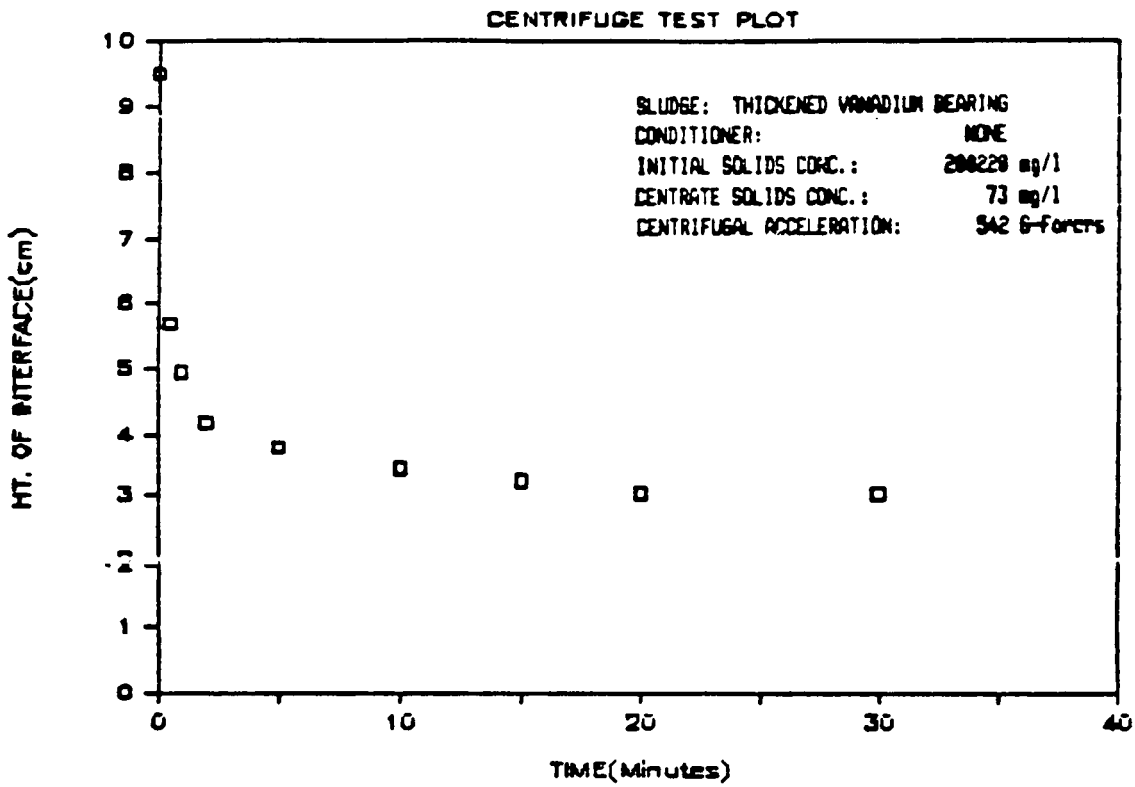


Figure A-101

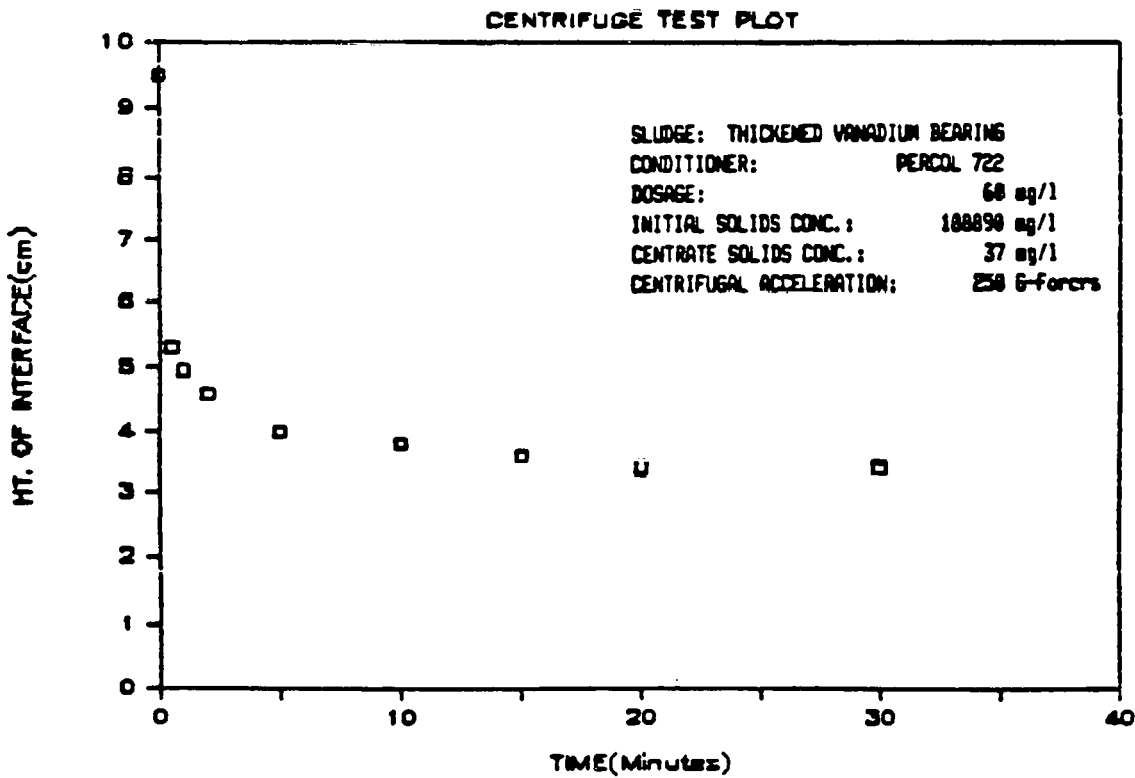


Figure A-102

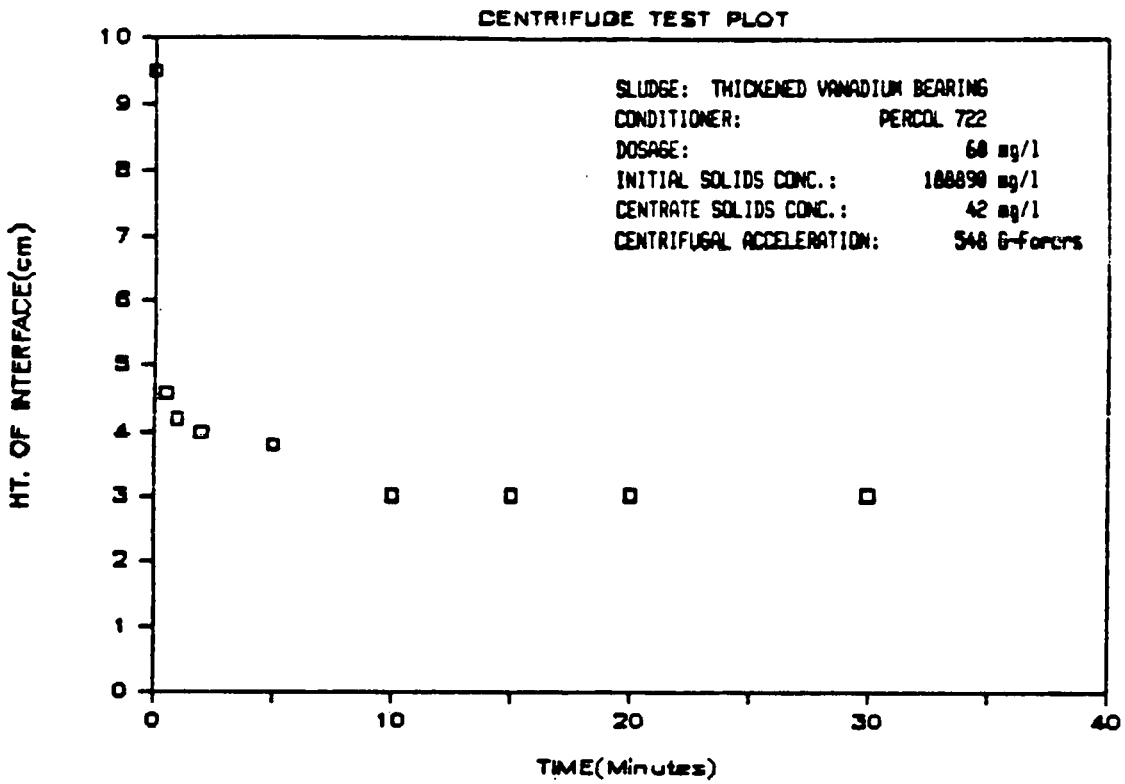


Figure A-103

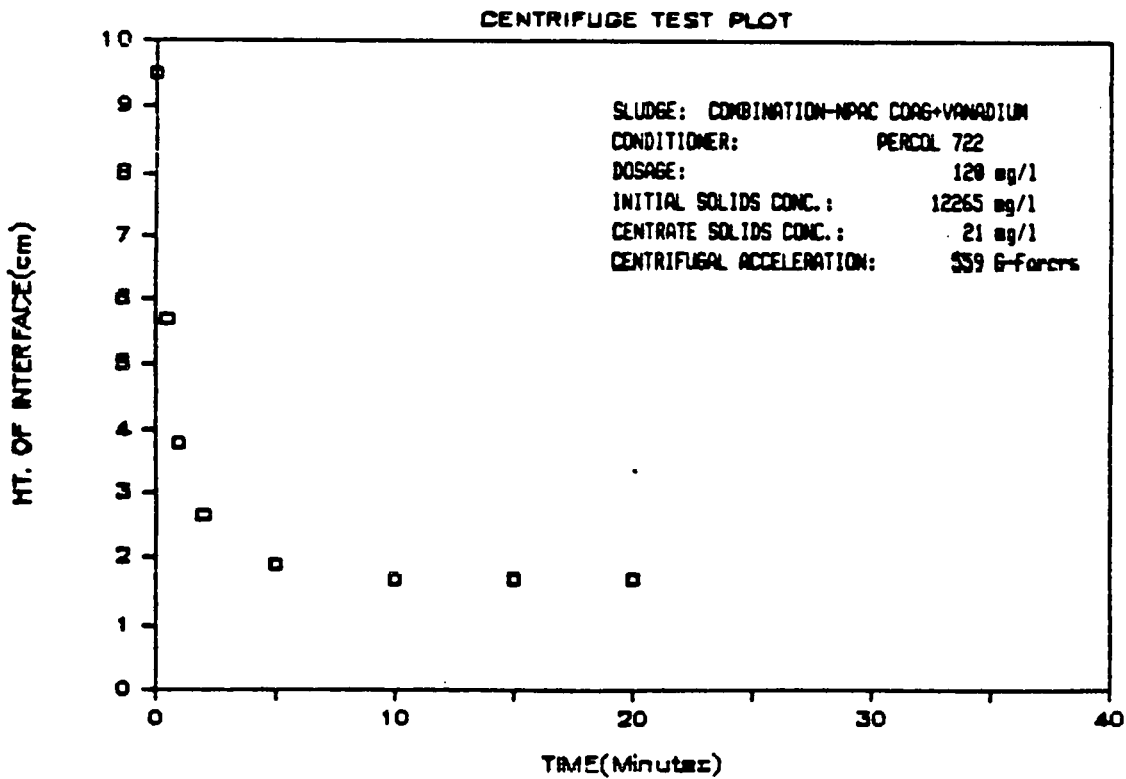
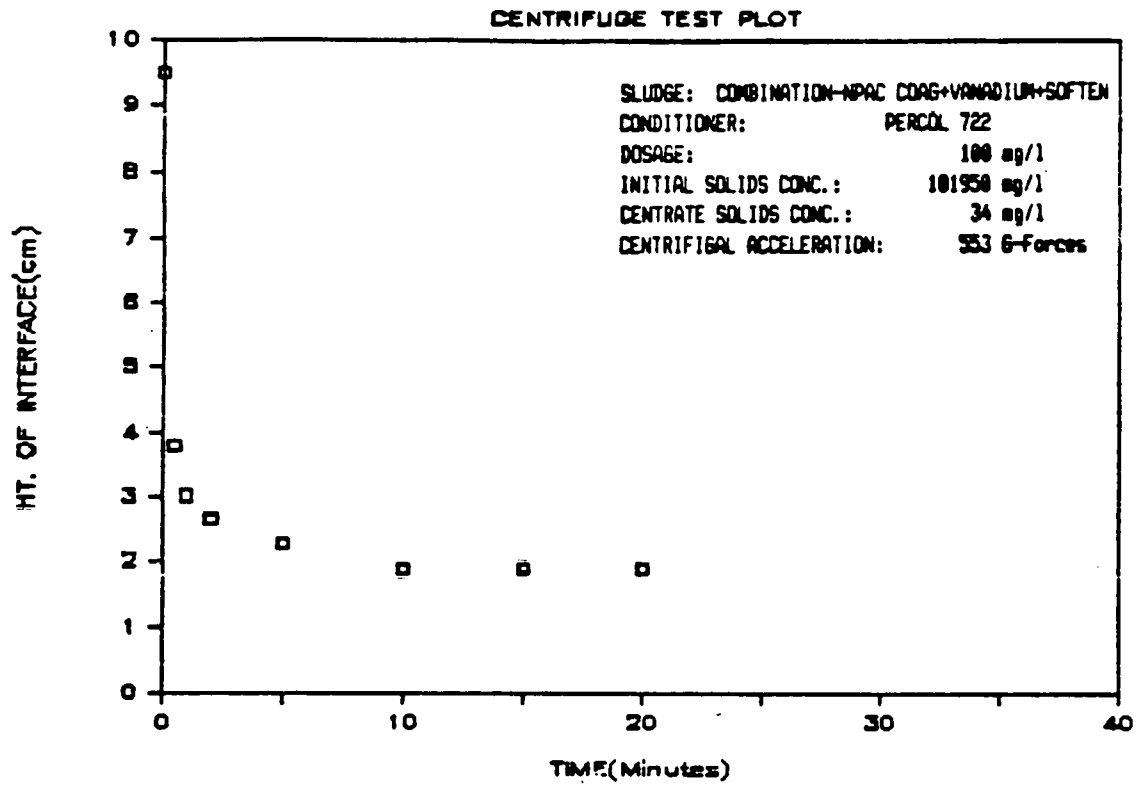


Figure A-104



APPENDIX B

ANALYTICAL METHODS

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ANALYTICAL METHODS

QUALITY CONTROL PROCEDURES

The routine quality control procedures described in Quality Assurance Program for Environmental Systems Division Laboratory Facility, Catalytic, Inc., were strictly followed. To control "accuracy" of analyses, that program requires spike recovery determination on distilled water and samples. For distilled water spiking, the following equation is used to calculate the recovery:

$$P = 100(C/T)$$

(1)

where P is percent recovery of a standard, C is the measured concentration, and T is the true concentration. For each analysis, P must fall within the prescribed range for that analysis.

For sample spiking, the percent recovery P is:

$$P = 100(dC/\text{spike added})$$

(2)

where dC is the difference between the concentrations measured for the spiked and unspiked samples. Spike added is the concentration increase of the analyte if the recovery were 100%. Again, P must fall within the acceptable range for a given analyte.

The quality assurance program also controlled "precision" of the analyses. Precision was controlled by analysis of replicate pairs; the difference between the two analyses was compared to a prescribed standard.

This is expressed mathematically as:

$$R = |A - B| \quad (3)$$

where A and B are observed concentrations of the replicate analyses, and R is the absolute value of the difference. R must fall within the acceptable range for each analytical procedure and is concentration dependent.

A frequency of 10% of sample load was used for analyzing sample spikes or water spikes. Also, 10% of the sample load was used for replicate sample analysis. Where replicates were run, the average value was reported.

Total Organic Carbon (TOC)

TOC was determined on unfiltered samples after treatment with concentrated hydrochloric acid, to provide removal of inorganic carbon during analysis on a Dohrman DC-50 TOC Analyzer. Interferences were due to sulfate, which gradually lowered the conversion efficiency of the rhodium catalyst in the reduction zone of the furnace tube, where carbon dioxide was reduced to methane for detection. This interference was accounted for by frequent recalibration of the instrument with potassium acid phthalate standards. Sample dilution was also used whenever possible.

Total Dissolved Solids (TDS)

TDS was found by filtration of unpreserved samples and evaporation of the filtrates in an oven set at 180°C, according to EPA (3) Method 160.1.

The practical range of the determination is 10 to 20,000 mg/l; the lower limit of detection of the method as practiced with a sample volume of 50 ml was estimated to be 20 mg/l.

Quality control measures involved the prewashing of the glass fiber filters used in the separation of solids from the samples, and so were replicate analyses.

Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS)

TSS and VSS were performed on unpreserved samples, according to Methods 209.D and 209.E in Standard Methods⁷. In these procedures, the residue on the filter from the TDS determination is dried at 103-105°C, then at 550°C to find the TSS and VSS components of the wastewater.

The limit of detection for a sample volume of 50 ml was estimated to be 20 mg/l for TDS or VSS.

Quality control measures involved the prewashing of the glass fiber filters and blank checks on filters with distilled water passed through them in place of a sample. The weight change was recorded on quality control sheets. Sample replicate data were also recorded for TSS. The results of the TSS showed a high variability (low precision) for samples with very high suspended solids levels, due to the difficulty of sampling these suspensions.

pH

pH was measured with a combination glass electrode standardized against commercially available buffer solutions, as referenced in EPA (3) Method 150.1. Temperature compensation, if required, was provided by manual adjustment of the meter control, after measurement of the sample temperature.

EXTRACTION PROCEDURE (EP) TOXICITY

Dewatered sludges were leached with water at pH 5±0.2 as specified in "Test Methods for Evaluating Solid Waste" (SW-846, 1980), published by the U.S. EPA. The filtrate from the leaching test was analyzed for the following eight metals with atomic absorption methods in the cited reference: Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Silver, and Selenium. The chromium +6 ion was determined in the filtrate if the total chromium was above the maximum concentration of 5.0 mg/l for this metal.