UCRL-52829

Improving the performance of brine wells at Gulf Coast strategic petroleum reserve sites

Edited by L. B. Owen and R. Quong

November 5, 1979

Lawrence Livermore Laboratory

DISCLAIMER

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under Contract W-7405-Eng-48.

UCRL-52829
Distribution Category UC-~~65~~ 92

Improving the performance of brine wells at Gulf Coast strategic petroleum reserve sites

Edited by L. B. Owen and R. Quong

Manuscript date: November 5, 1979

LAWRENCE LIVERMORE LABORATORY
University of California • Livermore, California • 94550

Available from: National Technical Information Service • U.S. Department of Commerce
5285 Port Royal Road • Springfield, VA 22161 • $26.00 per copy • (Microfiche $3.50)

CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ACKNOWLEDGMENTS

We wish to acknowledge the contribution of all the participants in the brine injection investigation.

George Tardiff, Leader, LLL Geothermal Project, was initially contacted by Strategic Petroleum Reserve (SPR) management personnel on November 17, 1978. Subsequently, Tardiff, Larry Owen, and Gary Higgins, representing the LLL Associate Director for Energy Programs, visited the DOE New Orleans Field Office on November 20, 1978, to discuss the nature of the brine injection problems at Gulf Coast SPR sites. By the conclusion of that meeting, a scope of work and a cost estimate were developed for implementation of an evaluation program to establish the reasons for injection well failures. Remedial steps required to prevent further well impairment at three SPR sites were also considered. LLL personnel visited the three sites and a detailed field test plan was subsequently developed. The plan was presented at the New Orleans field office in the presence of DOE/SPR contractors and consultants. After review and approval, the field portion of our program was implemented by late December, 1978, and was concluded by April, 1979.

A field project of this magnitude could not have been completed on schedule without the enthusiastic support and participation of numerous people. We are especially indebted to Bob Mazurkiewicz (DOE, New Orleans Office) and his management and technical staff for their assistance with site logistic problems and their review of our program plans. Maury Sweetin served as DOE's technical coordinator. Dr. Charles Patten and Dr. Charles Hudgins provided critical reviews of our program and periodic status reports. Dr. Hudgins and Bob Mazurkiewicz also provided critical review of this final report.

The cooperation of DOE SPR field site personnel is also greatly appreciated. Specifically, we would like to thank Allan Fruge, Oscar Bowling, and Ivan Johnson (West Hackberry, Louisiana), Bill Bonvillain (Bayou Choctaw, Louisiana), and George Crook, Charles Bellam, and Lynn Coleman (Bryan Mound, Texas) for their assistance.

Ken Street, LLL Associate Director for Energy Programs and his staff (Alfred Holzer, Gary Higgins, and Del Lowe) made it possible for us to quickly overcome initial funding and subcontract authorization difficulties. Their assistance and interest also enabled us to mobilize the necessary LLL personnel and equipment for the field work.

SPR site mechanical and electrical coordination activities were efficiently and expertly handled by Rodger McLain and Norm Rector. Richard Hasbrouck provided electrical engineering support, and Rene Nurath served as our field electronics technician.

The design and implementation of the electrochemical corrosion tests were significantly aided by Dan McCright. Bill Beiriger and Dick Ryon were responsible for the x-ray diffraction and x-ray fluorescence analyses, respectively, of particulate samples. Hazards Control personnel Lee Partlow and Pat Ellis assisted us with the preparation and implementation of SPR site safety plans. Field work was supported by mechanical technicians from the Research and Development Division: P. W. Burkland, T. C. Erven, R. G. Grogan, D. I. Gutierrez, T. D. Knorr, R. Netherton, and W. Simpson.

We especially thank Loraine Marshbank for the efficient manner in which she handled the typing of the manuscript. Ruth Mayo, EG&G, Inc., performed final editing and was responsible for converting our rough draft into its present form.

IMPROVING THE PERFORMANCE OF BRINE WELLS AT GULF COAST STRATEGIC PETROLEUM RESERVE SITES

ABSTRACT

At the request of the Department of Energy, we developed field techniques to evaluate and improve the injection of brine into wells at Strategic Petroleum Reserve (SPR) sites. These wells are necessary for the disposal of saturated brine removed from salt domes where oil is being stored. The wells, which were accepting brine at 50 percent or less of their initial design rates, were impaired by saturated brine containing particulates that deposited on the sand face and in the geologic formation next to the wellbore. Corrosion of the brine-disposal pipelines and injection wells contributed to the impairment by adding significant amounts of particulates in the form of corrosion products.

When we implemented our tests at the SPR sites, we found that the poor quality of injected brines was the primary cause of impaired injection; that granular-media filtration, when used with chemical pretreatment, is an effective method for removing particulates from hypersaline brine; that satisfactory injection-well performance can be attained with prefiltered brines; and that corrosion rates can be substantially reduced by oxygen-scavenging.

CHAPTER 1

GENERAL REVIEW

L. B. Owen and R. Quong

1.1 INTRODUCTION

The Strategic Petroleum Reserve (SPR) Program of the Department of Energy (DOE), enacted April 18, 1977, provides for the storage of as much as one billion barrels of crude oil to offset the immediate effects of a severe disruption in the normal supply of imported oil. Five underground storage sites in Texas and Louisiana were initially selected for oil storage because of their availability and their proximity to interstate oil pipelines and tanker ports (Fig. 1-1). One of these SPR sites consists of mined near-surface dry chambers; the others are deep water-leached caverns in subsurface salt domes.

The water-leached caverns are at depths ranging from 305 to 1220 meters and are filled with saturated sodium-chloride brine. During filling, the oil forces equivalent volumes of brine to the surface, where it must be transported or stored.

Disposal pipelines for transporting the brine to the Gulf of Mexico are already planned or are being constructed at the two storage sites nearest the Gulf. The other sites are too far inland to make brine disposal in the Gulf cost-effective. Therefore, at the inland sites, the displaced brine is injected through deep wells (1200 to 2400 meters) into permeable geologic formations. The same subsurface brine-disposal process is also necessary at the near-Gulf sites until the disposal pipelines are completed.

The problem with brine injection was the rapid and irreversible decline of injection rates to 50 percent or less of their initial design rates. In late November, 1978, DOE asked LLL to design and implement a means for evaluating SPR brine-injection practices at three SPR sites (Bayou Choctaw, West Hackberry, and Bryan Mound) and to recommend remedial steps for improving injection-well performance. SPR personnel suspected that this decline resulted primarily from the poor quality of untreated brines and from damage to the geologic formation during well drilling.

LLL was chosen for this task because of the experience it gained when evaluating processing requirements for long-term injection of hypersaline brine (20 to 30 weight percent total dissolved solids at 100 C) produced at the Salton Sea Geothermal Field in southern California.

The SPR field activities began in late December, 1978, at West Hackberry and were concluded by April, 1979, at Bryan Mound.

1.2 LLL FIELD PROGRAM

To ensure satisfactory long-term performance from the brine-disposal system, LLL personnel designed and implemented a program to identify problems in the injection process, to establish the preinjection requirements for brine processing, and to determine the capacity of injection reservoirs. The program consisted of five parts:

1. Brine characterization was undertaken to determine the chemical and physical properties of all injected fluids.
2. Injectability testing was undertaken to determine how fast and how much raw brine can be injected and to determine the possible improvements in well performance if brines are processed.
3. Brine processing was studied to establish minimum requirements for preinjection filtration of brines through granular-media systems. (National Technical Service, Corvallis, Oregon, under a subcontract, assisted in establishing filtration system requirements for SPR injected effluents.)
4. Corrosion was assessed to determine the nominal corrosion rates of raw brines; to ascertain the potential for bacterial-induced corrosion; and to identify optimum oxygen-scavenging systems and their effect on the corrosiveness of brine. The biological assessment was completed under a consulting agreement with Professor Richard Morita of Oregon State University.
5. Reservoir assessment was undertaken to characterize SPR injection reservoirs by analyzing geological, geophysical, and well performance data and by testing the response of neighboring SPR wells at Bayou Choctaw. The reservoir assessment plan was designed by LLL personnel and implemented under a subcontract to Keplinger and Associates, Inc., Houston, Texas.

1.3 SUMMARY

1.3.1 Brine Injection

Figure 1-2 is a generalized schematic diagram of an SPR oil-storage injection system. Oil is pumped into brine-filled caverns through the annulus of a cavern entry well, displacing equivalent volumes of brine from the cavern into large surface surge ponds that also act as crude settling basins for removing suspended solids. The untreated brine is then pumped directly from the surge ponds to injection wells up to 4 km away, at rates of up to 200,000 bbl/d.

The extensive deposits of relatively shallow (1200 to 2500 meters deep), unconsolidated Miocene sands that underlie the Gulf Coast are ideal for brine injection because they are well isolated from potable aquifers, have a large storage capacity, and are very permeable (0.8 to 5 darcies) and porous (25 to 35 percent). Injection wells completed in these sands were expected to accept 30,000 bbl/d/well.

Because wells at Bayou Choctaw and West Hackberry were performing at 50 percent or less of their initial design rates, we made a preliminary review of operational activities at these sites. From our review, we were able to identify potential causes for the decrease in brine-injection rates. One of the main causes appeared to be the deposition of suspended solids from untreated brines on the sand face (the surface of the drilled formation exposed to brine) and within the geologic formation next to the wellbore. Others were insufficient reservoir capacity for desired injection rates and possible deficiencies in well design or completion.

We set up a test facility next to the main brine surge ponds at each SPR site. This facility, consisting of one large trailer (3 by 15 meters), was equipped with LLL analytic and test equipment. We used small (20-mm-diam) lines to bring various process streams, including strong (saturated) brine from the surge ponds, low-salinity dilution water, and weak (undersaturated) cavern leach brine, directly into the trailer for granular-media filtration and injectability tests (Fig. 1-3). We also equipped the trailer so that we could characterize the physical and chemical properties of the brine. To measure the injectability of raw brines at the injection sites, which were up to 4 km from the surge ponds, we outfitted a mobile van. The test apparatus in the van allowed us to prefilter the brines, using cartridge filters to simulate the effect of processing on injectability.

1.3.2 Brine Characterization

Table 1-1 summarizes the characteristics of various process streams ultimately injected at SPR sites.

The cavern brines were saturated or nearly saturated salt solutions with notable--but apparently harmless--amounts of known scaling and solid-forming constituents. They were also relatively clean, containing less than 3 ppm suspended solids.

During the approximately 24 hours the brines resided in the surge ponds, they became oxygenated and contaminated with windblown soil and debris, derived principally from the pond berms. A slight to moderate cooling during the same period resulted in significant salt precipitation.

To offset the salt precipitation, SPR personnel diluted the brine 5 to 10 percent with untreated lake and river water; at other times, they used these same sources of fresh water to leach new caverns and then injected the residual effluent directly. However, the dilution waters were quite turbid, containing up to 100 ppm suspended solids, and they significantly increased the particulate load in the injected effluents. Corrosion of the carbon steel piping and well casing also added suspended solids, in the form of iron-rich corrosion products, to the brine.

To establish whether post-injection precipitation might impair the wells, we conducted incubation tests at the highest probable injection-wellhead temperature (35°C), using brine samples from the surge ponds. However, we found these brines did not tend to form new particulates over a 24-hour period at the higher temperature.

1.3.3 Injectability Tests

We established brine injectability with a combination of membrane-filtration tests and particle size analyses. Membrane-filtration tests were the primary means by which we established raw brine injectability and determined how much injection-well performance could be improved by preprocessing brines. In addition, a commercial particle-counting device with a laser light source was used to measure particle-size distributions. It was particularly well suited to evaluating the performance of pilot filter systems [systems having a throughput rate of 6×10^{-5} m^3/s (1 gpm)]; it also allowed us to correlate changes in filtration-system parameters directly with effects on brine quality as reflected by slight changes in particle-size distributions.

The standard membrane-filtration tests described in the literature involve flowing water through 0.45-μm pore-size membrane filters at constant differential pressure. A qualitative indication of water quality is then obtained from the decline in filtration rate caused by the deposition of suspended solids on the filter. The 0.45-μm membrane filter is also used routinely for measuring the concentration of suspended solids in water.

We calculated a mean pore size of 10 μm for the subsurface injection formations, basing our estimate on formation permeability and porosity values derived from SPR well logs. Then we modified the standard membrane-filtration test and used 10-μm pore-size filters to represent the unconsolidated sands in the injection zone.

The results of the LLL high-pressure membrane filtration tests demonstrated that raw brines cannot be passed through 10-μm pore-size filters without reducing throughput rates significantly. However, throughput-rates were maintained when brine was filtered upstream of the membrane filter.

To estimate the useful life of injection wells, we used an analytic method based on an interpretation of membrane-filtration data. This method assumes that injection rates decline when particulates are deposited and cake within the wellbore or on the sand face, or when they invade the injection zone. The resistance of the particulate-derived cake, together with the resistance of the natural geologic formation, leads to rapidly decreasing injection efficiency. Table 1-2 summarizes injectability test results for the SPR sites.

1.3.4 Brine Processing

We equipped our test facility with four small-scale, granular-media downflow filters that could be backwashed. Each filter was constructed from 0.10-m-diam Lexan and was equipped with the flow- and pressure-monitoring instruments needed to quantify performance.

To establish performance efficiency under various conditions, we operated the filters with and without chemical coagulants and aids and with different filter media. Because there was little or no documentation on the performance of chemical coagulants in hypersaline brines, we used conventional jar-testing procedures to field-test numerous coagulants. With experimental scale-filtration systems (systems having a throughput rate of 6×10^{-5} m^3/s), we subsequently verified that high-molecular-weight, anionic polyacrylamide polymers are effective coagulants in brines. However, we found that the activity of these compounds was inhibited by the presence of residual hydrocarbon contaminants or by reduced salinity. Under these conditions, nonionic polymers were more effective filter aids.

At the Bayou Choctaw site, we were able to compare the results of our subpilot scale-filtration tests directly with data generated from larger capacity granular-media filters that were operated simultaneously. These larger capacity commercial pilot systems were part of an independent DOE-funded study to identify the most cost-effective commercial filtration system for installation at SPR sites. We found the LLL systems consistently capable of producing processed brines with less than 0.3 ppm (by weight) suspended solids, a performance equivalent to that obtained with the larger commercial systems. In general, the combination of chemical pretreatment and granular-media filtration is an effective method for removing particulate matter in hypersaline brines. The LLL jar-testing procedure for systematic screening of active chemical coagulants and filter aids and our use of subpilot filters are cost-effective field evaluation techniques.

1.3.5 Corrosion Assessment

The injectability test data indicated that the quality of raw brines declined significantly between the outlet of the surge ponds and the injection wellheads and that differences in the filtration properties of raw brines were caused by the production of new, iron-rich particulate matter (magnetite--Fe_3O_4) from corrosion of the injection-system pipeline. Therefore, we ran several tests designed to assess the corrosiveness of untreated brines and to identify possible remedial procedures.

We measured the dissolved oxygen in process streams and observed that cavern brines became oxygenated as they flowed through surge ponds, while dilution water and weak leach brine were saturated with atmospheric oxygen initially. We also noted that corrosion rates increased significantly in oxygenated brines.

To reduce the corrosion rates to acceptable levels, it was necessary to remove oxygen from injected brines. The simplest method involves injecting oxygen scavengers into effluents before they enter the injection-system piping. Because no data for assessing the efficiency of oxygen-scavenging systems in hypersaline brine were available in the literature, we conducted a series of kinetic experiments to measure the oxygen-scavenging rates directly. These experiments helped to identify the optimum scavenger-catalyst system for the various SPR sites.

At West Hackberry and Bayou Choctaw, we checked the results of our oxygen-scavenging kinetic experiments with on-line dynamic experiments. The test setup for these experiments is included in Fig. 1-3. We passed brine through a 50-mm- (2-inch) diam pipe at a velocity equivalent to the nominal velocity [about 1 m/s (3 ft/s)] in the main injection-system piping, and we provided an injection point for the scavenger (sulfur dioxide gas) and catalyst (copper chloride) near the influent point. Electrochemical corrosion probes were inserted in the line at points upstream and downstream of the scavenger inlet. An almost instantaneous decrease in corrosion rates occurred from about 0.6 mm/y (24 mils/y) in raw brine to 25 μm/y (1 mil/y) or less in scavenged brine.

The use of oxygen scavengers is imperative when brine is injected at rates of up to 150,000 bbl/d because the scavengers have the potential for eliminating, for each ppm of dissolved oxygen, up to 37.6 Mg (8.28×10^4 lb) of iron-rich particulates per year. In addition, a significant reduction in corrosion rates contributes to the overall integrity of the injection system. Bacterial-induced corrosion phenomena will probably not be a significant problem in the disposal of hypersaline brines. However, periodic evaluations would be desirable to establish whether sulfate-reducing bacteria are adapting to the hypersaline environment.

1.3.6 Reservoir Assessment

An analysis of reservoir properties is critical to understanding the performance capabilities of subsurface disposal systems. Reservoir assessment was an integral part of our examination of existing SPR injection capabilities. In conjunction with Keplinger and Associates, we undertook a detailed analysis of all available geologic and geophysical data for the Bayou Choctaw SPR site. We also completed a well test program at Bayou Choctaw. From these data, we reconstructed the subsurface stratigraphy and structure and estimated the total reservoir volume available for storage of injected effluents to determine if reduced injection rates reflected poor brine quality or insufficient reservoir capacity. From our preliminary assessment, we concluded that the reservoir capacity was sufficient and that design injection rates of 30,000 bbl/d were possible; however, we found that the formation adjacent to the injection wells had been seriously invaded by fine particulates and irreversibly plugged during initial drilling operations and by subsequent injection of untreated effluents. Our work indicated that preinjection brine-processing systems should be installed as soon as possible at SPR sites where long-term injection will be required.

1.4 RECOMMENDATIONS

1.4.1 Reservoir Assessment

1. Standard oil field drilling practices should be implemented in the SPR project with emphasis on drilling fluid and corrosion control programs.
2. A Drilling Advisory Group should be formed to review all future well plans and drilling, coring, and well completion operations.
3. Specific responsibilities should be allocated to members of the advisory group in their areas of expertise. It will be incumbent upon the group to coordinate properly among themselves; under no circumstances should there be more than one final authority in any phase of the operation of the wells.
4. Future selection of drilling contractors should be based on the ability of prospective contractors to perform and on their history of success under similar conditions. Drilling contracts should be awarded to companies with local knowledge and local crews. Rigs should be inspected prior to the award of each contract.
5. New SPR wells should be gravel-packed, screened, and backwashed using compressed airlift techniques. For initial testing, only treated, filtered brine should be injected.

6. Before injection operations begin on any new well, the surface filtration and scavenger systems now under consideration must be on line and in full operation.
7. Effective and reliable operational well data collection procedures should be implemented at all SPR sites.
8. A comprehensive testing program for all sands penetrated by existing SPR injection wells should be completed to assess the extent of skin damage caused by the injection of untreated brine.
9. A plan should be formulated for recompletion of damaged injection wells if skin damage is too severe for remedial workover (i.e., acidizing).
10. Effective injection monitoring and maintenance programs on all data recording equipment should be implemented at all SPR sites.
11. Effective supervision of all injection well operation and maintenance schedules should be implemented on all SPR sites.
12. A Phase II program is recommended to evaluate the other SPR sites in sufficient detail to define present geological conditions and necessary remedial responses to improve well injectability and operational longevity. Initial emphasis should be keyed to the development activities at the Sulphur Mines site in an effort (a) to obtain proper baseline geological data (e.g., cores), initial formation fluid samples, and initial temperature and pressure data; and (b) to ensure that proper drilling completion practices are employed. Such baseline data may be generally or specifically useful in reconstructing initial subsurface conditions at the other SPR sites. In particular, potential formation water sensitivity problems and injected effluent--in situ fluid incompatibility problems should be addressed.

1.4.2 Brine Characterization

Based on our experiences at the three SPR sites, a schedule for periodic chemical monitoring of SPR fluid streams has been prepared and is summarized in Table 1-3. Periodic chemical monitoring activities are essential to maintaining proper functioning of the brine conditioning and injection systems. The frequency of sampling and analysis is based on continuous brine disposal at rates on the order of 10^5 bbl/d. During periods of intermittent operation, the frequency of analysis could be reduced. Except for solids phase identification, most of the analytical requirements can be satisfied by on-site personnel using conventional water analyses kits. The quarterly comprehensive analytical requirement should be satisfied by a local contractor. An annual assessment of the potential for adaptation of sulfate-reducing bacteria to hypersaline brine should also be conducted by a contractor.

1.4.3 Preinjection Brine Clarification

1. Filtration of all effluents injected at SPR sites is mandatory for satisfactory operation of brine disposal wells.
2. The surge ponds at SPR sites should be improved where possible to enhance their utility as settling basins.
3. Pond berms should be cleaned and paved to eliminate the introduction of extraneous solids that contaminate injected effluents.
4. An evaluation should be made to determine the feasibility of covering surge ponds to eliminate wind-induced disturbances that interfere with particulate settling and introduce new wind-blown debris.
5. While technically feasible, the potential benefits of prefiltering cavern leach waters do not appear to justify added costs.
6. A single effluent filtration system should be installed at an appropriate point in the main SPR site injection lines for the conditioning of all injected effluents.
7. Suitable granular media clarification systems for SPR sites are summarized in Table 1-4.
8. Granular media filtration systems requiring chemical feeds should be equipped with coagulation control centers to regulate chemical additives and feed rates in accordance with varying brine characteristics.
9. Stringent operational monitoring and quality control measures should be instituted to ensure proper operation of filtration systems at SPR sites.
10. Residual polymer in clarified effluents are a potential cause of injection well impairment. This problem should be more fully evaluated. In particular, a disposable cartridge filtration system should be evaluated as a possible method for removal of excess polymer from conditioned effluents prior to injection.

11. Subpilot tests should be run at new SPR sites in order to establish brine conditioning requirements.
12. Postprecipitation tendencies of processed effluents should be part of the evaluation process of clarification requirements at all new SPR sites.
13. Since ultrafiltration is effective without chemical pretreatment and is relatively insensitive to changing brine conditions, it merits further evaluation for clarifying large quantities of brines.

1.4.4 Corrosion Control

1. Oxygen scavenging systems at all SPR sites are required to eliminate corrosion product-induced damage to injection wells.
2. An effective oxygen scavenging system for hypersaline brine consists of a sulfur dioxide scavenger and copper or cobalt catalyst.
3. Biocide additions are not required to control growth of sulfate reducing bacteria in SPR injection systems. Nearly saturated brine is apparently an effective biocide. However, a more detailed evaluation of the cavern inflow leaching system might be warranted since fresh water with high biological activity is employed for this operation.
4. Oxygen scavenging systems should be integrated with brine filtration plants to control overall costs.
5. A routine monitoring program for each site is desirable to ensure satisfactory performance of the oxygen scavenging systems.

TABLE 1-1. Characteristics of process streams at SPR sites.

Source of process stream	pH	Density, g/mℓ	Constituents, mg/ℓ							
			Cl^-	Dissolved Fe	Total Fe	Ca^{++}	$SO_4^=$	HCO_3^-	Dissolved solids	Suspended solids
West Hackberry										
Cavern	7.5	1.182	172,000	–[a]	0.19	650	1475	294	–[a]	–[b]
Surge pond	7.6	1.177	170,000	–[a]	0.40	612	1319	293	288,300	2.9
Injection site	7.6	1.176	167,000	–[a]	0.42	603	1250	296	288,200	3.3
Bayou Choctaw										
Cavern	6.8	1.197	192,000	–[a]	0.33	465	833	148	312,100	–[b]
Surge pond	6.8	1.196	191,000	0.14	0.34	398	700	148	312,800	10.4[c]
Injection site	6.9	1.189	184,000	0.17	0.62	380	650	159	–[a]	11.1
Lake	7.8	1.0	53	0.36	1.0	28	17	103	215	113
Weak brine	6.5	1.173	164,000	0.48	1.10	1060	1115	97	263,500	22.4
Bryan Mound										
Cavern	6.8	1.198	197,000	1.35	1.7	901	3000	110	291,800	–[b]
Surge pond	6.9	1.191	187,000	0.39	1.68	894	2275	112	278,700	4.5
Injection site	6.8	1.186	179,000	0.43	1.40	821	2375	116	308,800	6.8
River	8.1	1.0	240	0.28	0.43	58	80	153	528	–[a]

[a]Not determined.

[b]Unreliable because of salt precipitation.

[c]After 5 to 10% dilution with untreated lake water.

TABLE 1-2. Estimated half-life of injection wells at three SPR sites based on 10-μm membrane filtration data.[a]

Site	Pretreatment	Estimated half-life, yr, at indicated brine		
		Strong brine (surge ponds)	Injection wellhead	Weak brine (leach effluent)
West Hackberry	None	0.20	0.16	–[b]
	Filtered	50	7	–[b]
Bayou Choctaw	None	0	0	0.02
	Filtered	30[c]	–[b]	39
Bryan Mound	None	0.25	0.02	–[b]
	Filtered	50	53	–[b]

[a]The half-life of an injection well is the time required for the injection rate, at constant pressure, to fall to one-half of its initial value.

[b]Not available for testing.

[c]Direct filtration of strong brine was not feasible because of salt precipitation; therefore, the half-life estimate is based on the filtration of 90 strong brine and 10 dilution water.

TABLE 1-3. Recommended brine chemistry monitoring program.

Source	Type of analysis at indicated frequency			
	Daily	Weekly	Monthly	Quarterly
Pond input (caverns)	pH Density or Cl^- Temperature	Dissolved and total iron Dissolved oxygen Suspended solids >0.4 µm	$SO_4^=$, $CO_3^=$, HCO_3^-, Ca^{++}	Complete water analysis, including solid phase identification
Pond discharge	pH Density or Cl^- Temperature	Dissolved and total iron Dissolved oxygen Suspended solids >0.4 µm	$SO_4^=$, $CO_3^=$, HCO_3^-, Ca^{++}	Complete water analysis, including solid phase identification
Weak brine	pH Density or Cl^- Temperature	Dissolved and total iron Dissolved oxygen Suspended solids >0.4 µm	$SO_4^=$, $CO_3^=$, HCO_3^-, Ca^{++}	Complete water analysis, including solid phase identification
Injection site brine	--	pH, density, or Cl^-, temperature. Dissolved and total iron Dissolved oxygen Suspended solids >0.4 µm	--	--
Dilution water	--	pH, Suspended solids >0.4 µm	--	One-time complete water analysis

TABLE 1-4. Recommended granular media clarification systems for SPR sites.

Site location	Chemical additive	Concentration, mg/ℓ	Chemical type	Media construction	Comments
West Hackberry	Alum $Al_2(SO_4)_3$ $14H_2O$	3	Inorganic Al salt	Triple media (coal, sand, garnet) or dual media (coal, sand)	1. Less alum is required during periods of strong brine flow. 2. Straining without chemicals is sometimes effective.
Bayou Choctaw[a]	Visco 3340	2-4	Anionic polymer	Triple media (coal, sand, garnet)	1. Polymer does not work in the presence of oil contamination. 2. Dual media filter is effective, but at a lower total throughput. 3. During periods of strong brine injection alum may be necessary in place of Visco 3340.
Bryan Mound[a]	Alum + Cyfloc 4500	10 + 0.2	Inorganic Al salt + nonionic polymer	Triple media (coal, sand, garnet)	--

[a]Ultrafiltration without chemical aids was tested at these sites and was as effective and less sensitive to changing brine conditions.

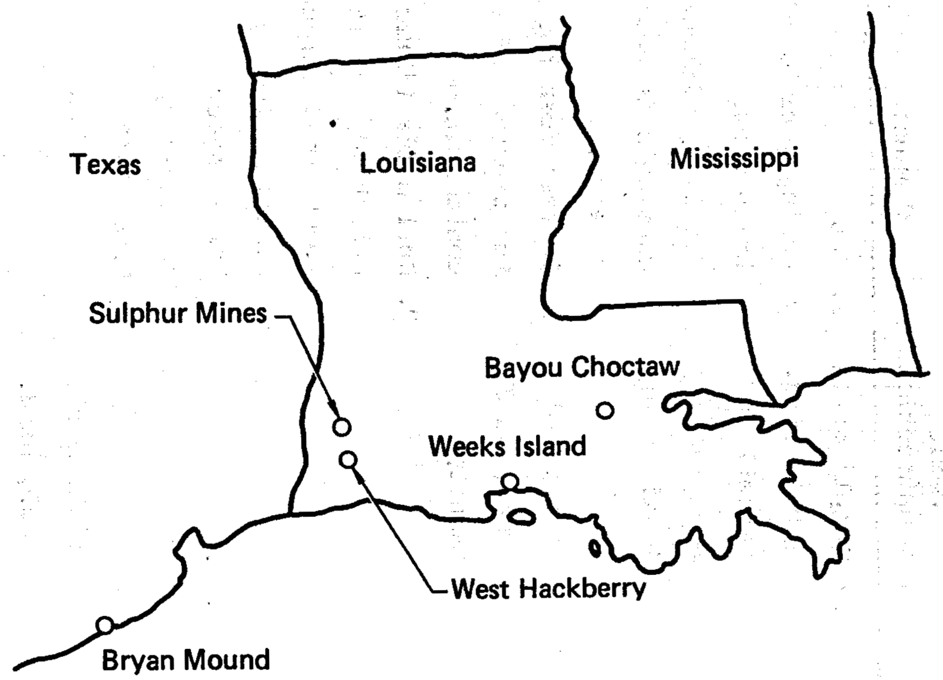


FIG. 1-1. Map of coastal Louisiana and Texas, showing SPR sites for crude-oil storage. When completed, the Weeks Island salt dome will provide a dry storage capacity of 89 million barrels (in the form of two mined, near-surface chambers). The anticipated fill-withdrawal rates of the two chambers are 50,000 and 60,000 bbl/d, respectively. The other storage sites--West Hackberry, Bayou Choctaw, Sulphur Springs (under development), and Bryan Mound--are deep, water-leached caverns in subsurface salt domes. Approximately 87 million barrels of crude oil are now stored in these deep caverns, and their total storage volume will be expanded to 210 million barrels when fresh-water leach-mining techniques are used to create new caverns in the subsurface salt domes. A disposal pipeline for transporting brine to the Gulf of Mexico was completed at Bryan Mound during the summer of 1979. Construction of a Gulf disposal pipeline for West Hackberry should take about 2 years.

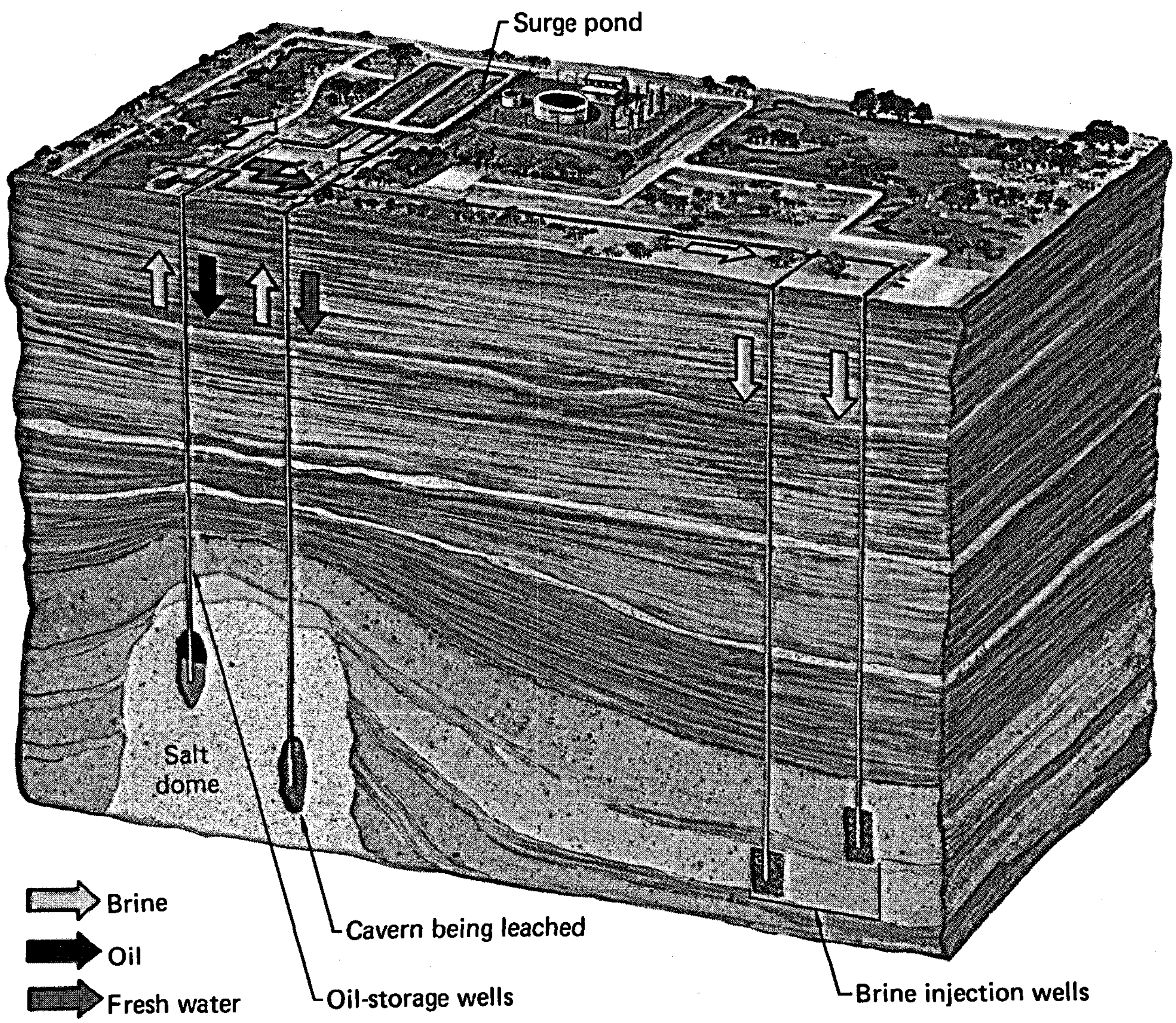


FIG. 1-2. Oil-storage and brine-disposal system. In this system, oil is pumped into a salt dome, displacing equivalent amounts of brine from leached caverns into surface surge ponds. The displaced brine is then pumped from the surge ponds into injection wells located up to 4 km away. New caverns are leached in the salt dome by injecting fresh water. The weak (undersaturated) leach brines displaced to the surface are also pumped to the injection wells.

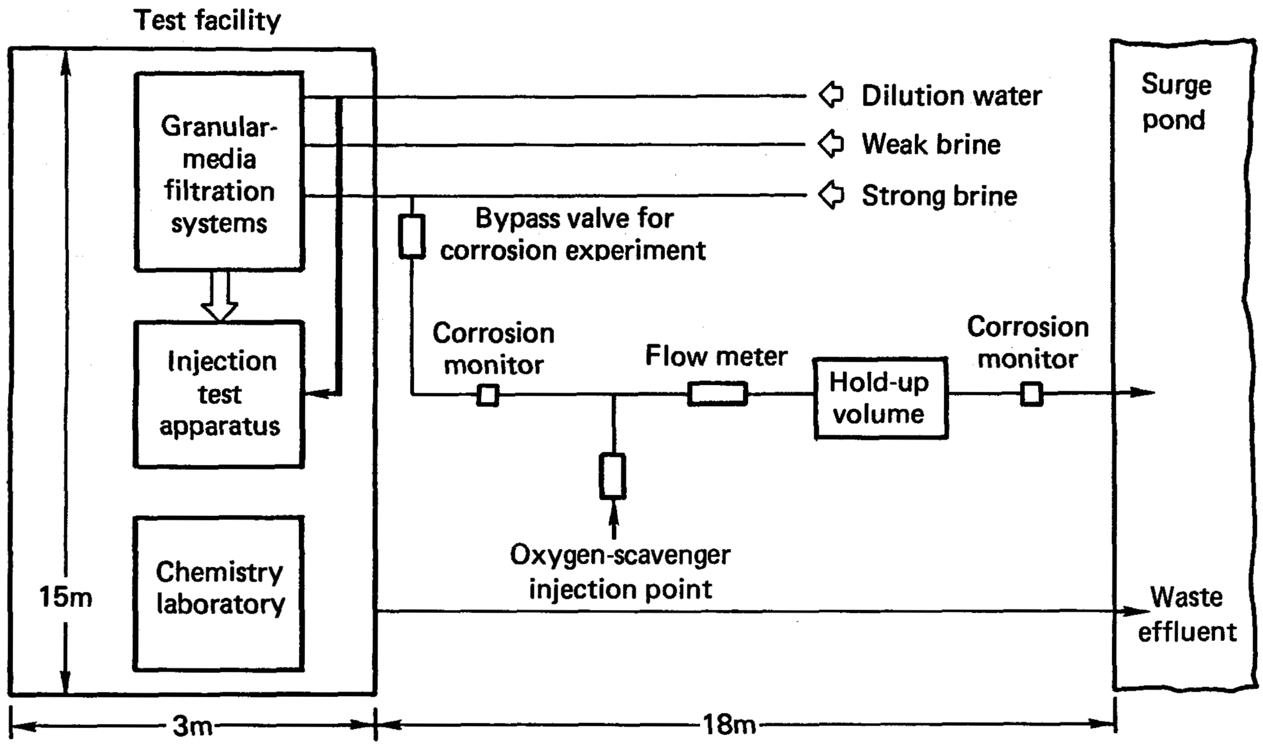


FIG. 1-3. Plan view of the LLL test facility. Lines leading into the trailer carried process streams for granular-media filtration and injection tests.

CHAPTER 2

RESERVOIR ASSESSMENT

M. D. Campbell,* G. Mistrot,* and D. Towse

2.1 INTRODUCTION

Keplinger and Associates, Inc., performed the Phase I evaluation of the Bayou Choctaw SPR site. Keplinger also evaluated the drilling and completion techniques used at all SPR sites where data were available. Subsurface reservoir testing was designed and conducted on selected injection wells at Bayou Choctaw. Regional injection well histories were reviewed to characterize the typical problems encountered in high-volume brine injection systems and to summarize pertinent industrial practices that related to the SPR program. As part of the development of a Phase II program, a summary, based on the results of Phase I, was prepared of the critical path topics that would need immediate detailed evaluation and response. The Phase II program emphasizes Bayou Choctaw and Sulphur Mines, with priorities to be designated by DOE for West Hackberry and Bryan Mound.

2.2 GEOLOGICAL INTERPRETATIONS

A geological evaluation was undertaken for the SPR Bayou Choctaw site, and all available data were incorporated in the evaluation. The Bayou Choctaw injection field site was selected because it is located in an area near the storage site that is not significantly influenced by faulting surrounding the Bayou Choctaw dome and by nearby growth faults. Although there would be other equally good sites for brine injection nearby, there is no reason to anticipate that any would be superior to the one chosen. The Miocene sand intervals extend from approximately 3300 feet to below 8000 feet. The intervals chosen for brine injection are from 4345 to 7710 feet, and they consist of sands with excellent permeability. The miocene section is a widely used section for brine injection along the Gulf Coast.

---

*Keplinger and Associates, Inc., Houston, Texas.

2.2.1 Permeability and Porosity

Conventional cores are available from only two wells in the Bayou Choctaw injection field, but sidewall cores are available from nine wells (Appendix I). Core analyses and log interpretations indicate consistently high porosity (generally 30 to 36 percent) and permeability (generally over one darcy). The sands are fine- to coarse-grained, and the only available sieve analysis indicates only 4 percent silt and clay. Values of silt and clay content derived from Saraband-type logs could be excessive because of uncorrected effects of shallow invasion.

The self-potential curve as well as the gamma-ray, resistivity curve and the neutron-density cross plot are used to calculate the silt and clay percentages. When the self-potential is reduced by the effects of shallow invasion, the Saraband computer program interprets this as a clay increase; actually, however, the shallow invasion indicates a sand with decreased clay content. It should be noted that there are other possible causes, such as radioactive mineral content, for this excessive shale value.

Sidewall core permeabilities could be unreliable because of distortion caused by the percussion sampling, but the values given by the analyses are quite reasonable. Although theoretically there would be greater compaction with depth in the interval 4345 to 7710 feet, no significant change in porosities or permeabilities is indicated via log calculations. No core data were available from the deepest sand, Sand Interval 8, but log interpretation indicates that it may be just as porous and permeable in both the vertical and horizontal directions as the shallower sands.

Keplinger performed a sand count on Well 1. This well was chosen because it was deep and because it was drilled with a fresher mud, thus making the sand count more precise. The sand count indicated 72 percent sand and 28 percent shale from 3500 to 7560 feet. At the present time, 12 injection wells have been drilled on three pads (Plate IV). All sands can be easily correlated throughout the injection field and beyond. Lenticularity is noted in both the predominantly sandy intervals and in the predominantly shaly intervals.

Evidence from the logs suggests that much of this lenticularity in the sand intervals is sand-on-sand lensing which usually will not limit the reservoir for injection purposes. There would probably be some vertical permeability reduction at sand lens boundaries. If the boundary was a few feet away from the wellbore, it probably would not affect injectability or be noted on pressure response testing.

The environment of deposition is interpreted as a sand delta. This is a high-energy delta with sand-on-sand lensing as contrasted to a low-energy shale delta where bar sands occur as isolated lenses in a predominantly shale section. The upper half of the section (3500 to 5500 feet) is primarily of interbedded thick sands and thin to thick shales. The lower half (5500 to 7500 feet and deeper), however, contains thin lignite and limestone beds.

The high sand percentage also indicates that even if minor faulting is present, it would not limit the reservoirs for injection purposes since sand units would probably be faulted against other sand units allowing for a continuous reservoir. Such a fault contact would lead to a minor, insignificant reduction in permeability.

2.2.2 Faulting

The structural interpretations indicate two common patterns of faulting in the general region of the Bayou Choctaw injection field. One is a radial pattern of faulting around the shallow salt domes, such as the Bayou Choctaw dome. This pattern dissipates a mile or so from the dome and also dissipates at shallow depth. The other familiar salt dome fracturing pattern is that of a central graben, which is not common in this area. Bayou Bleu dome, 6 miles southwest of the Bayou Choctaw dome, however, does have a central graben.

The other common pattern throughout the Louisiana and Texas Gulf Coast is the growth fault, which is a result of adjustments via deformation caused by sediment load. This type of fault is typically downthrown toward the center of the basin; downthrown is toward the south (or slightly east of south). The fault through Bayou Plaquemine, located 2 miles south of the injection field, is probably of this type although the regional mapping does not show its continuation east and west (Plate II). These faults would tend to give greater transmissibility east and west or along strike instead of down dip.

There are two faults to the northwest of the injection field. One is regional and extends from the Bayou Choctaw dome to the Bayou Bleu dome. The other is apparently radial from the Bayou Choctaw dome (Plate III).

2.2.3 Baseline Subsurface Pressure and Temperature

Normal formation pressures and temperatures exist in the injection zones (Appendix III). The geothermal gradient is approximately 1.0 deg F/100 feet, which would yield temperatures of from 120 F in Sand Interval 2 to 153 F in Sand Interval 8. The temperature of the injection zones would be lower because of the injection of cooler brine which was measured at 70 F in Well 3, 27 hours after 50 hours of brine injection.

The pressure gradient is approximately 0.4487 psi/ft, which is normal for a column of water ranging from fresh at the surface to approximately 130,000 mg/ℓ at a 7000-foot depth.

2.2.4 Baton Rouge 2800-Foot Aquifer

Based on work by Smith,[1] Magorian has identified Sand Interval 1 as one of the lower sand units of the Baton Rouge 2800-foot aquifer.[2] Correlations published by Smith have now been reviewed. Correlations have been attempted between the nearest well used in Smith's cross sections (Amerada Petroleum Corporation #1 Aillet Est. et al. Unit, Sec. 102 T S 12 E West Baton Rouge Parish, Louisiana) and wells in the brine injection field. The correlation between the known 2800-foot aquifer and Sand Interval 1 is questionable. In addition, the fresh water portion of the 2800-foot aquifer is separated from Bayou Choctaw field by a major growth fault, the Addis Fault (bounding fault of the West Addis field) and the Baton Rouge fault.

The tests conducted in the Bayou Choctaw injection field indicate a strong southeast flow in Sand Interval 6 (25 psi in 4000 feet). The magnitude and possibly the direction of this hydraulic gradient are in question because Sand Interval 6 is probably in communication with Sand Interval 5 in Well 1. Well 1 was open to both sand intervals and may not have been properly sealed. The most likely gradient in Sand Interval 1 is to the south, although it may be slightly southeast or southwest. Any brine deliberately or accidently injected into Sand Interval 1 should tend to flow away from the Baton Rouge aquifer. Based on our preliminary evaluation, saline water encroachment in the 2800-foot sand or any other Baton Rouge fresh water aquifer appears to be highly unlikely. Further study, however, is merited to substantiate this position. A monitoring program, discussed elsewhere in this report, is capable of monitoring the behavior of Sand Interval 1 under conditions imposed during injection operations (Section 2.3).

2.2.5 Overview

The geological data indicate that although lenticularity and very minor faulting may exist, the injection reservoirs appear to be continuous over many square miles. This conclusion is supported by the reservoir-limit, continuity tests conducted in Sand Interval 6. In addition, the most recent fluid level measurements in Sand Intervals 2, 3, 6, and 7 indicate that present formation pressures are not appreciably different from initial formation pressures after the injection of 700,000 to 3,000,000 barrels into each injection interval. No value is available for Sand Interval 5. Formation pressure is discussed further in Appendix III.

2.3 WELL LOGGING PROGRAM

The well logging program employed during the construction of the SPR injection wells was reviewed. In particular, the log type and applicability were assessed.

The typical logging program for the 12 brine injection wells at Bayou Choctaw and one well at Sulphur Mines is as follows:

1. ISF-Sonic Induction--Spherically Focused Sonic log from surface casing to total depth;
2. Compensated Density log;
3. Gamma-Ray--Neutron log;
4. Cement Bond log; and
5. Borehole Geometry log (oriented 4-arm caliper).

The logging program was sufficient to evaluate the formations, the well, and the cement bond. However, only Bayou Choctaw Well 1 had a continuous dip meter log. One of the most important logs that can be run in wells drilled around salt domes is the dip meter; all future well logging programs should include this log. Wireline formation tests were run (unsuccessfully) in Well 1.

Although several of the early wells drilled had selected logs digitally recorded so that computer analyses could be performed, the practice was discontinued in the later well logging program. Computer analysis of digitized logging data permits rapid determination of a large volume of data giving percentages of sand, shale and certain other selected lithologies and porosities and saturations corrected for lithological variations. However, excessive percentages that must be adjusted by other techniques may be calculated.

The ISF-Sonic, or equivalent, log run by companies other than Schlumberger, is the basic log used for geological correlation. The SP curve run with it, in addition to its correlation function, gives formation water salinity data, and distinguishes sand from shale (a sand count, or sand-shale ratio is commonly derived from this curve).

The two resistivity logs, in addition to their correlation function, enable the determination of true formation resistivity and water saturation and to some extent enables the identification of other lithologies. Mud filtrate invasion can also be evaluated qualitatively.

The sonic log, measuring acoustic travel time, is one of the porosity measuring devices and furnishes other lithological data.

The compensated density log measures formation density in grams per cubic centimeter and is the best porosity log for lithology encountered in the area of Bayou Choctaw. In addition, it furnishes other lithological and geophysical information.

The gamma-ray-neutron log also serves a correlation function. The gamma-ray (or natural-gamma) log identifies shale and helps determine other lithologies. This log also can be useful in other applications (Section 2.3.1). The neutron curve is another porosity curve. In combination with the density log, the neutron curve identifies gas saturation and furnishes other lithological data.

The cement bond log assesses the quality of the casing cement job by determining bond to both pipe and formation and detects channels in the cement.

The borehole geometry log (or 4-arm caliper) permits a more accurate determination of hole size and shape for determining cement volume in cement jobs and gravel volume required in gravel packs.

The continuous dip meter log, in addition to permitting determination of formation dip, gives information on crossbedding attitudes in sand bodies to permit assessment of depositional environment and is valuable in identifying fault cuts and unconformities.

Monitoring of injection wells to be certain that brine is being injected into the designated zones is often accomplished by means of temperature surveys run after a reasonable period of injection. Thief zones can develop either through accidental pressure parting of continuous shale beds or through failures of casing or cement sheath.

The original formation brine temperature in this area is in the range of 120 to 150 F, and the injected brine temperature is approximately 60 to 70 F. Therefore, a significant contrast in temperature, even with a small leak, should be apparent.

Well 3 is completed in Sand Interval 6 (6720 to 6970 feet). A spinner survey run March 19, 1979, showed that about 30 percent of the injected fluid passed through the "tell-tale" screen that was opposite Sand Interval 5. A subsequent spinner survey indicated that approximately 50 percent of the injected fluid passed through the tell-tale assembly. This caused concern that the casing might be parted above the completed interval. The spinner surveys also indicated that most of the remaining fluid went out through the lower portion of the screen intervals.

The temperature log run March 16, 1979, about 27 hours after injection, indicated that the brine had uniformly entered the entire injection zone (constant temperature of 70 F from top of screen to TD). Brine had not entered Sand Interval 5 (temperatures above 110 F). There is a small anomaly from the top of the tell-tale down caused by the additional cooling of the flow down the annulus. Three conclusions can be made: (1) no casing parted; (2) no brine traveled from the wellbore above the completion interval or entered Sand Interval 5; and (3) brine flowed down the annulus from the tell-tale screen and entered the upper part of Sand Interval 6.

The gamma-ray (or natural-gamma) log can detect brine movement between injection intervals. As brine moves into the wellbore it will precipitate radioactive concentrations at the point of entry. If the fluid flows up around the pipe, its path also will be marked by increased radioactivity. Since the baseline gamma-ray logs on each well are available, small changes in radioactivity can be detected. Logs run at a later date will indicate the extent to which brine has moved between injection intervals.

The neutron lifetime log (or Schlumberger TDT log) in a cased hole can differentiate in a nearby well (within a few hundred feet) between injected brine (200,000 ppm Cl) and formation brine (70,000 ppm Cl). This log can also be used to trace movement of injected brine using independent physiochemical responses of the injected brine as a guide to its movement over short distances, e.g., behind pipe channels. A brine-soluble radioactive tracer can be added to brine in an up-gradient well, e.g., Well 10 and detected in a down-gradient well, e.g., Well 12. If the tracer-identified brine appears on top of the previously introduced brine, it would suggest that the permeability was seriously reduced wherever the brine has flowed. If the tracer was diffused throughout the brine column in the down-gradient well, it would suggest there was no serious restriction in the flow path of the brine between wells.

Welex is developing a "water movement log" that reportedly will detect salt water movement in the formation through a cased hole, and a planned variation will detect the direction of salt water movement in a cased hole. When available it may be useful in evaluating the direction of flow, e.g., in Sand Interval 1.

An inexpensive monitoring program to protect the Baton Rouge 2800-foot aquifer could be implemented using a temperature survey, soon after a period of injection on Wells 6, 9, and 11 (all completed in Sand Interval 2). This program would be designed to monitor possible entry of injection brine into Sand Interval 1 through casing leaks, faulty cement jobs, or inadvertent ruptures of the shale beds separating the two sand intervals. Natural-gamma surveys for these wells would be optional, but probably should be run if supporting information is required. In addition, temperature surveys and natural-gamma logs should be run in Bayou Choctaw Wells 1 through 8, 10, and 12 from the present total depth of well to above Sand Interval 1 (about 3800 feet below the surface). The first well should be logged to surface; if no significant anomalies are noted above 3800 feet, the upper section need not be logged in subsequent logging jobs.

In addition to monitoring the integrity of the seal between Sand Intervals 1 and 2 and the integrity of the seal above each injection zone, the logging methods discussed above are expected to (1) demonstrate the extent of movement of the injection front; (2) characterize the degree of mixing between injected brine and formation water; (3) determine degree of continuity of shale beds within the major sand intervals; and (4) indicate any interchange of fluids between sands within the wellbore (flow to "thief" zones).

Because density will dominate the flow patterns of the injected brine, the degree of mixing is of significant importance in monitoring the introduced brine after it enters the formation. The temperature survey is sufficient to monitor where the fluid is leaving the well. In a general sense, the only question remaining is whether the reservoirs are capable of accepting the anticipated volumes. Accurate information on injection rates and bottom hole pressure surveys usually provide the necessary data for assessing the potential capabilities of the reservoir.

The invasion patterns shown on the induction electric logs indicate very high horizontal and vertical permeabilities. Very few barriers to vertical permeability appear to be suggested by the invasion pattern.

2.4 SUBSURFACE INJECTION PRACTICES

A review was undertaken of the existing data on injection well systems in the region as well as data from other brine injection systems throughout Louisiana and Texas. In addition, when possible, the similarities in standard injection system practices and the SPR program were indicated.

The petroleum industry has been injecting oil field brines in the subsurface for more than 45 years. It has been estimated that more than 45,000 brine injection wells are in operation within the continental United States at the present time.[3] Of these, over 20,000 wells are in Texas and Louisiana. The number of satisfactory and successful installations of high-volume deep-injection wells is growing at an increased rate. The popularity of underground injection and storage has increased substantially in the last few years as petroleum and industrial operations have become more complex and as state and federal agencies have become more stringent with surface water quality requirements and regulatory criteria.

Well injection systems, however, have their limitations. All areas of the United States are not suitable for injection well systems. Experience has shown that the subsurface geological conditions necessary for economically viable waste injection systems are zones of sufficient permeability and hydraulic capacity to readily accept the volume to be injected. Such geological conditions are found in about one-half of the land area of the United States, predominantly in the Central Plains states and the coastal areas of the Southeast. These injection systems are heavily concentrated in the Northcentral and Gulf Coast areas of the United States. The SPR program utilizes the Miocene age sands in the Gulf Coast region. As described in Section 2, the use of the Miocene is not unusual, for such sand intervals constitute excellent injection reservoirs.

In the entire Gulf Coast region of Texas and Louisiana, there is a minimum of 1000 feet of highly permeable sandstone intervals within the zone between 2000 and 6000 feet deep. Extensive exploratory drilling in this region has yielded sufficient subsurface information to permit adequate mapping of subsurface structure and general reservoir characteristics. Sufficient information is also available to establish, within reasonable limits, the anticipated drilling conditions.

2.4.1 Brine Injection Performance in the Gulf Coast Area

High-volume injection has been frequently demonstrated in the Gulf Coast region. There are several examples of individual well injection rates of 35,000 bbl/d or more.[3] As an example, an injection field that utilizes the same geologic and reservoir parameters as found at the SPR sites is in operation; it has injected 30,000 bbl/d/well for the last 10 years. In addition, over 75 active injection wells in Louisiana have had injection rates of over 25,000/bbl/d since 1968. These wells are completed in reservoirs similar to those indicated at the SPR sites (Section 2.2). In the areas near Bryan Mound, Texas, rates as high as 30,000 bbl/d/well are known, and the wells have been operated for extended periods of injection.

Most high-rate injection systems have been properly designed and operated. Several high-volume injection wells have been failures as a result of poor knowledge of the subsurface conditions, such as low sand/shale ratios and faulting of the selected injection intervals. Poor well design and construction are also indicated factors in subsequent well failures.[4] In addition, at least 25 percent of high rate wells have been plugged and abandoned because of improper or nonexistent surface treatment facilities. In general, it has seldom been possible to inject large volumes of untreated brine over an extended period. Thus, pretreatment (surface filtration) is universally accepted by the industry as one of the most important requirements to the success of a brine injection program.

The well life is normally a function of the ability of the operator to backwash, acid treat, or perform other remedial operations to maintain or improve the injectability of the injection interval.[5] In all cases regarding brine injection in Texas and Louisiana, pretreatment of brine and backwashing operations are common practices. The formations in the area have the capability of accepting large quantities of brine. The principal operational objective is to maintain the permeability in and around the well bore. Backwashing of the injection interval is periodically accomplished in all successful operations and is routinely initiated when wellhead pressures increase to a predetermined level. With backwashing performed in a proficient manner, individual injection zones have been known to accept high-volume fluids for more than 10 years.

2.4.2 Well Planning Practices

Data from wells in the region are useful for anticipating drilling conditions and injection well design planning. Specific reservoir data are normally obtained from all prospective intervals before casing is set in the initial well drilled. In addition to logging, core samples are required to establish reservoir characteristics throughout the proposed injection zone or zones. The samples are normally analyzed for sand grain size, permeability, porosity, and silt and clay contents. In addition to core samples, formation fluid samples must be taken for compatability studies. The fluid sample is taken before any injection by backwashing the well to obtain a sufficient volume of uncontaminated formation water. Following an initial backwash operation, a static bottomhole pressure is generally measured with a pressure bomb in the hole after the final injection test. Based on these data, the initial flow capacity of the well is determined for evaluating future well performance. Potential injection reservoirs are selected from an evaluation of engineering and geological data obtained after the first test injection well of the field is drilled.

The deepest zone penetrated by the test well is usually selected as the initial injection zone. This procedure allows recompletion in the next shallower zone if performance of the deeper zone deteriorates because of formation damage or excessive injection pressures. The second well drilled might be completed in the next sand above the deepest zone initially completed, depending on the distance between wells and other factors. This procedure also allows for secondary completion zones, if required. Economic considerations must be made, however, because well cost depends directly on well depth.

2.4.3 Equipment and Material Selection Practices

The volume of fluid to be injected and the estimated injection pressure dictate the diameter of the tubing required. The tubing material should be carbon steel (coated to resist corrosion) or stainless steel. The annular space between the tubing and the casing is filled with a noncorrosive fluid. Clean brine with a corrosion inhibitor additive is a commonly employed annular fluid. The use of a screen and/or liner and packer is the preferred completion practice in the Gulf Coast region because it provides minimum pressure and flow restriction to the fluid injection. The gravel pack design restricts formation sand from caving and entering the well during remedial back-flushing operations. The use of a packer allows positive pressure control and keeps injection pressure away from the casing. The annular pressure is not constant since the injection tubing is subject to expansion and contraction, and temperature and pressure change. It is generally desirable to maintain annular pressure at a fixed differential above injection pressure (at 100 psi above). The physical condition of the tubing is of critical importance in all successful injection programs involving corrosive fluids.

The proper selection of drilling mud is extremely important to minimize hole washout and formation damage.[6] The mud should have sufficient water loss to maximize hole support but should not excessively invade and damage a potential injection formation.

2.4.4 Fluid Incompatibility and Corrosion-Incrustation (Scaling) Control

A factor that must be considered in detail during the early stages of a brine injection program is the quality of the brine to be injected. Solids content, chemical stability, temperature and pressure conditions, and corrosion and scaling potential must be established to determine the relative compatibility between the formation fluid and the brine to be injected and between the brine and the well equipment with which the brine will be in contact. Injection fluid compatability with the indigenous formation fluid is mandatory to avoid subsequent formation plugging.[7]

Casing and cementing programs must be designed to meet corrosion protection requirements. Corrosion protection is normally planned and designed to protect both surface and downhole equipment.[5]

A surface filtration system is required when fluid injection is anticipated in a porous medium reservoir. With reservoirs in a fractured reservoir, however, filtration may not be required. The function of a filter system is to trap solids. Hence, periodic backwashing of the surface filter system removes the trapped solids before such solids can enter the injection well and seriously reduce injection capacity. It should be emphasized that backwashing of the surface filter system is economically preferable to backwashing the formation. A surface filter is easier to clean than a plugged injection interval thousands of feet below the surface. The formation is the final filtration system, and its functional longevity depends directly on the extent to which solids have been removed at the surface via filtration systems.

In considering surface filtration system requirements, two major features are examined: (1) the maximum particle dimensions the injection formation will accept, and (2) the maximum total-solids content that the surface filtration system is capable of removing economically. The design of the surface filtration system is also affected by the following factors:

1. physical characteristics of the solids contained in the brine both before and after surface filtration;
2. density of the solids to be introduced to the injection interval;
3. chemical characteristics of the brine (e.g., pH and temperature); and
4. volume of fluid to be injected a function of subsurface reservoir storage capacity, i.e., porosity, thickness, permeability, and compatibility of formation brine and matrix mineral constituents (clays) with brine to be introduced.

Surface facilities are designed so a nonplugging, compatible fluid is injected into the target formation or sections thereof. The following subsystem design features are normally incorporated in brine injection systems:

1. closed system with oxygen scavengers (to remove O_2 from the brine and subsequent corrosion of piping and tubing);

2. gas separation (to prevent two-phase segregation in the injected formation);
3. chemical treatment (to reduce incompatibility between formation brine and matrix and the brine to be injected);
4. settling filtration (to reduce solids content of brine to be injected)*;
5. wellhead filtration (to serve as polishing filters to reduce post-filtration system solids input to formation); and
6. equipment utilizing corrosion resistant materials (to increase well systems longevity and maintain formation injectability).

2.4.5 Systems Monitoring Practices

Brine quality, injection pressure, temperature, corrosion inhibitors, and injection volumes must be rigorously monitored periodically in both surface and down-hole systems. It should be reemphasized that the formation is the final filtration system, and its longevity and utility in addition to the longevity and utility of the injection well equipment are solely dependent on the characteristics of the fluids to be injected and the solids they contain. Surface systems designed to reduce solids content are periodically backwashed while subsurface systems, which include the screened or perforated intervals of the well structure are backwashed only as a final attempt to improve injectability and to prolong the functional life of the system. The most economically feasible surface filtration systems will pass certain quantities of solids with time, resulting in plugging that cannot be removed via backwashing or acidizing.

2.4.6 Remedial Methods and Practices

2.4.6.1 Well Longevity. Based on our evaluation, the capacities of injection wells deteriorate with time. This is usually the result of plugging in the formation with mineral precipitates, solids and with other materials carried in the water after surface filtration systems have either failed, or have been improperly maintained or have been bypassed during downtime of filtration systems.

*Open settling ponds to achieve settling filtration have created serious oxygen problems in the SPR programs. See Ref. 7.

Scale deposits in the tubing have been shown to increase the friction and reduce the capacity of injection well systems. Case histories report that scale deposits have been found in certain parts of the well exposed to brine, i.e., on tubing interior, on screens, and on the face or within the injected formation. This can be a result of the commingling of two or more brines of different chemical compositions or as a result of changes in temperature or pressure or both. Some of these deposits are calcium carbonate, introduced or precipitated iron oxide, iron sulfide, barium sulfate, strontium sulfate, calcium sulfate, and various other forms, some of which are precipitated as a result of bacterial activity (e.g., iron oxidizing and sulfate-reducing species).

Comprehensive and accurate records and appropriate supervision, such as maintaining accurate injection rate and pressure information is normally practiced to monitor formation response characteristics. For example, when injection pressure rises to a predetermined level, immediate action should be taken. Remedial expense can be minimized by backwashing or acidizing before serious formation plugging has occurred. Thus, expensive workover operations can be generally eliminated. The potential for scaling can be estimated by previously conducted compatibility tests. Once the relative potential is established, a remedial program can be designed and implemented if required. This predetermines the probable method for treating the well and often eliminates trial-and-error remedial methods. Without sound baseline data on original physio-chemical conditions of the brine to be injected and of the environment into which the brine is to be injected, remedial programs must of necessity be based on time consuming and costly trial-and-error methods.

2.4.6.2 <u>Backwashing</u>. Formation backwashing is the normal response to declining injectability. Nitrogen or compressed air lift to create high-velocity backwashing is in common use. If the interval is relatively shallow and if the casing is of sufficient diameter, submergible pumps can be employed to achieve cleaning. Davis[8] achieved some excellent results in backwashing with compressed air while conducting workover operations on Well 2 completed in Sand Interval 6, one of the deeper injection intervals of the Bayou Choctaw site. The effectiveness of such workovers, however, cannot be established as long as brine with high solids content is injected after a workover has achieved cleaning.

2.4.6.3 Acidizing. A common chemical workover technique is the injection and backwashing of hydrofluoric or hydrochloric acids in an attempt to improve well injectability. This technique assumes that the deposits are acid-soluble and are treated in the early stages of formation plugging. Hydrofluoric or mud acid will dissolve clay and mud around the injection well. Special additives can be used with the acid to prevent the dissolved material from precipitating and being redeposited in the formation. Barium, strontium, calcium, and iron sulfates and sulfides as well as other complexes are generally insoluble in acid and must be removed mechanically. Therefore, it is necessary to ensure that such mineralization does not occur within the well structure or formation.

The recommended types and sizes of acid treatment methods vary in different areas and geological conditions. Experience and local conditions determine the remedial procedures best suited for a particular well.

Where the formation or gravel pack face is severely plugged, treating with acid through a jet tool is normally more beneficial than with conventional and acid backwashing techniques. The entire length of the zone is treated with acid, and the position of the jets is adjusted from the bottom to the top of the injection interval.[9] This procedure is advantageous in cased hole completions where scale or deposits may form in the screen or perforations and cannot be reached with other mechanical means.

Acid is normally pumped with a pump pressure of 1000 psi or more if conditions warrant. Normal acid concentrations of 15 percent are used for jetting purposes. Sometimes it was more advantageous to use large volume treatments. The concentration may be reduced and the volume increased for approximately the same treating cost as a smaller more concentrated treatment. This procedure is often more successful than high concentration applications.

2.4.6.4 Overpressuring. Acidizing may be ineffective in improving the injectability of a well because of the insoluble characteristics of the plugging materials. Overpressuring may be more effective in certain wells. This procedure can create partings in the porous medium. These partings allow new zones of higher permeability to be developed through plugged intervals into zones of the formation where plugging has not occurred or is minimal.

Furthermore, the procedure may force the solids farther away from the wellbore relieving some of the restriction.

Brine is generally used as the overpressuring fluid. Other fluids may not be compatible with the brine to be injected and may cause deposits to form when the two are mixed. Best results have been obtained when using large volume treatments and high injection rates.

2.4.7 Other Methods

Corrosion inhibitors are used in many injection wells to protect equipment and to prevent the formation of corrosion products that could corrode both surface and downhole pipe. The inhibitor is often injected continuously into the well by means of a chemical pump or periodically into the surface filtration systems, water line, or injection well. Work is still under way by industry to determine the effects of corrosion inhibitors in treating injection wells. It is apparent at this time that some advantage may be obtained from the sequestering and surface-tension reducing characteristics inherent in certain chemicals under development.

2.5 INJECTION FALL-OFF INTERFERENCE PRESSURE TESTING

Keplinger and Associates, Inc., conducted down-hole pressure tests at the Bayou Choctaw site and assumed the responsibility for overall logistical and field supervision of the testing operation. The extent of damage due to plugging was characterized and assessed.

2.5.1 Test Procedure

An injection fall-off interference test was conducted at the Bayou Choctaw brine injection field from March 13 through March 17, 1979. Approximately 30,600 barrels of brine were injected into Well 3 at a rate of approximately 16,000 bbl/d over a period of approximately 46 hours. Well 3 is located on Pad 2 (Plate IV), in the center of the injection field. Response pressures were measured in wells located on all three pads. This procedure permitted the monitoring of pressure movement in two directions from the injection well.

The tests were conducted on Sand Interval 6, a sand unit designated by Louis A. Records and Associates, Inc. This sand interval was selected on the basis of stratigraphic position in the Miocene injection interval and on the basis that Sand Interval 6 has been completed in all three pads.

Well 3 was the injection well, and Wells 2 and 7 were the response wells. Injection rates were measured, and pressures were recorded in all three wells.

All wells completed in Sand Interval 6 reportedly were shut in at least 8 days and perhaps longer before testing and operations were begun. On arrival, the pressure bombs (Hewlett-Packard) were run into Wells 7, 2, and 3. The entire reservoir was shut in long enough to allow pressure transients to dissipate.

Well 3 was injected into, and pressures and injection rates at the well were recorded. A measure of reservoir continuity was demonstrated by pressure response at the response well sites. As will be discussed, average reservoir permeability is a function of response time.

The results of tests are shown on the Horner plots (Figs. 2-1 and 2-2), the pressure-time plots (Figs. 2-3 and 2-4), and the data sheets (Appendix IV).

2.5.2 Test Results

The injection test indicated the following characteristics:

1. A rapid buildup occurred from 3101 psia to 4433 psia from 10.17 hours to 11.05 hours (t = 0.8 hour) on March 13. This buildup corresponds to a thin, near-well skin zone.
2. A gradual buildup occurred from 4433 psia to 4443 psia from 11.05 hours to 12.05 hours (t = 1.8 hours) on March 13. This buildup had a slope of 34 psi per cycle. Injection rate varied from 18,975 to 17,750 bbl/d.
3. A buildup occurred from 4443 psia to 4465 psia from 12.05 hours to 13.38 hours (t = 3.52 hours) on March 13. This buildup had a slope of 86 psi per cycle. Injection rate during this period varied from 17,500 to 18,100 bbl/d.
4. An erratic period from 13.38 to 15.05 hours occurred when the operator switched pumps and changed rates (t = 4.80 hours). Injection rates varied from 13,750 to 18,000 bbl/d.

5. A relatively stable period occurred from 15.05 hours on March 13 to 07.00 on March 14 (t = 20.72 hours). During this period, pressure was stable at around 4455 psia and injection rate varied from 16,425 bbl/d to 15,000 bbl/d.
6. An erratic period, corresponding to backwashing of the recently installed surface filters, was followed by a period of rapid pressure buildup to 4545 psia from 07.00 on March 14 to 01.57 on March 15 (t = 39.67 hours). Injection rates varied from 0 to 17,500 bbl/d.
7. A final stabilized period occurred from 01.57 to 09.45 March 15 (t = 47.47 hours). During this period, pressure ran from 4545 to 4547 psia, and injection rates varied from 16,425 to 17,250 bbl/d. Final injection rate was 17,250 bbl/d.

For the fall-off test, a pseudo t of 42.57 hours was calculated. The fall-off test showed the following characteristics:

1. A very rapid drop occurred from 4547 psia to 3429 psia from 09.45 to 09.47 hours March 15 ($1 + t/\Delta t = 1424$). This drop apparently reflected near well-bore effects.
2. An apparent straight line section from 09.47 hours to 09.55 hours, March 15 ($1 + t/\Delta t = 254.9$). Pressure drop during this time was from 3394 to 3292 psia. The apparent slope was 210 psi per cycle.
3. Another apparent straight line section occurred from 09.55 to 10.06 hours 15 March ($1 + t/\Delta t = 122.6$). Pressure drop during this period was from 3292 psia to 3176 psia, and the apparent slope was 370 psi per cycle.
4. A gradual, continuous change of slope falloff occurred to 3102 psia at 08.30 hours March 16 ($1 + t/\Delta t = 2.87$).
5. The pressures in the response wells showed small but perceptible increases throughout the injection period and small but perceptible declines during the fall-off period. Time lag between beginning of injection, or shut-in at Well 3, and response at Wells 2 and 7 was on the order of 15 minutes.

2.5.3 Data Interpretation

The following observations are based on the test data and Horner plots:

1. The apparent straight-line portions of the injection test do not correspond in slope or time period to the apparent straight-line portions of the fall-off test.

2. The highest permeability that can be calculated from the Horner plots is 104 md, from the 34 psi per cycle slope on the injection test. If this is a correct permeability, response time at the injection wells would be expected to be on the order of 5 hours.
3. Deviating from a pressure buildup with time and injection to a stabilized pressure is not characteristic of injection tests if the reservoir is homogeneous vertically and laterally.
4. The anomalous pressure increase at t = 20.72 hours, followed by another stable period at t = 39.67 is not characteristic of injection tests in homogeneous reservoirs.

Based on the above, the following conclusions can be made:

1. There is severe formation damage. This is apparent from the considerable pressure differential required to inject.
2. The damaged zone is sufficiently deep to behave, as far as a Horner plot is concerned, much like a uniform, undamaged reservoir. The first 1.8 hours of the Horner plot (injection test) appear to be reflecting a near wellbore skin zone factor on the order of 11.5, and second damaged zone with a permeability on the order of about 100 md.
3. The undamaged reservoir has a very high permeability. This is reflected by the injection periods (t = 4.80 to t = 20.72 hours, and t = 39.67 to t = 47.47 hours) in which there was virtually no pressure buildup and the very short response times at Wells 2 and 7.
4. The reservoir is calculated to contain approximately 2.35×10^9 barrels of formation water. This is based on an apparent 2.33 psi pressure increase (arithmetic average of the three wells) with the injection of approximately 30,600 barrels of injected brine.
5. Based on the above estimated volume of water in place, approximately 13.1×10^6 barrels of brine could be injected into Sand Interval 6, with a 1000 psi increase in reservoir pressure (dp/dh = 0.60 psi/ft).
6. Faulting that could severely limit the potential reservoir capacity is not indicated.
7. The injection pressure increase at t = 39.67 hours was probably caused by solids in the injected brine plugging the formation.

The test data were run on an unsteady-state radial flow computer simulator. The computer printout and report from Dr. Donald Warner outline the results of the simulation tests. Basically, the interpretation is as follows:

1. There is a near wellbore damage area (inner zone) with a thickness of less than 1 foot, and a permeability of around 25 md. Pressure drop through this zone is on the order of 350 psi.
2. There is a central damaged zone of no more than 175 feet or less in radius, which is based on calculations derived from the volumetric cylindrical flow equation. Permeability in this zone would depend on the radius of the damage. For example, assuming a 175-foot radius calculations yields a central zone permeability of 102 md. However, a central zone with a 5-foot radius yields 49 md; a thinner central zone would approach the very low permeability of the inner zone (25 md). The permeability of the central zone may be gradational, from very low at the gravel pack-formation boundary to high as the undamaged reservoir is approached.
3. Permeability in the undamaged reservoir is in the range of 668 to 1548 md. The results from the simulator runs corroborate the interpretations based on the Horner plots and pressure responses in Wells 2 and 7.

2.5.4 Damage Modeling

The testing data interpretation made indicate the general configuration and extent of injection interval plugging. It is advantageous, however, to predict within the framework of the above data and interpretations, the location and nature of the permeability reduction that has occurred using an approach independent of the above tests.

Available information on the drilling and completion practices employed, on the volume of brine injected, and on the apparent solids content of the brine injected suggest that most of the solids injected could well have been trapped within the gravel pack. Based on the available data, it appears that only the finest fraction of the solids introduced has escaped the gravel pack and entered the formation. The available volume within the gravel pack for each injection well has been calculated. In addition, an average solids content of the previously injected brine has been estimated at 20 mg/ℓ. This value was selected on the basis of analytical work on the raw brine for the three sources (weak brine, strong brine and cavern lake water).[7,10]

Table 2-1 summarizes these calculations. Most of the solids injected into each of the wells, with the exception of Wells 3 and 4, could have been trapped within the gravel pack.

With initial injection, each well probably experienced a slug of miscellaneous solids (greater than 50 mg/ℓ) that consisted of (1) iron oxide (as oxidation products of flocculants from the cavern lake and from piping corrosion products and welding debris) and (2) excess drilling and completion fluids and muds (probably introduced before or during initial injection). The completion techniques employed did not properly remove the drilling and completion fluids before initial injection was begun, resulting in a thin invaded zone at the face of the formation containing drilling fluid materials such as clay, barite and polymers. This probably occurred during underreaming and gravel pack installation. The formation-gravel pack boundary subsequently received the initial slug of injected brine solids during start-up operations. Table 2-2 indicates the amount of solids available for plugging according to injected volume. It should be noted that a load of 80 mg/ℓ solids would result in at least 280 pounds of solids after 10,000 barrels have been injected and that at least 1400 pounds of solids would be injected after 50,000 barrels have been injected.

If the initial slug contained 200 mg/ℓ, which is a distinct possibility, 350 pounds (5.2 ft^3) of solids would be introduced to the gravel pack after injection of 5000 barrels of brine during the first day of injection. This would be of sufficient volume to significantly reduce the permeability at the gravel pack-formation boundary.

With subsequent injection, solids would build up on the interior of this boundary beginning on the inside of the thin zone of residual drilling fluid invasion. With increased pressure, packing of the soft fibrous floc-like solids would occur, firmly lodging and molding around the individual sand grains and reducing the pore space of the matrix. As injection continued, solids would progressively fill the interstices from the formation-gravel pack boundary back toward the screen resulting in decreasing permeability with increasing cumulative volume of injected brine.

Assuming certain solids content, Wells 4 and 3 data exhibit extensive plugging of the gravel pack, to such an extent that the volume capacity of the gravel pack has probably been exceeded (Table 2-1). If the brine carried an average solids content in excess of 20 mg/ℓ, the capacity of the gravel pack has certainly been exceeded. The injection plot for Well 4 (Appendix V) indicates a very short period of relatively high surface injection pressure followed immediately by a significant increase in injectability and an accompanying reduction, of long duration, in surface injection pressure. This suggests that increased pressure could have created permeable zones through the inner, highly damaged zone and allowed solid-laden brine to reach the formation and areas of higher permeability.

Based on conversations with industry sources familiar with high-volume injection systems, overpressuring or low-level hydraulic fracturing is in common practice to overcome some types of formation damage. Although high-pressure hydraulic fracturing has been employed in oil fields since the 1940's, such practices have been limited in brine injection operations on the basis that the overlying confining beds may also fracture allowing brine under pressure to reach and contaminate overlying fresh-water intervals used for municipal, industrial or domestic purposes.

Regardless of whether high-pressure fracturing creates a serious threat to overlying fresh-water intervals thousands of feet above, low-pressure fracturing or overpressuring could have created zones of increased permeability in Well 4, thereby allowing increased injectability even with a heavy load of solids. If such zones were created and the solids were allowed to bypass the gravel pack, the formation would then receive the solids, creating damage that extends into the formation.

Based on current data, a very low permeability zone appears to be present within the gravel pack, beyond which permeability may increase abruptly, just beyond the gravel pack-formation boundary and then gradationally to the permeability of the undamaged reservoir. It is not now possible to estimate the radial extent of the central zone. The permeability may reach 500 md after only a foot or two into the formation. It should be noted that this discussion has emphasized the impact of the introduced solids overplugging other conditions that could promote well impairment (Section 2.7). The central zone is of critical importance in planning the remedial programs that are discussed in Section 2.6.

To place the injection history of each injection well in context with its initial potential, calculations have been made on the probable operating characteristics, i.e., bbl/d/psi ($p_1 - p_2$), and duration of injection. Appendix V contains the plots on Wells 2 through 11. It should be emphasized that three assumptions have been made: (1) injection rate of 30,000 bbl/d; (2) solids content no greater than 1 mg/ℓ; and (3) a 1-darcy and a 500-md reservoir.

Based on an inspection of the plots, it is apparent that the injection indexes of all wells are considerably below the indicated operational standards for a nonplugged 1-darcy reservoir and even below a 500-md reservoir. In some wells, the initial injectability index (bbl/d/psi) was in the range offered by an undamaged 500-md reservoir, but quickly deteriorated due to plugging (or due to mineral precipitation caused by fluid incompatibility). In other cases, even initial injectability was low, indicating the effects of either extensive gravel pack damage due to improper drilling and completion practices or an initial slug of very high solids in the injected brine, or a combination of both. It should be noted that most of the highly erratic behavior of the "reported conditions" curve is probably due to (1) errors in operator records; (2) improperly maintained gauges; and (3) poor planning for injection timing. In addition, the behavior of the injection curve after prolonged periods of noninjection is not consistent, indicating different fluids with varying solids content were injected and have created various pressure and injection index responses.

Figure 2-5 is a plot showing the relationship between the optimum initial injection index and the injection zone thickness for the wells of the Bayou Choctaw field. The reported initial injection indexes of the same wells are also shown, indicating the extent of the damage relative to an optimum 1-darcy and 500-md reservoir.

2.6 INDICATED REMEDIAL ACTIONS

2.6.1 Surface Systems

2.6.1.1 Surface Filtration Systems. Preliminary evaluations[7] indicate that surface filtration systems should be installed as soon as possible at any SPR site where high rate subsurface brine disposal is required.

2.6.1.2 Wellhead Gauges. The operating data now available are considered unsatisfactory for a project of this magnitude and importance. Pressure gauge reliability should be reviewed and the gauges replaced with the appropriate ones, if required. Pressure should be recorded at least every two hours. Brine flow meters should be of the sonic or magnetic varieties or a nonmetallic impeller meter; these should be indicating and recording, and a complete record should be made of all fluid injected. Specific conductance calibrated to TDS and/or pH should be monitored at each well. All meters and gauges should be tested on a routine basis and recalibrated if necessary.

2.6.1.3 Safety Precautions. All safety programs should be reevaluated as soon as possible, especially since new contractors who may not be fully aware of all necessary safety precautions will be on site.

2.6.1.4 Corrosion Protection. Oxygen scavenger systems should be included in the surface filtration circuit as soon as possible. In addition, surface piping should be coated and wrapped or painted with corrosion-resistant paint.

2.6.2 Subsurface Systems

The information developed during this evaluation suggests that we investigate what remedial action should be undertaken to significantly improve well injection. The present intervals are of sufficient areal extent, of sufficient thickness, and of sufficient permeability to accommodate high-volume injection (possibly the 30,000-bbl/d rate originally anticipated). This assumes that other plugging problems do not become apparent after the solids have been removed from the raw brine before injection (Section 2.7).

If the solids and oxygen contents of the brine will be reduced considerably in the near future via the surface filtration and scavenger systems, a decision must be made regarding the damaged injection intervals, considering that the extent of damage may be solely due to the volume of raw brine that has been injected to date and to the thickness of the screened and completed zone (Fig. 2-5).

The gravel packs in some of the wells are so severely plugged that neither air-lift backwashing nor acidizing may be an effective approach. If considerable brine volume remains to be injected, comprehensive remedial action is required. The following procedures appear to be in order. The first, and economically the most attractive, is to overpressure the injection interval with the objective of creating high-permeability zones through the damaged gravel pack. Based on our preliminary calculations, a pressure buildup to, but not exceeding, the maximum permitted under Louisiana regulations should be attempted on a pilot basis and the results evaluated in detail before remedial actions are taken. If an improvement in injection occurs, the procedures should be applied to the other wells. The additional costs of such a procedure would be minimal, time being the only requirement.

If this does not produce the desired results, three other options are available. The first and operationally the most attractive is to continue the approach initiated by Davis.[8] After a period of backwashing, acidizing should be conducted followed by a second backwashing treatment. The initial air-lift or pumping if possible, would remove particles not firmly lodged or attached to the gravel pack and formation matrix. Acidizing could then be directed toward the more tightly held material, which could be broken down and/or dissolved if the proper type and concentration of acid is applied.

Secondary high-velocity backwashing would remove such material. It should be noted that backwashing and acidizing may be effective for the wells that have not received high volumes of raw brine to date, i.e., Wells 5, 6, 8, 11, and of course, 12.

The second option is to pull or mill out the entire screen and gravel pack and underream again. It also appears to be possible and practical to reunderream somewhat beyond the gravel pack-formation boundary in an attempt to remove the indicated near wellbore, very low permeability zone. The interval can be properly recompleted via a new screen and gravel pack. In addition, well development with high-volume backwashing could be accomplished to ensure proper cleaning the near well formation and gravel pack. Wells 2, 3, 4, 7, 9, and 10 are candidates for such remedial procedures.

The third alternative is to recomplete through casing in upper zones. Although sacrifices will be made regarding injection fluid flow pattern conservation, corrosion control (at the perforations) and the ease with which backwashing of the injection zone can be accomplished, recompletion through the casing may be an economically viable alternative.

2.7 ASSESSMENT OF UNKNOWNS

A number of unknowns still exist in the Bayou Choctaw injection systems and by analogy in the other SPR sites. The obvious problems associated with the solids content of the brine are now well understood. Associated potential problems that have been masked to date by the effects of brine solids on plugging, include formation fluid incompatibility with the injected brine. A reliable sample of the original formation water has not been recovered and unless additional wells are drilled, such samples will never be available. Baseline data such as analyses of original formation water, adequate cores, initial bottom-hole temperature and pressure are mandatory for new SPR sites, i.e., Sulphur Mines. By obtaining such baseline data at the Sulphur Mines site, some insight regarding potential incompatibility may be gained that could apply to the other SPR sites.

2.8 DEVELOPMENT OF PHASE II PROGRAM

The results of the Phase I evaluation were used to prepare a summary of all critical path topics identified to date. Detailed evaluation and immediate action are indicated for the Bayou Choctaw site and the other existing SPR areas, with special emphasis on the Sulphur Mines site.

2.8.1 Bayou Choctaw Site Requirements

1. The economic evaluation of options and implementation of selected pilot injection well workover programs are of critical importance to the SPR program.
2. A comprehensive evaluation is required for assessing the potential behavior of mixing two distinctly different brines under anticipated injection conditions. As a result, measures could be defined to chemically pretreat the brine to be compatible with the formation brine, thereby reducing the potential for formation plugging.
3. A comprehensive petrographic evaluation of the available cores from all SPR injection well sites is necessary to anticipate formation incompatibility and to anticipate potential behavior of the intervals from which cores have been obtained. The evaluation would establish the type

and characteristics of clay minerals present and if the brine to be injected is likely to create plugging within the formation.

4. One of the least severely plugged wells should be tested via overpressuring methods before other recommended remedial activities are considered.
5. Pressure response testing should be conducted both before and after remedial well activity. However, if submersible pumps can be installed, pump testing could be employed in place of pressure testing. The relative effectiveness of such a remedial technique could be established. This approach may require further evaluation.
6. After remedial action has been completed on the wells, a properly designed start-up program should be implemented for the surface filtration system and injection.
7. Downhole closed-circuit television or stereo photography should be investigated to ascertain whether this equipment is applicable. This approach can be used to determine the condition of the screens if the fluid is relatively clear, if temperatures will permit and if the depth is not excessive.
8. A brief evaluation should be conducted on the desirability and feasibility of monitoring Sand Intervals 1 and 2 and overlying equivalents of the Baton Rouge Aquifer, if present.

2.8.2 Sulphur Mines, West Hackberry, and Bryan Mound Site Requirements

1. Priorities should be established as to which of the other SPR sites require immediate detailed geological evaluations similar to the one conducted for Bayou Choctaw.
2. Pressure response testing of the various reservoirs will be necessary to establish boundaries, if present. Bryan Mound appears to have significant structural involvement of the target reservoir. Although time did not permit a detailed evaluation, West Hackberry may also require a pressure testing program. The experience gained during this evaluation indicates that only two or three injection sand intervals at each SPR site would require pressure testing to establish an extensive reservoir. However, if faulting becomes apparent, additional testing may become necessary.

3. Remedial techniques found successful at Bayou Choctaw should also be instituted at the other SPR sites once similarities of existing condition have been established.
4. All present and future drilling and completion activities should be planned, designed, and monitored using standard oil-field practice (Section 1.4).

2.9 CONCLUSIONS

1. The Bayou Choctaw reservoirs selected for brine injection are technically feasible for storing large volumes of brine injected at high rates over a sustained period of time. Based on the evaluations conducted to date, Sand Interval 6 appears to be of sufficient areal extent, thickness, and permeability to accommodate high-volume brine injection. The other intervals selected for injection also appear to be capable of accepting substantial volumes of low solids brine under reasonable pressures.
2. The selection of any particular injection interval was based on inadequate information. The coring program conducted resulted in very little useful geological information. Baseline data are absent for determining the potential incompatibility between the brine to be injected and the formation brine.
3. Injection wells drilled at Bayou Choctaw appear to have been in poor or less than optimum condition prior to initial brine injection, subsequently compounding problems associated with the high solids content of the injected brine.
4. General interpretations based on the available records indicate well injectability is very low due to plugging. Two wells, however, may have been overpressured, which allowed solid-laden brine to breach the plugged gravel pack and reach higher permeability zones within the formation creating damage in that part of the formation.
5. Most of the plugging has occurred within the area occupied by the gravel pack. Present permeability of the inner zone is approximately 25 md. A central zone of somewhat higher permeability of an indeterminate thickness is probably a zone of gradational permeability ranging from near 25 md at the gravel pack-formation boundary to undamaged regions within the

formation of 1.0 darcy or greater. The radial extent of the central zone may only be 1 or 2 feet.

6. Remedial techniques to improve, if not restore, anticipated formation injection rates for all existing wells are feasible but will require immediate action to reduce out-of-service time.
7. In some wells in the Bayou Choctaw field, plugging may be so extensive that air-lift backwashing and acidizing may not be effective. Overpressuring up to allowable limits may be effective in improving injectability using only treated brine and should be attempted. If overpressuring is not effective, re-underreaming to remove damaged gravel pack and eliminate in place screens appears to be a feasible operation. Recompletion would involve installation of a new screen and gravel pack. Success of such an approach will depend on the radial extent of the central damaged zone of each well. If the central damage zone is found to be extensive during tests after workover, the final alternative is to recomplete through casing in upper injection zones.
8. In other less-damaged wells, air-lift backwashing and acidizing could be effective for well rehabilitation. Such an approach will require some redesigning to avoid the foaming problems experienced when this technique was initially evaluated at Bayou Choctaw. A method of storing the backwashed fluids must be found via surface storage or via overpressure reinjection into a nearby severely damaged well selected for recompletion according to procedures indicated in Item 7.
9. A field inspection reveals that surface equipment is in extremely poor condition. Specific examples include leaking flanges and valves and meters out of calibration.
10. Problems resulting from previously introduced solids have been serious enough to mask other physio-chemical factors that may be present. Incompatibility between the brine to be injected and the formation brine is a distinct possibility.
11. If the recommendations are implemented, injection well performance should be improved considerably, assuming surface filtration and oxygen scavenger systems are on-line and effective in removing suspended solids and controlling corrosion and assuming potential formation incompatibility problems can be resolved.

TABLE 2-1. Solids introduced to gravel pack and well injectability.[a]

Well No.	Injection sand interval	Completion zone thickness, ft	Fluid volume injected, bbl	Initial vol. pore space w/in gravel pack, ft^3	Solids introduced to well, ft^3 at 20 mg/ℓ level	Plugging ratio[b]
2[c]	6	238	1,063,000[d]	139	110	0.79
3[e]	6	245	1,344,000	143	138	0.97
4	5	172	1,036,000	101	107	1.06
5	3	312	346,000	183	35	0.19
6	2	310	579,000	181	60	0.33
7[c]	6	270	706,000	158	72	0.46
8	3	230	387,000	135	40	0.30
9	2	357	878,000	209	88	0.42
10	7	168	633,000	98	65	0.66
11	2	263	126,000	154	13	0.08
12	8	163	500	95	0.1	0.001
		2,728[f]	7,098,500[f]	1,596	728[g]	avg 0.53

[a]Well 1 is not included because it was initially completed via gravel pack in Sand Interval 6, subsequently completed via perforations in Sand Interval 5, and finally completed via perforations in Sand Interval 3.

[b]Defined here as the extent to which the available pore space within gravel pack has been filled with introduced solids, i.e., 1.00 = introduced solids equal available pore space for solids.

[c]Wells used for pressure monitoring.

[d]Injected volume and pressure data for Well 2 were not recorded prior to October 8, 1978. An estimated additional 500,000 bbl have been added to the recorded volume to account for period without records.

[e]Well used for injection during pressure buildup and fall-off testing.

[f]2602 bbl (109,300 gal) of brine injected per foot of interval injected.

[g]0.27 ft^3 (18.3 pounds) of solids injected per foot of interval injected.

TABLE 2-2. Brine injected and equivalent contained solids.[a]

Brine injected, bbl	Solids, lb, at indicated brine content, mg/ℓ						
	1	2.5	5	10	20	40	80
1,000	0.4	0.9	1.8	3.5	7.0	14.0	28.0
5,000	1.8	4.4	8.8	17.5	35.0	70.0	140.0
10,000	3.5	8.8	17.5	35.0	70.0	140.0	280.0
50,000	17.5	43.8	87.5	175.0	350.0	700.0	1,400.0
100,000	35.0	87.5	175.0	350.0	700.0	1,400.0	2,800.0
500,000	175.0	437.5	875.0	1,750.0	3,500.0	7,000.0	14,000.0
1,000,000	350.0	875.0	1,750.0	3,500.0	7,000.0	14,000.0	28,000.0
5,000,000	1,750.0	4,375.0	8,750.0	17,500.0	35,000.0	70,000.0	140,000.0

[a]Solids (pounds) = brine solids content (mg/ℓ) × brine injected (000s bbl) × 0.35.

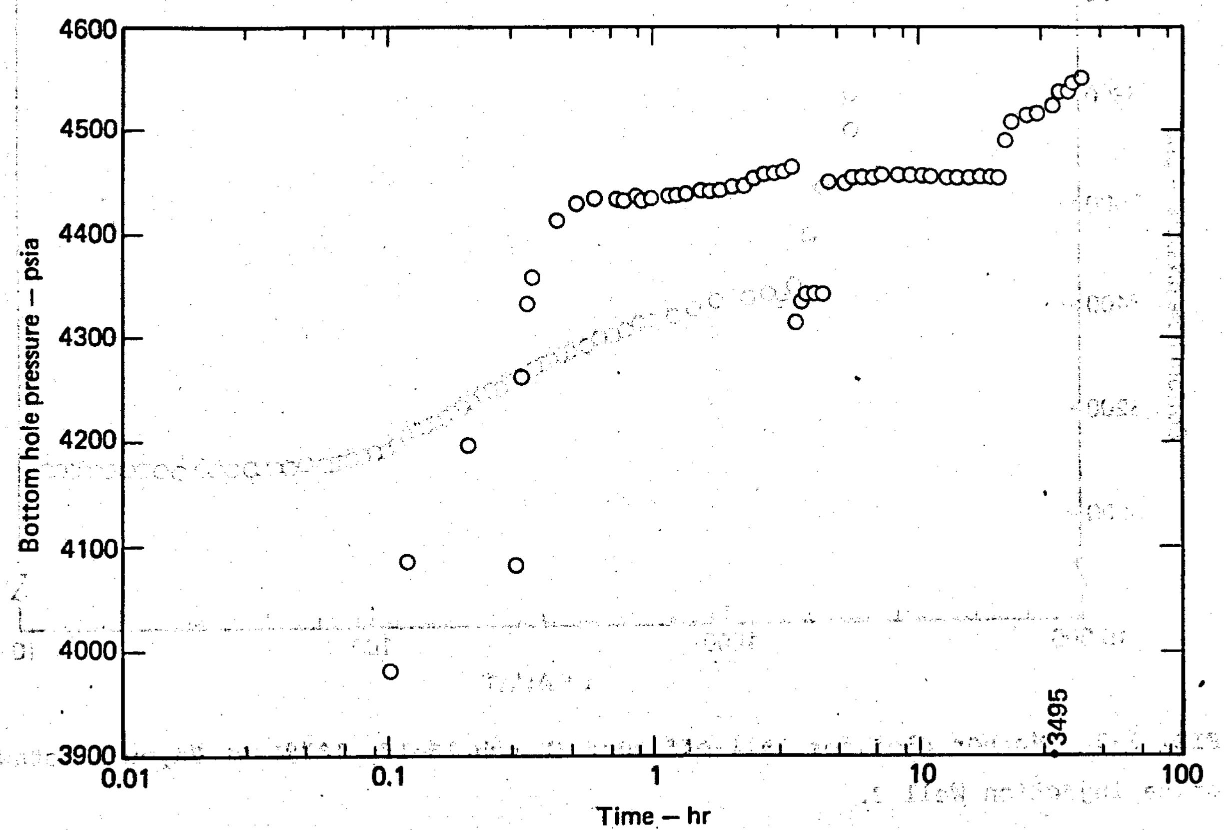


FIG. 2-1. Horner plot for injection test (March 13-15, 1979) at Bayou Choctaw brine injection Well 3.

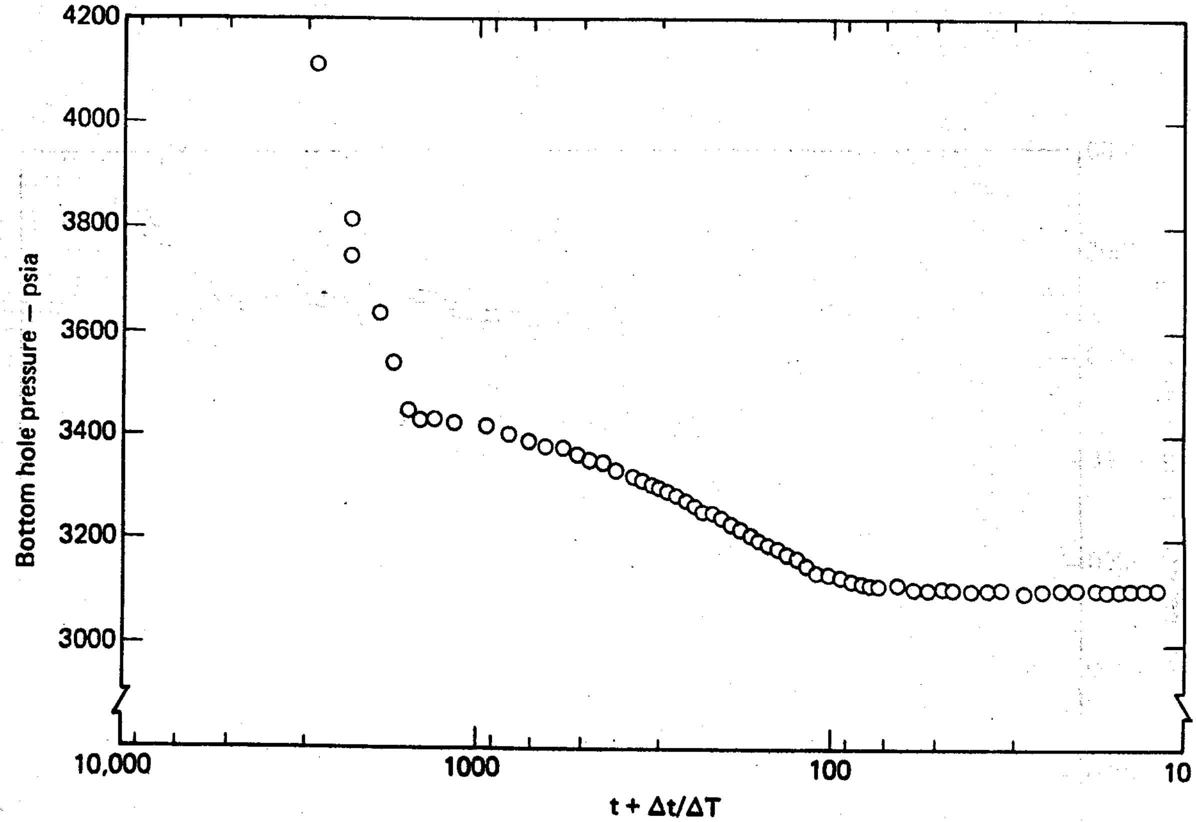


FIG. 2-2. Horner plot for fall-off test (March 15-16, 1979) at Bayou Choctaw brine injection Well 3.

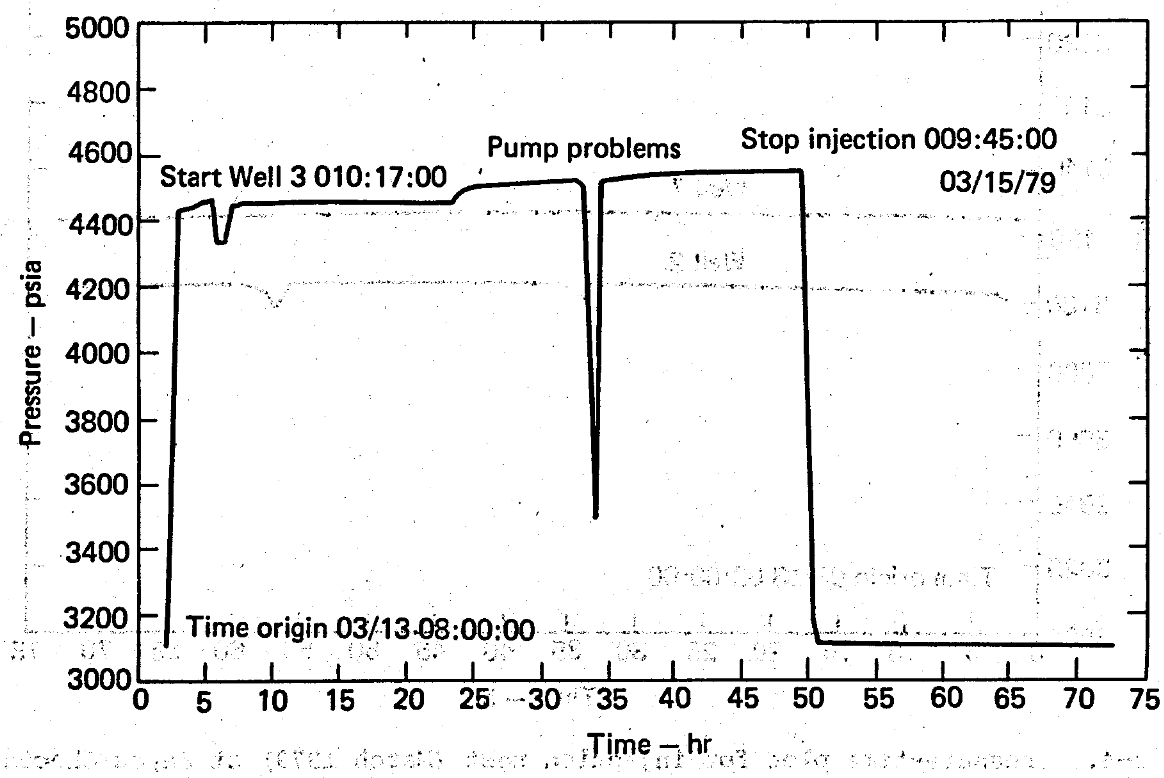


FIG. 2-3. Pressure-time plot for injection test (March 1979) at Bayou Choctaw brine injection Well 3. Probe depth was 8871 feet.

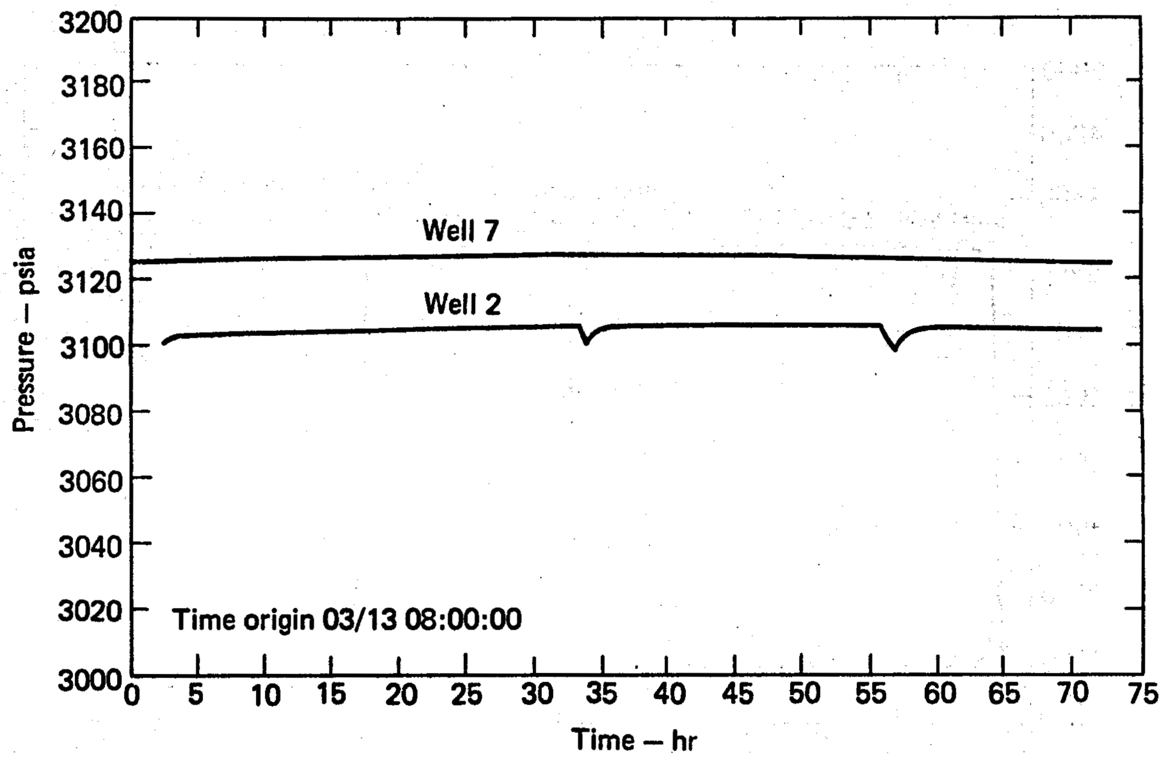


FIG. 2-4. Pressure-time plot for injection test (March 1979) at Bayou Choctaw response Wells 2 and 7. Probe depth was 8871 feet.

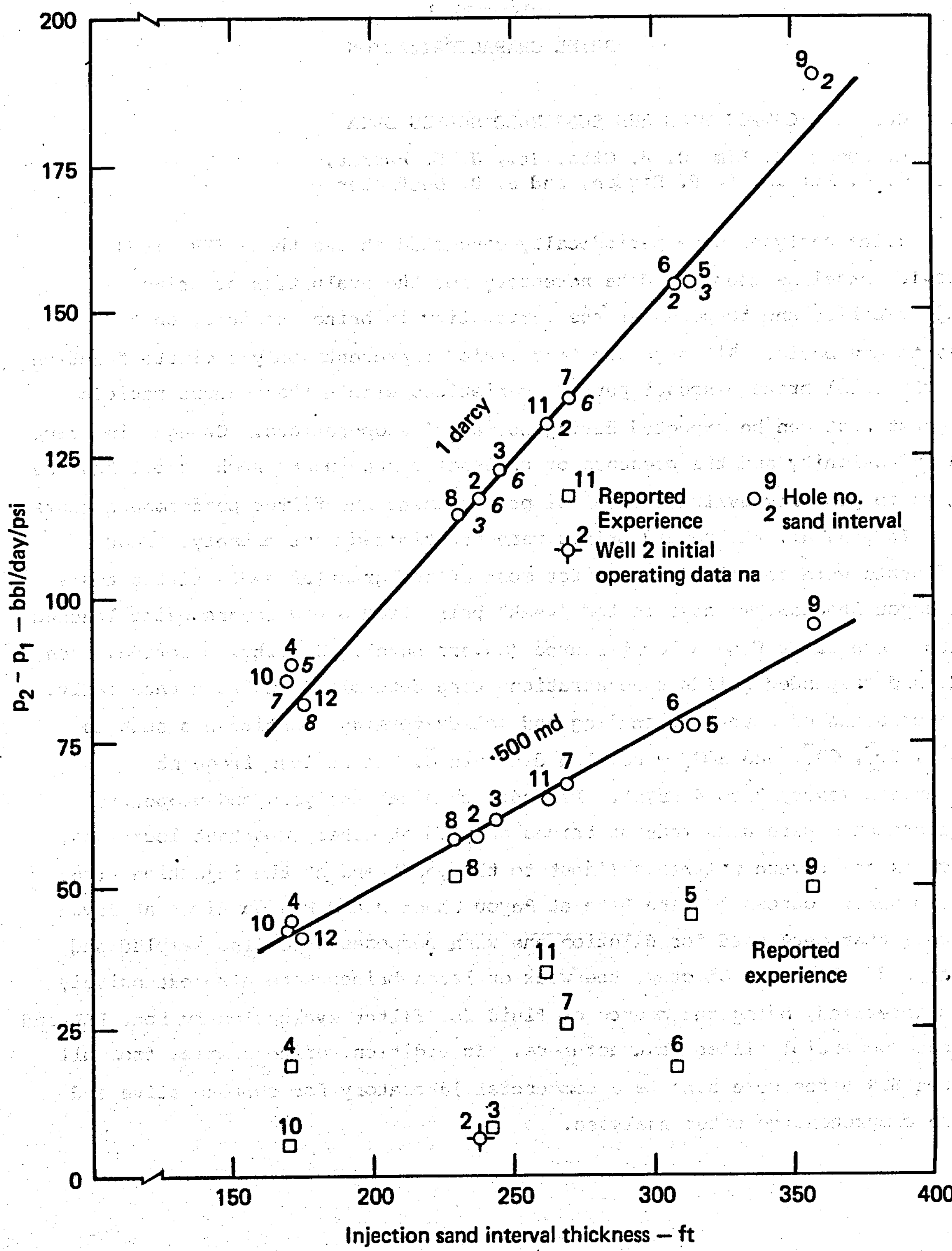


FIG. 2-5. Relationship between optimum initial injection index and injection zone thickness for the Bayou Choctaw injection wells.

CHAPTER 3

BRINE CHARACTERIZATION

3.1 CHEMICAL COMPOSITION AND SUSPENDED SOLIDS DATA

R. Quong, R. Lim, C. H. Otto, Jr., J. E. Harrar,
C. J. Morris, L. P. Rigdon, and S. B. Deutscher

Brine analyses were periodically conducted at the three SPR sites to provide baseline chemical data necessary for the evaluation of brine injectability and to document the variability in brine chemistry on a day-to-day basis. Although our test period represents only a minute fraction of the total brine disposal period, variations within these short periods suggest what can be expected during normal site operations. Changes in brine pH and salinity and the presence of external contaminants such as oil must be known to properly evaluate chemical pretreatment and filter performance tests.

In general, the ponded brines were scrutinized most closely. Pond effluents were the fluid source for most of the granular media filter tests. At Bayou Choctaw, we also tested "weak" brine from a new cavern being leached with fresh water from a local source (Cavern Lake). Density, chloride, iron, pH, and suspended solids concentrations were determined at least once daily. The presence of potential scaling and solids-forming constituents such as Ca^{++}, $SO_4^{=}$, $CO_3^{=}$, and HCO_3 were also determined, but at less frequent intervals (every 3 to 4 days). Periodic chemical analyses and properties measurements were also made on brines sampled at other important locations, such as the cavern wellheads (input to the pond) and at the injection site. Fresh water sources (Cavern Lake at Bayou Choctaw and Brazos River at Bryan Mound) that were used for dilution and wash purposes were also sampled and analyzed. At Bayou Choctaw, the weak or leach brines were also extensively characterized, being the source of fluid for filter evaluation by both LLL and three commercial filter manufacturers. In addition, brine samples from all three SPR sites were sent to a commercial laboratory for corroborative and more comprehensive water analyses.

3.1.1 On-Site Analytical Methods

Most analyses were conducted with a Hach Direct Reading Engineer's Laboratory colorimeter (Model DR-EL/2).

For dissolved iron determinations, a sample was first filtered with Whatman #1 paper. An aliquot was taken, and the procedure given in the DR-EL/2 Methods Manual was followed. The Ferro Ver Iron Reagent provided in the kit contains an acetate buffer, a reducing agent, and the color reagent 1, 10-Phenanthroline. After color development, the iron concentration is read directly from the meter scale. For total iron, a sample was acidified with hydrochloric acid. An aliquot was then taken through the same procedure.

Sulfate was determined by a turbidimetric method in the Hach kit. A Sulfa Ver IV Sulfate Reagent was used. This reagent contains barium salts which form insoluble barium sulfate. The concentration of sulfate was read directly from the scale on the meter.

Calcium was determined by titration with standard ethylenediamine tetracetic acid solution. The sample was made strongly basic with potassium hydroxide to precipitate magnesium hydroxide. A Cal Ver II Calcium Indicator was added. This indicator is Erio-T. The sample was titrated with Titra Ver Hardness Titrant obtained from Hach.

Bicarbonate alkalinity was determined by titration with standard acid using Brom Cresol Green-Methyl Red Indicator. The pH change for this indicator is 5.2. If the pH of the sample is greater than 9, then Phenolphthalein indicator must be used first. The color change for Phenolphthalein is about pH 9. The results of the titration was calculated using the alkalinity relationship table given in the Methods Manual.

Chloride was determined by titration with standard silver nitrate solution. Dichlorofluorescein was used as an indicator. Dextrin was added to the sample to hold the precipitate in a colloidal suspension, thus giving a color change throughout the entire solution.

3.1.2 Brine Analyses Results

Average brine compositions from the various locations at the three sites are given in Table 3-1. Fluid turbidity as measured by a Hach Model 2100 turbidimeter and suspended solids concentrations determined by filtration with 0.4 μm Nuclepore membrane filters are given in Table 3-2.

Daily brine properties and basic chemical data, and supplemental, but more comprehensive analyses are tabulated in Appendix VI for West Hackberry, Appendix VII for Bayou Choctaw, and Appendix VIII for Bryan Mound.

The principal dissolved species in these brines is NaCl. Other constituents present with potential for precipitation include Fe^{++}, Ca^{++}, $SO_4^{=}$, and $HCO_3^{-}/CO_3^{=}$. Although present in appreciable concentrations, none of these species appears to be at saturation levels, with the possible exception of the Bryan Mound brines. Cavern 4 at Bryan Mound contains 100 mg/ℓ of NaOH and has a pH of 11. It had been used in the past for disposal of brine processed by the Dow Chemical Company. Brine from Cavern 4 may be supersaturated with $CaSO_4$ and $CaCO_3$. Cavern 4 brine, however, was neither injected nor evaluated for injectability. Ultimately, Cavern 4 brine will need to be disposed of, but in order to do so, the pH must be lowered to within allowed standards for pipeline disposal in the Gulf. Section 3.1.6 summarizes results of bench-scale tests of several neutralization options for the treatment of Cavern 4 brine.

3.1.3 Brine Particulates

The cavern brines are saturated in NaCl at cavern temperatures of 30 to 32 C. Without dilution, salt precipitates when brine cools during the disposal operation. At West Hackberry, dilution water is added before the brine reaches the surge pond. The chemical composition of this diluent was not determined. At Bayou Choctaw, Cavern Lake water is injected into the disposal line at a point that is downstream of the surge pond . Prior to dilution, salt precipitates in the pond. A frothy layer entraining salt and windblown particulate matter is evident on the pond surface. At Bryan Mound, salt precipitation in the pond is eliminated by adding Brazos River water to the cavern brine at the point of entry to the surge pond. However, these sources of dilution water are extremely turbid and contribute as much or more solid contaminates than is contained in ponded brines themselves. This is true even though probably only 5 percent or less of dilution water is used (the actual flow rate of diluent is not measured, but inferred from changes in Cl^{-} concentration).

The brines, as they leave the caverns are saturated in NaCl, but are relatively free of particulates as indicated in Table 3-2. The brine picks up suspended solids in the open surge pond from windblown dust, soil runoff, and occasional dumping of foreign matter. The dilution water just described is the other major source of particulate contamination.

The ponds do serve as crude settling basins. At West Hackberry, brine was recirculated to provide test fluid during periods when oil was not being stored in caverns. The resultant agitation of the pond sediments raised particulate concentrations by an order of magnitude to 24 mg/ℓ. The suspended solids content (4.6 mg/ℓ) was still above normal 48 hours after recirculation of ponded brine ceased.

Corrosion products are another potential source of particulate contamination in the brine. The corrosiveness of the brine is greatly increased by oxygen that is absorbed in the brine while residing in the pond. This problem (and solution) is discussed in Section 3.3 and Chapter 6.

The weak or leach brines at Bayou Choctaw, as expected, have very poor injection characteristics. The suspended solids concentration is 20 mg/ℓ, about one order of magnitude greater than that of cavern brines, but a factor of 3 to 4 less than that of the Cavern Lake water, the original source. This indicates that about 75 percent of the particulates in the Cavern Lake water settles out in the leach cavern to the benefit of any surface treatment requirements.

3.1.4 Particulate Analyses

X-ray diffraction analyses of strong and weak brine solids captured on the granular media filters used for treatment tests at the three sites indicate the presence of quartz, amorphous silica, and montmorillonite and kaolinite clay phases, which are characteristic of the regional soils. Calcite and gypsum were not detected confirming the belief that precipitation of these species does not occur. It is possible, however, that conditions in the reservoir could, in time, cause deposition. For example, gypsum has inverse temperature solubility, and it is less soluble in dilute NaCl solutions. During injection, the temperature gradient and dilution with connate water are in the direction of reduced solubility. Deposition of solids, however, may be of little concern, provided these changes occur well beyond the wellbore.

Chemical composition by X-ray fluorescence analysis of the brine suspended solids are given in Table 3-3. At West Hackberry, a field determination of iron in the solids was attempted by acid treatment, followed by dissolved iron analysis. With 1M HCl at 25 C, 22 percent of the solids dissolved in which iron was 6.2 percent of the original sample. With hot 6M HCl + conc HNO_3, 20:2, 40 percent of the solids dissolved to give 10 percent iron in the original sample. These data are consistent with the iron and mineral determinations by X-ray analysis. The iron content in the solids is important in selecting pretreatment chemicals prior to filtration processes.

3.1.5 Incubation Tests

Brine samples were incubated at 35 C from 15 minutes to 24 hours and then filtered through 0.4 µm membrane filters to determine time-dependent changes in particulate concentrations. Brine stored in caverns for long periods of time are apt to be in equilibrium with the surroundings. However, when exposed to the cool surface surroundings and contaminates in and around the pond, the question arises as to whether particulates will begin to precipitate in the injection reservoir, particularly upon reheating. $CaCO_3$ and $CaSO_4$ exhibit inverse temperature solubility and could pose a problem. Tables 3-4, 3-5, and 3-6 summarize the test results of incubated brines. In general, the brines are quite stable over the 24-hour period, particularly the ponded brines, which are ultimately injected. Brine samples obtained from the cavern wellheads and from the injection sites are also stable at 35 C. Bryan Mound cavern brines are an exception because of relatively high dissolved iron concentrations.

Cavern 5 brine at Bryan Mound contains 1.35 ppm dissolved iron, much higher than at the other two sites. Oxidation by exposure to air results in $Fe(OH)_3$ precipitation, which presumably would take place in the pond. These new particulates should be removed before injection. However, the incremental increase in suspended solids due to iron precipitation is only a fraction of the total, particularly after brine dilution with highly turbid river water. At the other sites, dissolved iron also decreases with incubation time, but the absolute levels are so low, that the additional solids, owing to $Fe(OH)_3$ precipitation, cannot be detected within the precision of the measurements.

3.1.6 Treatment of Cavern 4 Brine at Bryan Mound

To dispose of Cavern 4 brines via pipeline to the Gulf of Mexico, the brine pH must be lowered from pH 11 to less than pH 10. This can be accomplished by direct acidification or by mixing with other existing lower pH brines. Cavern 5 is sufficiently large to contain the brine that already resides there plus the volume contained in Cavern 4. This combination was, therefore, evaluated.

Samples of brines from Caverns 4 and 5 at the Bryan Mound site were received at LLL on April 25, 1979. Measurements were made to establish the dependence of pH on brine mixture ratios and acid (HCl) titration. Individual brines and a 1.53 to 1 mixture ratio (by volume) of Cavern 5/Cavern 4 brine were filtered for suspended solids concentration determinations. The mixture ratio was based on the known volumes of brine contained in the two caverns as of April 18, 1979. Tables 3-7 through 3-11 summarize the measurements.

When Cavern 5 and Cavern 4 brines are mixed in the volume ratio of 1.53 to 1, a pH of 9.45 results. The pH declines steadily because of slow precipitation of $CaCO_3$. After one hour, the pH is lowered to 8.8. Further decline is small and probably not significant.

As indicated in Table 3-8, 4 ppm HCl is required to lower the pH from 8.8 to 8.0, but an additional 23 ppm of HCl is needed to reduce the mixture to pH 7 because of dissolution of $CaCO_3$. Removal of solid $CaCO_3$ first lowers the total acid requirements to 6.7 ppm to achieve pH of 7 (Table 3-9). Therefore, mixing the brines in Cavern 5 to allow settling, followed by surface acid treatment would consume less acid than other possible options. Acidification to pH 7 and disposal of Cavern 4 brines alone would require about 90 ppm HCl (Table 3-10). HCl costs for the options considered are as follows:

1. Acidification to pH 7 of 17 million barrels from Cavern 5 plus 11 million barrels from Cavern 4 requires 582 tons of 18° Bé HCl (162 tons pure HCl) at $40/ton (Gulf Coast tankage prices) or $23,280.[11]
2. Option 1 with all solids removed requires 137 tons 18° Bé HCl (38 tons pure HCl) or $5480.
3. Acidification to pH 7 of 11 million barrels of Cavern 4 brine alone requires 745 tons of 18° Bé HCl (208 tons pure HCl) or $29,800.

When brines from Caverns 4 and 5 are combined, the mixture becomes supersaturated in $CaCO_3$, and precipitation results. This raises the potential of calcite scaling of well casing and piping exposed to the nonacidified mixture. To be conservative, it may be most prudent to acidify Cavern 4 brines for separate disposal or combine the two cavern brines on the surface followed by acidification and disposal.

Suspended solids samples have been analyzed by X-ray diffraction and scanning electron microscopy and confirm the presence of $CaCO_3$ in the mixed brine precipitates.

3.2 PETROLEUM ANALYSES

K. G. Knauss

3.2.1 Experimental Technique and Calibration

The method of Gruenfeld (1975)[12] was used to measure petroleum dispersed in the various brines and freshwater at the West Hackberry, Bayou Choctaw, and Bryan Mound SPR sites. The only materials contacting the sample were glass and Teflon. All the equipment was rinsed thoroughly with Freon before it was used. Baker PHOTREX reagent grade Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane) was used to perform a solvent extraction on 1.5-liter acidified brine samples. The Freon extract was clarified when necessary by filtering through anhydrous sodium sulfate. Three such extractions, each using 25 mℓ of solvent, were performed, combined, and brought to 100 ml volume. Extraction efficiency was estimated to be better than 99 percent. The absorbance of this solution due to C-H bond stretching at 2930 cm^{-1} was then determined using a Beckman Acculab 8 Infrared Spectrophotometer with 10- and 100-mm path-length cylindrical cells. The detection limit under these experimental conditions is about 0.2 ppm. The blanks run at each site produced no detectable absorbance; hence, no blank correction was applied to the data.

Beer-Bouguer Law plots were derived using standards prepared from the crude oil actually being injected at each site. These plots (Fig. 3-1) are all linear ($r^2 > 0.999$) and pass through the origin. The regression equation determined at each site was used to calculate the petroleum content of each sample from that site.

3.2.2 Results and Discussion

The data obtained from the three SPR sites are summarized in Table 3-12. It should be noted that, a few days before the West Hackberry samples were collected, an oil storage tank was flushed-out with brine and discharged into the holding pond. The dispersed petroleum globules completely darkened the brine and undoubtedly the petroleum concentration in the brine pond out and injection samples would be higher by orders of magnitude. The relatively high concentrations actually observed probably represent a residual signal from this event.

3.3 DISSOLVED OXYGEN MEASUREMENTS

K. G. Knauss

3.3.1 Experimental Technique

Three methods were used initially to measure the dissolved oxygen content of the samples at the West Hackberry SPR site: model 5739 YSI (Yellow Springs Instrument) dissolved oxygen probe with 1.0-mil Teflon membrane/model 57 YSI dissolved oxygen meter combination; model 200 A Simplec dissolved oxygen probe with 1.0-mil Teflon membrane-meter combination; and the Chemetrics colorometric dissolved oxygen kit using reaction with rhodazine D. The Chemetrics kit had an upper limit of 1.0 ppm dissolved oxygen and employed visual color comparison and, hence, was only used to spot check the probe-meter observations. The two probe-meter combinations are essentially identical in principle although the Simplec meter apparently employs much more sensitive current sensing circuitry. The two probe-meter combinations produced results in good agreement with each other in a series of tests; hence, it was decided to standardize the procedure by routinely using the YSI system with the Simplec system used to spot check results. The high-salinity samples being measured produce, in effect, an amplified "apparent" dissolved oxygen content when no instrument compensation is employed and thus the observed dissolved oxygen values were well within the range the YSI system could detect.

A short length of tygon tubing was used to discharge sample at the bottom of a 1-liter vacuum flask in close proximity to the dissolved oxygen probe. Flow rate was controlled by a needle valve to provide sample at a rate of about 10 ℓ/min, but slow enough to prevent cavitation. Continuous flow was supplied for 5 minutes prior to recording the dissolved oxygen. The probe/meter combinations were calibrated several times daily by the water saturated air method and little drift was encountered. Temperature compensation was provided automatically via a thermistor in both systems, but no instrumental salinity compensation was used.

3.3.2 Dissolved Oxygen Salinity Correction Factor

As mentioned above the "apparent" or observed dissolved oxygen content in saline waters was higher than the true value when no system salinity compensation was used. An approximate correction factor was derived in the following manner. Oxygen solubility data contained in MacArthur (1916)[13] provide the only values mentioned in the literature for solutions as high as 4 N in NaCl. Hudgins (1979)[14] has provided a family of five curves (10 to 50 C) plotting dissolved oxygen versus mg NaCl/kg H_2O up to 320,000 mg NaCl/kg H_2O. MacArthur's data agree reasonably well with these plots. These plots provide oxygen solubility at saturation over most of the temperature-salinity range encountered at the SPR sites.

The pond influent brine at all three SPR sites contained little dissolved oxygen. While residing in the holding pond, the brine is presumed to approach equilibrium with the atmosphere. Hence, any sample of pond effluent brine should be at or near air saturation with dissolved oxygen. These samples then provided a means to estimate the value for this correction factor. A comparison was made of all values for pond effluent brine dissolved oxygen brine with the air-saturated values predicted for dissolved oxygen at that temperature and salinity. The value of observed dissolved oxygen to predicted saturation dissolved oxygen ranged from 0.26 to 0.56 but half the values fell in the narrow range 0.26 to 0.28 and the distribution of values was negatively skewed. Hence, for the extremely saline brines encountered in this study, a salinity correction factor of 0.26 was applied in the YSI probe-meter combination readings to account for all undeterminable probe-meter related effects. In later measurements with NaCl-saturated solutions in equilibrium with atmospheric air, readings ranging from 2.6 to 4.15 ppm were obtained with the same probe-meter combination, indicating definite instrument effects. In Tables 3-13 through 3-16, both the uncorrected and corrected values are reported.

In the absence of instrument effects, an alternative method for determining the correction factor, f, for dissolved oxygen in saturated brines is that suggested by Hudgins[14]:

$$f = C_s/C_o,$$

where C_s and C_o are the dissolved oxygen concentrations in a NaCl-saturated solution and in pure water, respectively, in equilibrium with atmospheric air. The relation is derived if it is assumed that the oxygen probe indicates the "true activity" of dissolved oxygen. Then,

$$A_s = A_o$$

where A = activity = γ_c, γ = activity coefficient. Therefore,

$$\gamma_s C_s = \gamma_o C_o$$

or

$$1/\gamma_s = C_s/C_o = f$$

Using a value of 1.35 ppm for C_s and 8.4 ppm for C_o,[14] a correction factor of 0.16 is obtained. By applying this method, the corrected dissolved oxygen concentrations would be 38.5 percent lower than the values presented throughout this report, clearly indicating that the brines assumed to be air-saturated are actually undersaturated.

3.3.3 Results and Discussion

Complete analyses are provided in Tables 3-13, 3-14, and 3-15, and the corrected data are summarized in Table 3-16. The following specific comments refer to these data.

West Hackberry:

1. Oil was not actually being injected while dissolved oxygen tests were being conducted at this site. The dissolved oxygen values observed may not be representative of those encountered when the system is actively injecting oil and displacing brine.

Bayou Choctaw:

1. Oil injection ceased on January 28, 1979; therefore, samples representative of an active system could no longer be acquired after this date.
2. Initial values observed in scavenging experiments indicate lake water values as high as 6.50 ppm. The salinity of these waters was low; hence, no salinity correction was applied to the data.

Bryan Mound:

1. The pond influent from Cavern 5 was charged with gas bubbles regardless of the flow rate and thus differed considerably from the Cavern 4 sample. The high dissolved oxygen value observed here may be due to the presence of CO, H_2S, SO_2, halogens, or neon gases that interfere.
2. As at Bayou Choctaw, the fresh water sample at this site required no salinity correction.

As anticipated, at all sites the brine being displaced from the caverns is essentially devoid of oxygen. However, the brine approaches air-saturation while residing in the holding ponds.

3.4 POTENTIAL PRECIPITATES FROM REINJECTION BRINES

T. J. Wolery

The potential for precipitation of solids from three SPR reinjection brines was examined theoretically by use of the EQ3/6 computer code package.[15] These brines are designated as SPR1, SPR2, and SPR3 in this report, and are described in Table 3-17.

The analytical data in Table 3-17 were used to evaluate the chemical potentials of the solution components and hence the saturation state of the fluids with respect to possible precipitates. Saturation state can be evaluated numerically as either of the functions

$$\log Q/K$$

or

$$2.303\ RT \log Q/K$$

where Q is the activity product of a mineral dissolution reaction, K is its equilibrium constant at the pressure and temperature of interest, R is the gas constant, and T is the absolute temperature. At equilibrium, Q = K and each function is zero. Positive values indicate supersaturation, negative one, undersaturation. Even in the best of cases the propagation of errors is such that the uncertainty in log Q/K is no less than about 0.1. For reference, 2.303RT = 1.364 at 25 C.

The EQ3/6 code package uses a set of activity coefficient approximations based on sodium chloride solutions, and applies them to individual chemical species as components. These are not considered reliable above ionic strengths of about 1 or 2 molal, except for sodium and chloride in pure sodium chloride solutions. The brines discussed here have ionic strengths in the range 5 to 6 molal. Hence, this treatment is not completely satisfactory.

These brines are well approximated by solutions in the system $NaCl-CaSO_4-H_2O$. Consequently, it was possible to evaluate log Q/K at 25 C for some minerals by using Wood's method[16] as well. This approach is more accurate for such concentrated brines than that currently used by EQ3/6. However, it has not been as generally worked out. It cannot currently be used, for example, to determine the saturation status of brines with respect to carbonate minerals. This is unfortunate, because the carbonates are the most important potential precipitates from these brines, according to the EQ3/6 results (Table 3-18).

The discrepancies in log Q/K for halite calculated by the two approaches are small, yet surprising because the brines are dominantly NaCl brines and the activity coefficient approximation in EQ3/6 is keyed to pure NaCl solutions. The most concentrated brine, SPR3, is just undersaturated with respect to halite.

All three brines are close to saturation with respect to calcite ($CaCO_3$), aragonite (its less stable polymorph), and dolomite [$CaMg(CO_3)_2$]. If the log Q/K uncertainty for gypsum is any guide, these solutions could be saturated, undersaturated, or supersaturated with respect to these carbonates.

Extremely high supersaturations were calculated for the iron oxides. This is probably only a consequence of colloidal ferric hydroxide passing through filters and contributing to the analyzed value of "dissolved" iron.

The effect of temperature on the saturation state for halite and the carbonates (as predicted by EQ3/6) is shown in Fig. 3-2. There is almost no effect on halite in this temperature range, although its solubility does increase with temperature. However, the function 2.303RT log Q/k increases linearly with temperature for all the carbonates. According to these EQ3/6 calculations, all the carbonates become supersaturated at temperatures above about 45 C. The variations with temperature, however, are of the same magnitude as the uncertainty suggested by the comparison with Wood's equations at 25 C.

The EQ3/6 code was run in another mode to calculate stable assemblages of precipitates. For SPR1 and SPR2, only calcite was volumetrically important. For SPR3, dolomite appeared instead. Equilibrium precipitation of the carbonate for each brine is shown in Fig. 3-3. The volume of precipitate increases with temperature once the carbonate appears. Although this trend is most probably correct, the absolute volumes could reasonably be incorrect by a factor of two.

TABLE 3-1. SPR Brine properties.

Source	pH	ρ, g/mℓ	Constituent, mg/ℓ					
			Cl^-	Fe(D)	Fe(T)	Ca^{++}	$SO_4^=$	HCO_3^-
West Hackberry								
Cavern brine	7.5	1.182	172,000	-	0.19	650	1475	294
Ponded brine	7.6	1.177	170,000	-	0.40	612	1319	293
Injection site	7.6	1.176	167,000	-	0.42	603	1250	296
Bayou Choctaw								
Cavern brine	6.8	1.197	192,000	-	0.33	465	833	148
Ponded brine	6.8	1.196	191,000	0.14	0.34	398	700	148
Cavern Lake water	7.8	1.0	<53	0.36	1.0	28	17	103
Injection site	6.9	1.189	184,000	0.17	0.62	380	650	159
Weak brine	6.5	1.173	164,000	0.48	1.10	1060	1115	97
Bryan Mound								
Cavern brine	6.8	1.198	197,000	1.35	1.7	901	3000	110
River water	8.1	1.0	240	0.28	0.43	58	80	153
Ponded brine	6.9	1.191	187,000	0.39	1.68	894	2275	112
Injection site	6.8	1.186	179,000	0.43	1.40	821	2375	116
Cavern 4 brine	11.1	1.196	190,000	0.02	0.07	921	3500	-

TABLE 3-2. Turbidity/suspended solids in SPR fluids.

Source	Turbidity, NTU		Suspended solids conc., mg/ℓ > 0.4 μm
	Average	Range	
West Hackberry			
Cavern brine	0.73	0.26 - 1.4	--
Ponded brine	3.2	0.61 - 20.0	2.9
Injection site	3.2	1.3 - 7.4	3.3
Bayou Choctaw			
Cavern brine	0.7	0.6 - 0.9	--
Ponded brine	1.5	1.2 - 1.8	3.0
Injection site	5.7	4.0 - 8.8	7.0
Weak brine	11.1	5.4 - 20.0	20.0
Cavern Lake water	70	--	76.0
Bryan Mound			
Cavern brine	2.2	2.1 - 2.3	--
Ponded brine	11.8	6.8 - 19.0	4.5
Injection site	12.5	12.0 - 13.0	6.8
River water	32	--	--

TABLE 3-3. Chemical composition of brine suspended solids (analysis by X-ray fluorescence).

Element	Amount detected, wt.%, at indicated location				
	Ponded brines at West Hackberry	Ponded brines at Bayou Choctaw	Weak brines at Bayou Choctaw	Ponded brines at Bryan Mound	Cavern Lake at Bayou Choctaw
Al	19.2	~6.5	~11.0	3.1	~15.0
Si	18.5	17.5	21.6	9.3	17.3
S	0.71	0.56	0.90	0.33	0.26
Cl	4.7	--	--	--	--
K	0.99	1.9	2.8	0.62	1.6
Ca	1.18	1.2	0.71	2.7	0.59
Ti	0.30	0.36	0.48	0.33	0.32
Cr	0.01[a]	--	--	--	--
Mn	0.06	--	~0.04	--	--
Fe	7.30	7.8	4.5	23.3	3.3
Cu	0.06	0.14	0.02	0.02	0.09
Zn	0.02	0.03	0.01	0.015	0.03
Ga	ND	--	--	--	--
Bv	0.001	--	--	--	--
Rb	0.008	0.006	0.01	0.0035	0.006
Sr	0.008	0.02	0.03	0.015	0.004
Y	0.004	--	--	--	--
Zr	0.02	0.01	0.02	0.007	0.01
Nb	0.001	--	--	--	--
As	0.003[a]	~0.02	~0.002	~0.01	~0.003
Pb	0.011	0.11	0.02	0.05	0.02
Sn	0.013	--	--	--	--
Sb	0.003	0.003	0.008	0.0015	--
Ba	0.072	0.17	0.13	0.63	0.03
La	0.005	--	~0.02	--	--
Ce	0.007	--	--	--	--
Ag	--	0.05	0.09	0.015	0.05

[a]Estimate.

TABLE 3-4. West Hackberry brine incubation data (35 C).

Time, hr	Pond input, mg/ℓ		Ponded brine, mg/ℓ		Brine at injection site, mg/ℓ	
	Solids	Fe filtrate	Solids	Fe filtrate	Solids	Fe filtrate
0	0.2	0.09	1.3	0.19	4.5	0.13
0.25	0.2	0.11	2.2	0.15	-	-
0.50	-	-	2.7	0.12	-	-
0.75	-	-	-	-	3.3	0.16
1	2.3	0.08	2.5	0.14	-	-
2	0.2	0.08	2.7	0.06	3.7	0.13
4	0.2	0.07	2.7	0.05	3.6	0.08
6	-	-	2.7	0.04	-	-
7	0.2	0.07	-	-	3.2	0.04
12	-	-	3.0	0.05	-	-
17	-	-	-	-	2.4	0.07
23	-	-	-	-	2.4	0.06
24	-	-	2.4	0.06	-	-
26	0.2	0.05	-	-	-	-

TABLE 3-5. Bayou Choctaw brine incubation data (35 C).

Time, hr	Cavern 18 brine, mg/ℓ		Ponded brine, mg/ℓ		9:1 Ponded brine/ Cavern Lake, mg/ℓ		Weak brine, mg/ℓ	
	Solids	Fe filtrate	Solids	Fe filtrate	Solids	Fe filtrate	Solids	Fe filtrate
0	2.4	0.23	5.4	-	10.1	0.13	19.1	0.33
0.5	2.7	-	5.4	-	13.0	0.19	15.2	0.38
1.0	2.2	0.33	5.4	0.28	13.7	0.10	13.6	0.33
2.0	2.3	-	5.4	-	13.2	0.12	13.1	0.25
4.0	1.7	0.19	4.4	-	12.3	0.11	13.2	0.13
6.0	1.4	-	-	-	11.9	0.12	12.7	0.10
24.0	7.3	0.14	2.6	0.10	11.4	0.07	17.0	-

TABLE 3-6. Bryan Mound brine incubation data (35 C).

Time, hr	Cavern 5 brine, mg/ℓ		Ponded brine, mg/ℓ		Brine at injection site, mg/ℓ		Chemically treated and filtered brine,[a] mg/ℓ	
	Solids	Fe filtrate	Solids	Fe filtrate	Solids	Fe filtrate	Solids	Fe filtrate
0	2.6	1.42	2.8	0.08	4.2	0.28	0.9	0.07
0.5	2.0	1.40	2.8	0.07	4.2	0.14	1.3	0.06
1.0	1.6	1.28	2.6	0.07	4.4	0.16	1.4	0.10
2.0	2.5	1.00	4.9	0.07	4.1	0.15	0.5	0.11
4.0	3.1	0.80	3.1	0.05	3.9	0.17	1.8	0.10
8.0	4.6	0.35	2.3	0.04	7.4	0.10	3.8	0.10
16.0	3.5	0.13	4.0	0.07	5.3	0.08	0.5	0.08
24.0	-	-	-	-	2.8	0.05	-	-

[a]10 mg/ℓ alum + 0.2 mg/ℓ Magnafloc 985 N; triple-media filter.

TABLE 3-7. pH of Cavern 5 and Cavern 4 brine mixtures (Bryan Mound).

Cavern 5 to Cavern 4 volume ratio	pH
0.0	11.01
0.2	10.89
0.4	10.76
0.6	10.62
0.8	10.46
1.0	10.26
1.2	9.97
1.4	9.61
1.53	9.45[a]
1.6	9.30
1.8	9.08
2.0	8.66
2.2	8.52
2.4	8.38
2.6	8.26
2.8	8.20
3.0	8.00

[a]pH declines to 8.8 within 1 hour because of slow precipitation of $CaCO_3$.

TABLE 3-8. HCl consumption and resultant pH in 1.53 (by volume) Cavern 5 to Cavern 4 brine mixture.

pH	HCl consumption, ppm by weight
8.8	0
8.7	0.48
8.5	1.92
8.0	4.32
7.5	17.3
7.0	27.6
6.5	34.8
6.0	43.2
5.5	52.3
5.0	59.0

TABLE 3-9. HCl consumption and resultant pH in 1.53 (by volume) Cavern 5 to Cavern 4 brine mixture prefiltered to remove precipitated solids (Bryan Mound).

pH	HCl consumption, ppm by weight
8.82	0
8.67	0.96
8.48	1.92
8.30	2.88
8.09	3.84
7.80	4.80
7.40	5.76
6.88	6.72
6.62	7.68
6.21	8.64
5.83	9.60
5.38	10.56
5.05	11.52

TABLE 3-10. HCl consumption and resultant pH of Cavern 4 brine (Bryan Mound).

pH	HCl consumption, ppm by weight
11.1	0
11.08	3.04
11.06	6.08
11.04	9.11
11.02	12.15
11.00	15.19
10.98	18.23
10.96	21.26
10.94	24.30
10.92	27.34
10.90	30.38
10.86	36.45
10.82	42.53
10.76	48.60
10.60	60.75
10.50	66.83
10.30	72.90
10.08	78.98
9.54	85.05
8.70	88.09
7.60	89.61
6.00	91.13
4.45	92.64

TABLE 3-11. Suspended solids concentration and pH of Cavern 4, Cavern 5, and combined brines (Bryan Mound).

Brine	Solids concentration, mg/ℓ	Solids concentration, ppm, by weight	pH
Cavern 4	0.85	0.71	11-11.1
Cavern 5	6.2[a]	5.17[a]	6.76
1.53 (by volume) Cavern 5 to Cavern 4 mixture after 1 hour	104.0	87.0	8.80

[a]May be high because of sampling and handling deficiencies.

TABLE 3-12. Petroleum concentration in SPR brines.

SPR site	Date	Sample	Petroleum concentration, mg/ℓ
West Hackberry	January 11, 1979	Pond in	0.21
		Pond out	3.92
		Injection	4.34
Bayou Choctaw	January 28, 1979	Pond in	<0.2
		Pond out	<0.2
		Injection	<0.2
		Weak brine	<0.2
Bryan Mound	February 25, 1979	Pond in	0.5
		Pond out	0.24
		Injection	<0.2
		Fresh water	<0.2

TABLE 3-13. West Hackberry dissolved oxygen measurements.

Date	Time	Brine temperature, °C	Dissolved oxygen content, ppm	
			Uncorrected	Corrected
Sample point: Pond in				
January 8, 1979	1600	14.	0.65	0.17
January 9, 1979	1400	33.	0.10	0.026
January 11, 1979	1730	26.3	0.15	0.039
January 12, 1979	1630	33.2	0.10	0.026
January 13, 1979	1400	28.3	0.10	0.026[a]
January 14, 1979	1655	27.4	0.05	0.013
January 15, 1979	1150	26.9	0.02	0.005
Sample point: Pond out				
January 8, 1979	1615	18.5	4.80	1.25
January 9, 1979	1115	20.5	2.80	0.73
January 11, 1979	0930	21.5	2.4	0.62[a]
	1700	21.7	2.0	0.52
January 12, 1979	1600	19.6	3.65	0.95[b]
January 13, 1979	1415	19.7	5.1	1.33[b]
January 14, 1979	1630	14.8	7.0	1.82
January 15, 1979	1140	16.	7.10	1.84
January 16, 1979	0900	23.5	1.90	0.49
Sample point: Injection site				
January 8, 1979	1500	18.	3.45	0.90
January 9, 1979	1000	21.5	2.80	0.73
January 10, 1979	1110	24.	1.45	0.38
January 11, 1979	1620	22.3	1.73	0.46[a]
January 12, 1979	1500	19.7	0.45	0.117
January 13, 1979	1120	20.5	3.20	0.83
January 14, 1979	1600	15.	5.90	1.53
January 15, 1979	1100	15.3	5.70	1.48
Sample point: Corrosion test out				
January 11, 1979	1710	22.3	1.65	0.43
January 12, 1979	1615	19.2	3.50	0.91
January 13, 1979	1425	20.1	0.15	0.04[c]
January 14, 1979	1640	15.	0.05	0.013

[a]Chemet = 0.5.

[b]Chemet ≥ 1.0.

[c]Chemet = 1.0.

TABLE 3-14. Bayou Choctaw dissolved oxygen measurements.

Date	Time	Brine temperature, °C	Dissolved oxygen content, ppm	
			Uncorrected	Corrected
Sample point: Strong brine pond in				
January 27, 1979	1425	28.3	0.05	0.013
Sample point: Strong brine pond out				
January 25, 1979	1730	24.8	3.80	0.99
January 26, 1979	1345	25.6	3.85	1.0
January 27, 1979	1405	25.4	4.05	1.05
Sample point: Injection site				
January 27, 1979	1145	24.2	4.55	1.18
Sample point: Corrosion test out-flow				
January 26, 1979	1355	25.4	1.03	0.27
	1545	25.3	0.08	0.021
January 27, 1979	1355	25.6	0.12	0.031
Sample point: Weak brine				
January 31, 1979	1200	11.6	10.5	2.73
February 1, 1979	1340	14.7	10.9	2.83
Sample point: Lake water				
January 28, 1979	1640	11.0	3.96	3.96

TABLE 3-15. Bryan Mound dissolved oxygen measurements.

Date	Time	Brine temperature, °C	Dissolved oxygen content, ppm	
			Uncorrected	Corrected
Sample point: Pond in				
February 24, 1979[a]	1530	29.4	0.05	0.013
February 25, 1979[b]	1100	32.6	0.125[c]	0.033
Sample point: Pond out				
February 23, 1979	1530	23.5	4.85	1.26
February 24, 1979	1550	23.4	5.15	1.34
February 25, 1979	1710	23.1	4.50	1.17
February 26, 1979	0945	25.6	3.18	0.83
February 27, 1979	1420	25.7	5.20	1.35
Sample point: Injection site				
February 26, 1979	1710	25.7	2.85	0.74
February 27, 1979	1345	25.1	3.73	0.97
Sample point: River water				
February 2, 1979	1550	17.4	3.97	3.97
February 24, 1979	1605	18.0	4.55	4.55
February 25, 1979	1700	17.6	5.20	5.20
February 26, 1979	0935	16.8	5.10	5.10
February 27, 1979	1410	17.0	6.35	6.35

[a]Cavern 4.

[b]Cavern 5.

[c]Charged with gas bubbles.

TABLE 3-16. Average corrected dissolved oxygen contents.

Source	Average corrected dissolved oxygen content, ppm, at indicated site		
	West Hackberry	Bayou Choctaw	Bryan Mound
Pond in	0.023 ± 0.012	0.013	0.013
Pond out	1.037 ± 0.559	1.014 ± 0.033	1.191 ± 0.216
Injection	0.790 ± 0.543	1.183	0.855 ± 0.161
Fresh water	—	3.96	5.03 ± 0.88
Weak brine	—	2.782 ± 0.073	—

TABLE 3-17. Brine properties.

	SPR 1[a]	SPR 2[b]	SPR 3[c]
ρ, g/mℓ	1.1987	1.194	1.2042
TDS, mg/ℓ	286,898	273,000	312,051
Na^+, mg/kg	97,189	110,970	101,501
K^+, mg/kg	229	--	--
Ca^{++}, mg/kg	619	771	246
Mg^{++}, mg/kg	9	--	11
Cl^-, mg/kg	139,737	159,548	156,563
HCO_3^-, mg/kg	98	92	226
$SO_4^=$, mg/kg	1,460	1,926	590
Fe^{++}, mg/kg	0.8	0.22	0.22
pH	7.22	6.80	6.86

[a]Bryan Mound pond output, analyzed by Petroleum Laboratories, Inc. (DR-17-2).

[b]Ponded brine, Bryan Mound, Sample 1410, February 23, 1979.

[c]Bayou Choctaw pond input, analyzed by Petroleum Laboratories, Inc. (DP-322-2).

TABLE 3-18. Log Q/K calculations.

Constituent	log Q/K at 25 C at indicated site		
	SPR 1	SPR 2	SPR 3
Hematite, Fe_2O_3	+23.3	+21.6	+21.7
Magnetite, Fe_3O_4	+17.1	+14.4	+14.6
Brucite, $Mg(OH)_2$	-6.0	--	-6.6
Halite, NaCl	-0.4(-0.2)[a]	-0.2	-0.2(-0.1)[a]
Sylvite, KCl	-2.7(-2.6)[a]	--	--
Calcite, $CaCO_3$	+0.2	-0.1	-0.1
Aragonite, $CaCO_3$	0.0	-0.3	-0.3
Dolomite, $CaMg(CO_3)_2$	-0.1	--	-0.2
Magnesite, $MgCO_3$	-1.9	--	-1.7
Gypsum, $CaSO_4 \cdot 2H_2O$	-0.9(-1.3)[a]	-0.8	-1.8

[a]Calculated by Wood's method (Ref. 14).

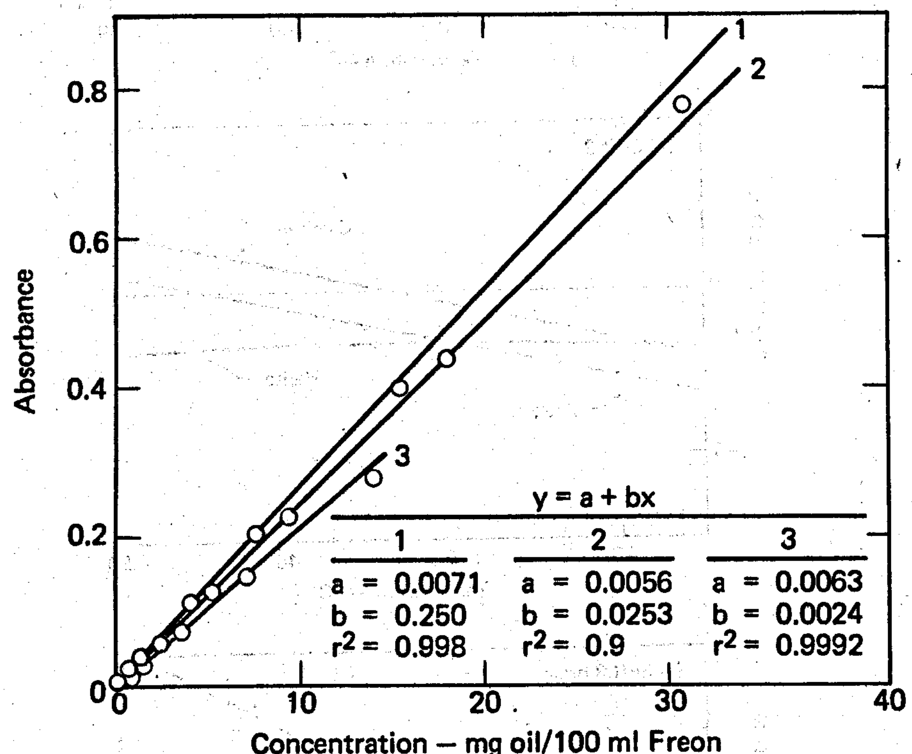


FIG. 3-1. Beer-Bouguer Law plots derived using standards prepared from the crude oil injected at each site.

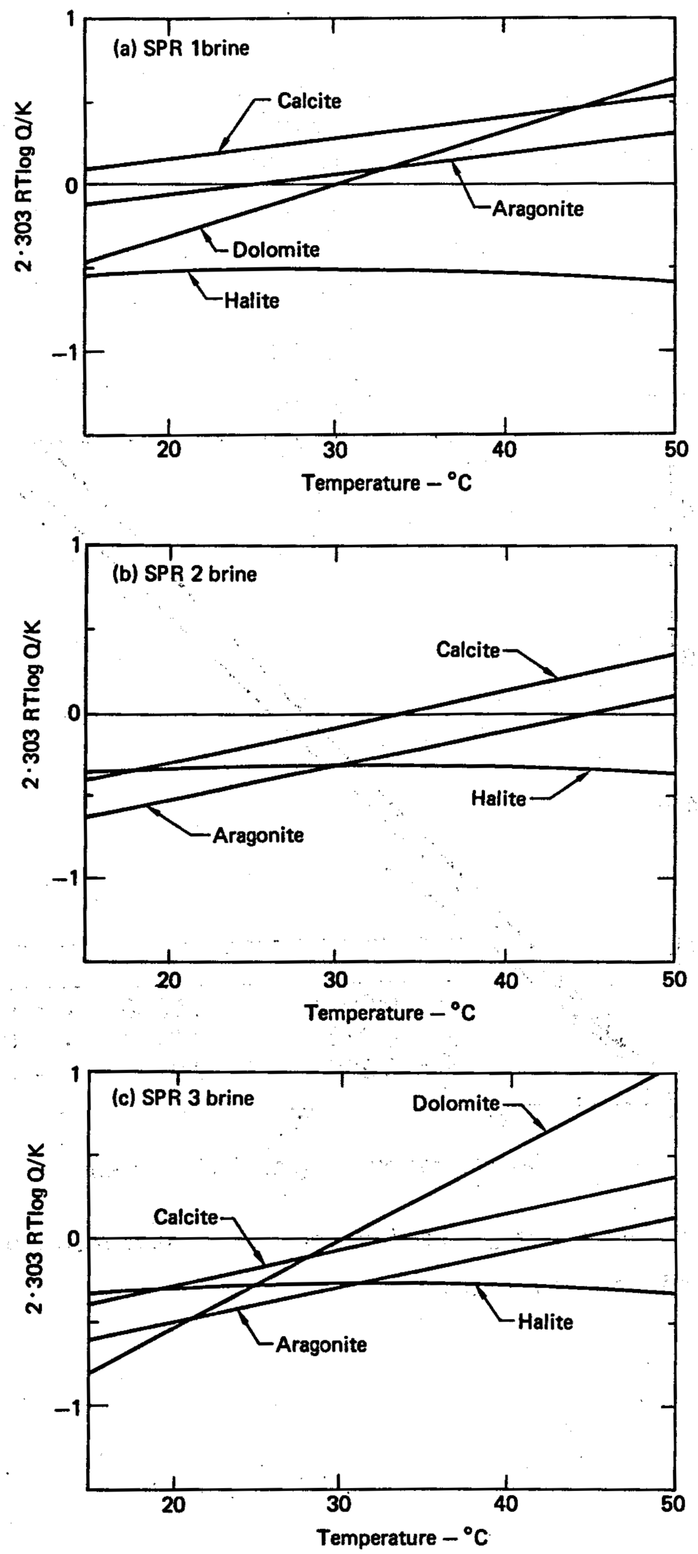


FIG. 3-2. Saturation states of SPR brines with respect to halite and major carbonate minerals produced by heating and cooling. Effects of actual precipitation are ignored.

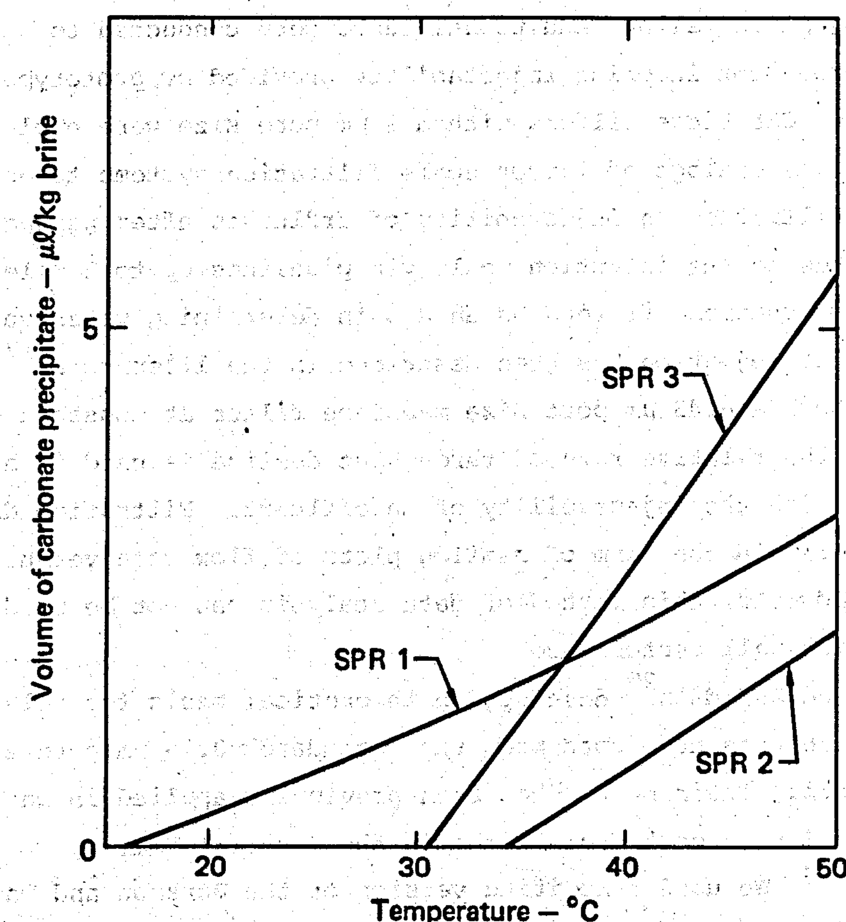


FIG. 3-3. Volume of carbonate precipitate (calcite for SPR 1 and SPR 2 brine; dolomite for SPR 3 brine) produced by equilibrium precipitation at temperatures between 15 and 55 C.

CHAPTER 4

EVALUATION OF BRINE INJECTABILITY

L. B. Owen, R. Quong, R. Netherton, R. Neurath, and E. Raber

Membrane filtration tests were performed at the West Hackberry, Bayou Choctaw, and Bryan Mound SPR sites to assess the relative injectability of various untreated process streams that are disposed of via deep (4000 to 8000-foot) injection wells. Additional tests were conducted to assess the potential improvement in brine injectability provided by prototype granular media filters. Cartridge filters with a 1 μm pore size were employed at the injection pads as analogs of larger scale filtration systems to establish the effect of prefiltration on injectability of effluents after passage from the main surge ponds to the injection wells via pipelines up to 2 miles long.

The use of membrane filters as an aid in determining water quality requirements for injection has been described in the literature.[17-19] Water is flowed through a 0.45 μm pore size membrane filter at constant differential pressure, and the relative rate of throughput decline is used in a qualitative sense to establish the injectability of an effluent. Filtration data are usually presented in the form of semilog plots of flow rate versus cumulative throughput. However, this method of data analysis can not be used to estimate actual injection well performance.

Barkman and Davidson[20] developed a theoretical basis for relating well performance with data developed from the "standard" 0.45 μm pore size membrane filtration tests. Their method has been previously applied in an assessment of brine injection at geothermal sites in the Imperial Valley, California.[21,22] We used a modified version of the Barkman and Davidson technique to study brine injection at the SPR sites.

Results of our SPR injection evaluation indicated that brine prefiltration with downflow sand or mixed media filters provides a significant improvement in brine injectability. Estimated injection well performance for untreated effluents agreed with observed behavior of wells. An important factor in the rapid impairment of SPR injection wells is shallow invasion of the injection interval by suspended solids less than about 10 μm in diameter. Injectability of raw effluents degrades as they flow from the surge ponds to the injection pads as a result of production of corrosion-induced particulates. At two sites (Bayou Choctaw and Bryan Mound), the use of untreated highly turbid fresh water as a brine diluent to prevent salt precipitation significantly degrades brine injectability. We concluded that a properly designed and maintained preinjection filtration and corrosion control system is essential for maintaining satisfactory performance of SPR injection wells.

4.1 INJECTION WELL HALF-LIFE ESTIMATES

The analytic models of Barkman and Davidson[20] were used to estimate the half-life of injection wells accepting raw and treated effluent. The half-life is defined as the length of time required for the injection rate to fall to one-half of its initial value at constant pressure. Half-life calculations are based on membrane filtration data obtained with apparatus described in Section 4.2. The standard filter data acquisition procedures were modified to better simulate the unconsolidated nature of the SPR injection zones and their corresponding high porosity (30 percent) and permeability (0.8 to 5 darcies). We concluded that injection tests with the standard 0.45 µm pore size membrane filter may yield half-life estimates for injection wells that are too conservative. More meaningful results could be obtained if the actual reservoir pore structure could be simulated by utilizing membrane filters with the appropriate pore size distribution.

The effect of particulate size distribution on the permeability of a porous matrix is shown in Fig. 4-1. Champlin et al. (1967)[23] suggested the following expression is useful in relating formation porosity and permeability to the mean pore diameter of an injection zone.

$$D = 4(1 - \emptyset)/[(\emptyset \times 10^3)/5K]^{1/2}, \qquad (4\text{-}1)$$

where Ø is porosity, K is permeability (md), and D is the mean pore diameter. They subsequently demonstrated, by means of core tests, that the largest size particle passing through core samples was about 25 percent smaller than the calculated mean pore size (Fig. 4-2). We estimated a mean pore diameter of 10.2 µm for the SPR injection zones with Eq. (4-1) assuming 30 percent porosity and 800 md permeability. Porosity and permeability values were obtained from SPR injection well logs (Chapter 2). We then completed filtration tests at each SPR site utilizing membrane filters with pore sizes ranging from 0.4 to 10.0 µm. Polycarbonate Nuclepore membrane filters were used in place of the standard Millipore cellulose acetate membrane filter because we found the former had superior elution loss characteristics (Section 4.3).

Filtration data were reduced in the form of linear coordinate plots of cumulative volume versus the square root of time (Fig. 4-3). If the membrane filter becomes impaired by formation of a filter cake, either on the surface of the membrane or within its pore structure, the filtration curve approaches a straight line. The slope of the linear portion of the filtration curve is proportional to the water quality ratio, $W(ppm)/k_c(md)$, defined as the ratio of suspended solids concentration to the permeability of the filter cake formed on or within the membrane filter. Since the suspended solids concentration is known (measured during the membrane filtration test), the filter cake permeability can be calculated and a half-life estimate can then be developed for the injection wells. The actual performance of an injection well will depend in part on whether suspended solids are filtered out at the sandface or invade some distance before bridging pores and constructing an internal filter cake. The extrapolation of the linear portion of the filtration curve allows an estimate of invasion to be made; a negative intercept indicates no invasion while a positive intercept indicates invasion.

Equations for wellbore narrowing and invasion were used to estimate half-lives of SPR injection wells.[20] If invasion was indicated by membrane filtration data, an invasion radius of 10 feet was assumed. The parameters for the half-life calculations are as follows:

Vertical injection interval (h) = 300 ft

Initial injection rate (I_o) = 30,000 bbl/d

Density filter cake (ρ_c) = 1.50 g/cc

Area of membrane filter (A) = 9.62 cm^2

Formation permeability (K_F) = 800 md

Formation porosity (Ø) = 30 percent

Brine viscosity (µ):

Salinity, wt%	Density, ρ_B, g/cc	Viscosity, cp, at 50 F	100 F	Density ratio, ρ_c/ρ_B
Strong, 26	1.193	2.4	1.33	1.26
Weak, 22	1.163	2.15	1.15	1.29

As shown in Fig. 4-4, brine viscosity is a strong function of temperature and salinity. We utilized the viscosity values shown above to estimate half-lives for the injection of saturated or nearly saturated cavern brines (strong) and undersaturated leach brines (weak). The temperature range 50 to 100 F reflects the most probable maximum seasonal variations in injection wellhead temperature.

The water quality ratio (w/k_c) is calculated from the expression

$$\frac{w}{k_c} = \frac{2,000}{S^2/60} \frac{(\rho_c/\rho_w) A_c^2 \Delta P_t}{\mu} \tag{4-2}$$

where S is the slope ($m\ell/\sqrt{min}$) of the linear portion of the membrane filtration curve and ΔP_t is the differential pressure (atm) across the membrane filter.[21] The slope S was calculated by linear regression of membrane filtration data. More convenient forms of Eq. (4-2) are as follows:

$$w/k_c = \frac{4.014 \times 10^5 \times \Delta P(psi)}{S^2} \text{ at 50 F} \tag{4-3}$$

and

$$w/k_c = \frac{8.378 \times 10^5 \times \Delta P(psi)}{S^2} \text{ at 100 F} \tag{4-4}$$

Equations (4-3) and (4-4) are based on two assumptions:

1. filter cake/brine density ratio is 1.275;
2. strong brine viscosity at 50 F is 2.4 cp and weak brine viscosity at 100 F is 1.15 cp.

These assumptions permit W/k_c to be estimated (for either strong or weak brine) over the temperature interval 50 to 100 F. In general, half-life estimates based on Eq. (4-4) will be 48 percent smaller than similar estimates based on Eq. (4-3).

The half-life ($T_{1/2}$) is computed from

$$T_{1/2\,(yr)} = F \times G_{1/2} \tag{4-5}$$

F and $G_{1/2}$ are defined as follows:

$$F = \frac{571.5\ yr \cdot h}{I_o \times W} \tag{4-6}$$

where h is the vertical injection interval (ft), I_o is the injection rate (bbl/d), and w is the concentration of suspended solids (ppm by weight) in the injected effluent.

$G_{1/2}$ is defined by separate equations for injection well impairment resulting from wellbore narrowing or invasion:

Wellbore Narrowing

$$G_{1/2} = 19.86\ (K_c/k_f) \tag{4-7}$$

Invasion

$$G_{1/2} = (19.86)(\emptyset)^2 (k_c/k_f)(r/0.67)^2 \tag{4-8}$$

For an invasion radius, r = 10 feet and $\emptyset$ = 30 percent, Eq. (4-8) reduces to the form

$$G_{1/2} = (398.17)(k_c/k_f) \tag{4-9}$$

Barkman and Davidson emphasize that half-life estimates have an accuracy no better than a factor of two because of the uncertainty in fixing the injection parameters and in determining the true time-average of the water quality ratio from spot measurements. Furthermore, a membrane test only resolves injection well impairment resulting from deposition of suspended solids or scale formation. The actual improvement in injection that might be realized as a result of prefiltering brine, for instance, prior to injection cannot be accurately estimated since deficiencies in injection reservoir properties, well completion practices or poor operating procedures may be in part responsible for SPR injection difficulties. These types of impairment mechanisms cannot be resolved by membrane filtration tests except indirectly when test results indicate no potential for particulate-induced damage. A detailed reservoir assessment and careful control of drilling and operational practices are essential elements of a properly functioning injection system.

An assessment of the injection reservoir at the Bayou Choctaw SPR site is provided in Chapter 2.

4.2 MEMBRANE FILTRATION APPARATUS

Two essentially identical membrane filtration systems were used to test brine injection. One system (Fig. 4-5) was located in the LLL experimental trailer. Surge pond effluent, obtained from the pressure side of the SPR low-pressure injection pumps, and other available process streams (e.g., leached brine and dilution water) were flowed into the trailer at atmospheric pressure. A manifold system allowed for rapid testing of either the raw brine or brine from any one of four prototype sand filters. Membrane tests were performed at pressure differentials of up to 50 psig. A gear pump and variable speed motor drive were used to repressurize the brine to the desired test pressure.

The system shown in Fig. 4-6 was located in the LLL step van for use at the SPR injection pads. An auxiliary pump was not needed in the van because the injection line operated at a pressure of about 1000 psig. Cuno, 1 µm pore size, cartridge filters were used in conjunction with the step van system to establish the improvement in injection that might be obtained by prefiltration. Test results indicated that the cartridge filters performed as reasonably good analogs of the much larger downflow sand filters located in the main experimental trailer.

The test apparatus shown in Fig. 4-7 was used to generate injection data for leach brine effluents after processing by commercial pilot-scale filtration systems operated by L'Eau Claire Systems, Inc., Kenner, LA, C-E Natco, Tulsa, OK, and Baker Filtration Co., Huntington Beach, CA. The filter vendors were participants in a concurrent DOE-funded study at Bayou Choctaw. Their objective was to establish the performance efficiency and suitability of available commercial filtration systems for treatment of SPR brines.

Three injection test boards were built and installed by LLL. Each board was mounted on a unistrut support and plumbed directly into the exhaust stream of each commercial filter system. After installation and initial check-out, vendor personnel were instructed on proper testing procedures. The vendors subsequently produced prodigious amounts of useful data. LLL personnel also performed several independent tests for each vendor.

The injection test systems were constructed from Type 304 stainless steel tubing. All valves, fittings, and pumps were constructed from Type 316 stainless steel. Nuclepore 47-mm standard polycarbonate membrane filters (pore size 0.4 to 10.0 μm) and Millipore type MF membrane filters were used exclusively. Nuclepore filters resist attack by most acids and organic solvents except for halogenated hydrocarbons and strong bases and have superior elution loss properties. Membrane filters were mounted in Millipore high-pressure stainless 47-mm in-line holders. All membrane filters were mounted on Nuclepore high-permeability fiber filter support pads. It was also necessary to displace trapped air in the filter holders prior to runs to avoid reduced filtration rates resulting from closure of filter pores by air bubbles.

4.3 EXPERIMENTAL PROCEDURE

Filter tests utilizing 0.4 and 0.45 μm membrane filters were run for ~30 minutes at a pressure differential of 50 psig. Tests with 1, 5, 8, and 10.0 μm membrane filters were run for periods of 30 to 60 minutes at differential pressures of 6 to 40 psig. The principal modes of monitoring flow rate and total volumetric throughput involved the use of 2-litre graduate cylinders and automated flow monitoring systems (Flow Technology). The automated systems utilized turbine flow meters and electronic signal processing techniques to provide continuous output via Hewlett Packard thermal printers of flow rate, total throughput and elapsed time. Field calibration runs indicated that the flow technology systems were capable of yielding accurate flow data when used with high-salinity brines. The particular systems obtained by LLL have a useful operating range of 0.001 to 0.4 gal/min.

Suspended solids concentrations were measured in accordance with standard published procedures. In the filter vendor tests, suspended solids data were obtained after each filter run by another DOE contractor.[22]

Numerous field and laboratory experiments were performed to establish the solubility (weight loss) of various membrane filters in hypersaline brine. Data on solubility or elution loss was obtained for Millipore and Nuclepore membrane filters. These data were collected by mounting two identical filters, separated by fiber support pads, in a filter holder and then exposing both filters simultaneously to brine. Weight loss of the lower filter is an indication of the filter elution loss and is used to correct suspended solids data. Our laboratory data, based on experiments with ultrafiltered brine from the Bryan Mound SPR site, are summarized in Table 4-1. These data show that Nuclepore polycarbonate membrane filters have low solubility in hypersaline brine (at ~30 C). Mixed cellulose acetate-nitrate Millipore membrane filters (type MF), however, have a significant solubility in low-temperature brine. Field data obtained at the Bayou Choctaw SPR site on leach brine by Analysis Laboratories indicated an elution loss of 0.8 percent for 0.45 µm pore size Millipore membrane filters. We used the 0.45 µm elution loss data to correct all suspended solids data obtained with Millipore type MF membrane filters; we used the laboratory elution loss data to correct all runs with Nuclepore filters.

4.4 RESULTS

4.4.1 West Hackberry SPR Site

Process stream suspended solids data and injection well half-life estimates are summarized in Table 4-2. The data presented are based on filtration tests with 0.4, 1.0, and 10.0 µm membrane filters. All experimental data for the filter test results listed in Table 4-2 are summarized in Appendix IX. Suspended solids concentrations in West Hackberry brine effluent range from less than 1 to more than 8 ppm. Conditions in the surge pond during the test period (January 3-15, 1979) were variable as a result of weather conditions and operational upsets that included a minor oil spill. Our injectability tests indicate that mixed media filtration systems can reduce suspended solids concentrations by more than one order of magnitude and thereby significantly improve brine injectability. Filtration systems would also tend to moderate the effects of periodic operational upsets in the brine injection system.

The 10 µm filter data indicate that the nominal initial half-life of injection wells accepting raw brine varies from 80 days, for brine tested at the surge pond, to 53 days for brine tested at the injection pad. These results are in good agreement with the observed performance of virgin injection wells at the site. As wells become impaired and worked-over, it is logical to assume that the impairment rate would increase since it is improbable that all well damage can be eliminated by a workover. As a result, a significant reduction may occur in the mean pore diameter in the injection interval immediately adjacent to the wellbore. The 0.4 μm pore size membrane data appear to be useful in evaluating the effects of near wellbore damage. The 0.4 μm data for raw effluents indicate half-lives ranging from 4 days for brine tested at the surge pond to 12 days for brine tested at the injection pad adjacent to well E-2. During the field test period at West Hackberry, injection well E-2 was acidized as part of a continuing workover program by site management. When the well was brought back into service, its observed half-life was about 1.5 days.

Preinjection filtration of brine has a dramatic effect on estimated injection well half-lives. As shown in Table 4-2 for the 10 μm filter data, half-lives can be extended to over 50 years. In contrast, half-life estimates based on 0.4 μm membrane filtration tests indicate that injectability is not significantly improved by prefiltration. The effects of prefiltration on brine flow through 0.4 and 10 μm membrane filters is shown in Figs. 4-8 through 4-11. In general, we observed a slight decline in raw brine injectability (based on 10 μm filtration data) between the surge pond outlet and the injection pad. This possibly reflects to a small degree corrosion of the injection line and wellbore and potential production of new suspended solids in the form of corrosion products. A more significant effect is probably related to the sporadic nature of the injection system operation, which may result in significant deposition of solids in the injection line during shut-downs or low flow periods. When the injection line operates under full-flow condition, extraneous material is swept into the wells. If a membrane filtration test happens to coincide with a major increase in injection rates, observed brine quality will decline significantly.

4.4.2 Bayou Choctaw SPR Site

This section summarizes injection test data for the raw and pretreated effluent sources described in Table 4-3. Suspended solids data and half-life estimates for fluid sources A through F (Table 4-3) are shown in Table 4-4. Results of the filter vendor injection tests are shown in Table 4-5.

Appendixes X and XI present the experimental data that form the basis for the half-life estimates given in Tables 4-4 and 4-5. The injection test results in this section are keyed to Table 4-3.

4.4.2.1 Strong Brines at Cavern Wellheads and Pond Outflow (A and B). It was not possible to accurately measure suspended solids in raw strong brine because membrane filters were rapidly plugged by precipitated NaCl. The strong brine is supersaturated with NaCl, and salt precipitation occurs as the brine cools. Salt precipitation also occurred after strong brine was prefiltered with a granular media filter. Strong brine cannot be injected directly.

4.4.2.2 Injection Pad C (C). The turbidity of strong brine increased significantly between the outflow of the strong brine pond and injection pad C (1 to 1.5 NTU at the brine pond to 8 to 9 NTU at injection pad C). The turbidity increase is a result of dilution of strong brine by injection of raw Cavern Lake water into the injection line at a point downstream of the main site low-pressure injection pumps. Membrane filters with pore sizes of 0.4, 1.0, and 5.0 microns plugged rapidly when injection wellhead brine was filtered. Unfortunately, the injection system shut down as a test with a 10-micron pore size membrane filter was starting. We concluded, on the basis of the 1 and 5 μm membrane filter data, that the mixture of Cavern Lake water and strong brine cannot be injected directly because of high suspended solids loading (11 ppm on 0.4 μm membrane filter). This conclusion was subsequently verified when we tested mixtures of brine and lake water in the LLL experimental trailer (Sections 4.4.2.3 and 4.4.2.4).

4.4.2.3 Cavern Lake Water (D). Direct injection of Cavern Lake water is not possible. Suspended solids (0.4 μm membrane filter) concentration exceeded 100 ppm. However, as shown in Tables 4-5 and 4-2, L'Eau Claire's upflow filtration system with chemical feed is capable of producing a high-quality effluent (Fig. 4-12).

4.4.2.4 Strong Brine and Cavern Lake Water Mixtures (E). Experiments were performed to evaluate the effect of lake water dilution on the injection of strong brine. An untreated mixture of 90 percent strong brine and 10 percent lake water could not be injected. The calculated half-life was 29 days based on 10 μm membrane filtration data.

We next evaluated the injection of strong brine after dilution with 10 percent clarified lake water. Two sources of clarified lake water were evaluated:

1. chemically flocculated and then settled, and
2. L'Eau Claire upflow filter effluent.

No significant improvement in strong brine injection was noted after dilution with either type of clarified lake water.

It should be emphasized that these tests were run after the injection system shut down. As a result of the shut-down, turbidity of ponded strong brine rose from a nominal value of 1 to 1.5 NTU to 5 to 6 NTU. The increased turbidity resulted from salt precipitation as ponded brine cooled. During periods of continuous operation of the strong brine injection system, use of clarified lake water as a diluent should produce a slight improvement in brine injection. The turbidity of the mixture would probably be lower than 3 NTU. However, this improvement in injection would probably not significantly extend the useful operating life of injection wells, especially if the injection system is periodically shut down.

We found that filtration of raw mixtures of strong brine and lake water yielded effluent of high injectability. Calculated injection well half-lives for 10 μm membrane filtration data ranged from 14 to 30 years. Straining the mixtures through granular media columns without chemical additions did not produce high-quality effluents. The use of polymer was mandatory for the production of injectable effluents by granular media filters. A 1 μm pore size cartridge filter, however, produced high-quality effluent without chemical feed.

4.4.2.5 Weak Brine (F). As shown in Table 4-3, raw weak brine cannot be injected because of high suspended solids concentrations (21.4 ppm on 0.45 μm membrane filter). The concentration of suspended solids retained by 8 μm membrane filters (23.7 ppm) was about the same as retained by 0.45 μm filters suggesting that the particle size distribution of particulates peaked near 8 microns. Interestingly, 10 μm pore size membrane filters plugged more readily than filters of smaller pore size. Calculated injection well half-life, based on 8.0 μm membrane filtration data, was about 7 days.

Filtration of weak brine with 1 μm pore size cartridge filters and 50,000 molecular weight ultrafilters without chemical feed or granular media filters with chemical feed resulted in production of injectable effluent. Prefiltration with a 5 μm pore size cartridge filter did not produce effluent that could be injected. The 1 μm pore size cartridge filter is, unfortunately, not practical because solids in the effluent plugged that filter in about 8 hours at a nominal flow rate of 1 gal/min/ft^2. The ultrafilter produced an acceptable effluent without chemical feed even when input turbidity exceeded 30 NTU. High turbidity in the weak brine was observed periodically when the Filter Vendors backwashed their filters into the weak brine storage tank. Calculated injection well half-lives varied from 5 to 24 years depending on the type of prefilter. Granular media filters produced the highest quality effluent. The ultrafilter is probably capable of producing the best quality effluent. In these tests, it is possible that the ultrafilter performance was degraded because its membrane was partially perforated by severe pressure fluctuations that occurred occasionally in the brine lines feeding the LLL trailer. A filtration curve for the 50 K molecular-weight ultrafilter is shown in Fig. 4-13. Filtration data for 1 μm cartridge and column prefilters (column A + polymer) are shown in Fig. 4-14.

4.4.2.6 Weak Brine Effluent Produced by Filter Vendors (G). Injectability test results are summarized in Table 4-4. Typical filtration curves for weak brine effluent are shown in Figs. 4-15, 4-16, and 4-17. Calculated injection well half-lives for effluents produced by Baker's downflow filter and C. E. Natco's upflow-downflow filter are essentially identical. L'Eau Claire's upflow filter performance resulted in the production of the lowest quality effluent. It is possible, however, that L'Eau Claire's performance could have been substantially improved if more time were available to the operators for determination of the optimum chemical feed for the upflow filter.

Weak brine injection can be substantially improved by prefiltration. State-of-the-art commercial filtration units are capable of producing high-quality weak brine for injection.

4.4.2.7 Bayou Choctaw Test Results Summary. Injection of untreated strong brine is not feasible primarily because of precipitated NaCl.

Dilution of strong brine by Cavern Lake water does not produce an injectable effluent primarily because of high suspended solids in the lake water. Dilution of strong brine by clarified Cavern Lake water does not produce a high-quality injectable effluent. At the best, the injectability of such a mixture would be about equivalent to West Hackberry raw strong brine, which, on the basis of membrane filtration tests, cannot be injected directly. A prefiltered mixture of strong brine and Cavern Lake water of high injectability can readily be produced by granular media filters with chemical feed and ultrafilters or cartridge filters without chemical feed. However, the high plugging rate of cartridge filters rules them out for large-scale utilization at Bayou Choctaw.

Raw weak brine by virtue of its high concentration of suspended solids (~22 ppm) is not directly injectable. Baker Downflow or C. E. Natco Upflow-Downflow filtration systems when used in conjunction with chemical feed can readily convert weak brine to a high-quality injectable effluent. We found that small 4-inch diameter granular media columns yield data on filterability and chemical feed requirements that compare favorably with similar data obtained in conjunction with much larger prototype commercial filtration systems. The use of the small systems for evaluating preinjection processing requirements is cost effective and efficient.

Cavern Lake water can be easily clarified by either chemical flocculation and settling or direct filtration with chemical feed. L'Eau Claire's Upflow filter did an excellent job in clarifying lake water. However, a single integrated filtration system that incorporates provisions for oxygen scavenging is probably the most cost effective method for preinjection conditioning of all injected effluents. It is not, therefore, essential that fresh water be clarified prior to leaching of new caverns.

4.4.3 Bryan Mound SPR Site

Suspended solids data and injection well half-life estimates are summarized in Table 4-6. Experimental data are listed in Appendix XII. We found that raw brine cannot be directly injected because of a high suspended solids content. The poor quality of ponded effluent results in part from the addition of highly turbid Brazos River water to the surge pond. Dilution of the cavern brines is necessary to prevent precipitation of NaCl. Data for the surge pond effluent, based on 10 μm pore size Nuclepore membrane tests, indicated that the quality of untreated effluent was low. Estimated injection well half-life was less than 120 days. When 10 μm membrane tests were performed, most membrane filters were invaded by fine particulates and plugged. Raw brine quality was significantly degraded, relative to the surge pond effluent, as brine flowed to the injection pad. The estimated half-life for raw brine at Well 3B was only 0.3 day.

Pretreatment of brine using granular media filtration with appropriate chemical aids, ultrafilters, or 1 μm pore size cartridge filters resulted in a dramatic improvement in brine injectability. Half-life estimates, based on 10 μm membrane filter tests, range from 26 to 53 years. Typical membrane filtration curves for raw and prefiltered effluent from the surge pond and injection pad are shown in Figs. 4-18 and 4-19, respectively.

TABLE 4-1. Laboratory elution loss data for Millipore type MF mixed esters of cellulose and Nuclepore standard-type polycarbonate membrane filters.

Filter type	Initial weight, mg	Final weight, mg	Cumulative throughput, ℓ	Elution loss, % of initial weight
10.0 µm Nuclepore	17.8	17.7	60	0.56
8.0 µm Millipore	57.6	55.6	40	3.47

TABLE 4-2. West Hackberry injectivity well half-life estimates.[a,b]

Brine source	Run	Filter	ΔP, psig	Volume, ℓ	SS, mg/ℓ	Intercept, mℓ	Slope, mℓ/$\sqrt{min}$	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
Surge pond	10P	0.4	50	5.3	1.85	-2444	1385	10.463	0.177	3.09	0.0044	0.014
	16P	0.4	50	6.0	1.12	-1390	1347	11.061	0.101	5.10	0.0025	0.013
	19P	0.4	50	3.9	1.69	-39	706	40.266	0.042	3.38	0.0010	0.004
	20P	0.4	50	3.8	0.95	-403	758	34.931	0.027	6.02	0.0007	0.004
	24P	0.4	50	2.2	8.65	155	406	121.757	0.071	0.66	0.0353	0.023
				avg	2.85							0.012
Injection pad	1	0.4	50	4.8	1.68	-1705	1242	13.011	1.129	3.40	0.0280	0.095
	2	0.4	50	2.2	0.23	-1639	693	41.791	0.006	24.85	0.0001	0.004
	22P	0.4	50	2.6	8.04	0.9	155	835.380	0.010	0.71	0.0050	0.004
				avg	3.32							0.034
Prefiltered surge pond	11P	0.4	50	6.9	0.13	-1547	1521	8.675	0.015	43.96	0.0004	0.016
	21P	0.4	50	9.0	0.02	3334	1025	19.103	0.001	285.75	0.0005	0.142
	25P	0.4	50	5.8	0.29	417	961	21.732	0.013	19.71	0.0065	0.128
	26P	0.4	50	3.6	2.56	-223	685	42.773	0.060	2.23	0.0015	0.003
	27P	0.4	50	4.6	1.72	-252	878	26.035	0.066	3.32	0.0016	0.005
	31P	0.4	50	2.8	1.95	-426	571	61.557	0.032	2.93	0.0008	0.002
				avg	1.11							0.049

[a] $T_{1/2}$ based on brine viscosity of 2.4 cp corresponding to injection temperature of 50 F. At 100 F, $T_{1/2}$ is about 50% lower.

[b] $T_{1/2} = F \times G_{1/2}$.

TABLE 4-2. Continued.

Brine source	Run	Filter	ΔP, psig	Volume, ℓ	SS, mg/ℓ	Intercept, mℓ	Slope, mℓ/$\sqrt{min}$	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
Prefiltered injection pad	3	0.4	50	10.3	0.09	-1170	2083	4.626	0.020	63.50	0.0005	0.032
	7	0.4	50	5.0	1.22	-218	921	23.661	0.052	4.68	0.0013	0.006
				avg	0.66			14.144	0.036	34.09	0.0009	0.019
Surge pond	12P	1.0	40	5.0	2.12	-1479	1178	11.570	0.183	2.70	0.0045	0.012
	13P	10	7	4.0	0.55	2783	217	59.670	0.009	10.39	0.0045	0.047
	14P	10	5	3.4	0.18	2100	623	5.171	0.035	31.75	0.0174	0.553
	23P	10	6	4.4	0.48	3203	220	49.760	0.010	11.91	0.0050	0.060
				avg	0.40							0.220
Prefiltered surge pond	15P	10	7	93.6	0.02	46495	6106	0.0774	0.258	285.75	0.1284	36.7
	30P	10	7	44.0	0.002	998	7918	0.0448	0.0450	2857.5	0.0224	64.0
				avg	0.01							50.4
Injection pad	4	10	6	4.4	0.66	3427	412	14.188	0.047	8.66	0.0234	0.203
	6	10	6	1.8	0.56	248	279	30.940	0.018	10.21	0.0090	0.092
				avg	0.61							0.148
Prefiltered injection pad	5	10	6	32.0	0.06	18336	2385	0.423	0.142	95.25	0.0707	6.73

TABLE 4-3. Bayou Choctaw effluent sources.

Symbol for effluent source	Description of effluent source
A	Strong brine (ρ > 1.185) at cavern wellheads.
B	Strong brine (ρ > 1.185) at pond outflow.
C	Strong brine (ρ > 1.185) at injection pad C.
D	Cavern Lake water.
E	Synthesized mixtures of 90% strong brine (ρ > 1.185) from pond outflow and 10% Cavern Lake water from high-pressure (~700 psig) site distribution system.
F	Weak brine.
G	Weak brine effluent produced by filter vendors.

TABLE 4-4. LLL Bayou Choctaw injectivity test results.[a,b]

Run	Filter, µm	ΔP, psig	Source	Suspended solids, mg/ℓ	Volume, ℓ	Comments	r^2	Intercept, ℓ	Slope, ℓ/$\sqrt{min}$	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
1C	0.4M	50	Prefiltered strong brine	-	0.600	Filter plugged								
3C	0.4M	50	Raw injection pad	11.11	0.180	Filter plugged								
4C	1.0M	50	Raw injection pad	6.67	0.180	Filter plugged								
6C	5.0M	50	Raw injection pad	0.91	0.660	Filter plugged								
8C	10.0M	15	Raw injection pad	0.53	1.880	Injection system shutdown								
2C	0.4M	50	Raw Cavern Lake water	112.8	0.047	Filter plugged								
53C	0.45M	50	90% raw strong brine + 10% raw Cavern Lake water	10.44	0.475	Filter plugged								
54C	10.0M	8	90% raw strong brine + 10% raw Cavern Lake water	0.25	3.211	-	0.9979	1.614	0.292	37.66	0.007	22.86	0.003	0.08
59C	0.45M	50	90% raw strong brine + 10% L'Eau Claire lake water filtrate	5.76	1.100	Filter plugged								
56C	10.0M	10	90% raw strong brine + 10% L'Eau Claire lake water filtrate	0.24	2.970	Filter plugged								
60C	10.0M	10	90% raw strong brine + 10% L'Eau Claire lake water filtrate	0.36	2.255	Filter plugged								
61C	10.0M	10	90% raw strong brine + 10% flocculated and settled lake water	0.35	2.200	Filter plugged								
			avg	0.32										

[a] r^2 indicates fit of the linear regression to membrane filtration data. A perfect fit is $r^2 = 1.0$.

[b] $T_{1/2} = F \times G_{1/2}$; $T_{1/2}$ is based on a brine viscosity of 2.4 cp corresponding to an injection temperature of 50 C. At 100 F, $T_{1/2}$ is ~50% lower.

TABLE 4-4. Continued.

Run	Filter, µm	ΔP, psig	Source	Suspended solids, mg/ℓ	Volume, ℓ	Comments	r^2	Intercept, ℓ	Slope, ℓ/$\sqrt{min}$	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
64C	10.0M	10	Mixture of 90% raw strong brine + 10% raw lake water prefiltered through 1.0 µm CUNO cartridge filter	0.01	81.000		0.9992	-78.107	29.127	0.005	2.11	571.50	0.052	30.0
17C	10.0M	6	Granular media prefiltered mixture of 90% raw strong brine + 10% raw lake water	0.013	31.000	-	0.9921	11.975	3.469	0.200	0.065	439.62	0.032	14.2
32C	0.48	50	Raw weak brine	18.60	0.500	Filter plugged								
26CJ	0.45M	50	Raw weak brine	20.92	1.000	Filter plugged	0.9995	0.125	0.166	586.08	0.036	0.273	0.0179	0.0049
41C	0.45M	50	Raw weak brine	23.62	0.800	Filter plugged								
43C	0.45M	50	Raw weak brine	22.52	1.000	Filter plugged								
			avg	22.35										
25C	8.0M	12	Raw weak brine	23.91	1.40	-	0.9999	0.451	0.172	131.02	0.182	0.239	0.091	0.022
27CJ	8.0M	12	Raw weak brine	23.46	1.05	-	0.9996	0.288	0.136	209.56	0.112	0.244	0.056	0.014
			avg	23.69										0.018
33C	10.0M	6	Raw weak brine	2.19	0.320	Filter plugged								
42C	10.0M		Raw weak brine	7.31	-0.260	Filter plugged								
			avg	4.75										
18C	0.45M	50	50,000 Molecular weight ultrafilter prefiltered weak brine	1.20	8.800	Ultrafilter membrane partially perforated by severe inlet pressure fluctuations	0.9957	2.116	1.214	10.958	0.110	4.763	0.055	0.260
20C	0.45M	50	50,000 Molecular weight ultrafilter prefiltered weak brine	0.24	10.800		0.9986	0.423	1.878	4.579	0.062	23.813	0.026	0.620
19C	8.0M	20	50,000 Molecular weight ultrafilter prefiltered weak brine	0.54	56.000		0.9996	-48.827	19.045	0.22	24.4	10.583	0.606	6.4

TABLE 4-4. Continued.

Run	Filter, µm	ΔP, psig	Source	Suspended solids, mg/ℓ	Volume, ℓ	Comments	r^2	Intercept, ℓ	Slope, ℓ/√min	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
26C-5	0.45M	50	5 µm CUNO cartridge prefiltered weak brine	-	0.384	Filter plugged								
29C-1	8.0M	14	5 µm CUNO cartridge prefiltered weak brine	2.28	3.200	Filter plugged								
26C-L	0.45M	50	1 µm CUNO cartridge prefiltered weak brine	0.62	4.800	For nominal 2 ℓ/min (~1 gal/min/ft) flow rate, ΔP across cartridge filter went from 20 psi to 100 psi in 8 hours	0.9993	1.231	0.643	39.062	0.016	9.218	0.008	0.073
27C-L	8.0M	14	1 µm CUNO cartridge prefiltered weak brine	0.14	46.288		0.9999	-24.409	13.864	0.029	4.79	40.821	0.119	4.9
38C	0.45M	50		0.33	3.350	-	0.995	1.605	0.319	197.23	0.002	19.050	0.001	0.016
58C	0.45M	50	Granular media prefiltered weak brine	0.50	2.695	-	0.999	0.298	0.323	192.37	0.003	11.430	0.001	0.015
49C	0.45M	50		0.51	4.200	-	0.998	1.091	0.570	61.77	0.008	11.206	0.004	0.046
			avg	0.45										0.026
29C	8.0M	140		0.29	12.945	-	0.999	2.942	1.800	1.734	0.167	19.707	0.083	1.64
31C	8.0N	16		0.33	12.964	-	0.999	5.270	1.407	3.244	0.102	17.318	0.051	0.89
			avg	0.31										1.27
37C	10N	8		0.007	74.358	-	0.996	-52.735	23.171	0.006	1.170	816.429	0.029	23.7
48C	10N	8		0.001	60.960	-	1.000	42.943	10.066	0.008	1.254	571.500	0.031	17.8
36C	10N	8		0.008	63.600	-	1.000	-30.971	17.288	0.011	0.745	714.375	0.018	13.2
			avg	0.008										18.2

TABLE 4-5. Bayou Choctaw vendor filter effluent injectivity test results.[a,b]

Vendor	Run/filter, µm	ΔP, psi	Source	Filtrate volume, ℓ	Suspended solids, mg/ℓ	r^2	Intercept, ℓ	Slope, ℓ/√min	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
C. E. Natco	M1/0.45	50	Weak brine	12.000	0.23	0.9875	3.053	1.682	7.094	0.032	24.848	0.016	0.398
	29/0.45	50	Weak brine	18.000	0.20	0.9975	-0.251	3.218	1.938	0.103	28.575	0.003	0.073
	34/0.45	50	Weak brine	15.230	0.17	0.9979	-0.529	2.896	2.393	0.071	33.618	0.002	0.059
	39/0.45	50	Weak brine	15.200	0.16	0.9932	-4.897	3.625	1.527	0.105	35.719	0.003	0.093
	51/0.45	50	Weak brine	13.100	0.16	0.9998	-2.782	2.900	2.386	0.067	35.719	0.002	0.059
	42/0.45	50	Weak brine	14.400	0.15	0.9992	2.787	3.154	2.018	0.074	38.100	0.002	0.070
	55/0.45	50	Weak brine	10.440	0.16	0.9914	-0.322	1.981	5.114	0.031	35.719	0.001	0.028
	69/0.45	50	Wesk brine	12.825	0.14	0.9979	0.396	2.275	3.878	0.036	40.821	0.018	0.734
	77/0.45	50	Weak brine	14.000	0.13	0.9879	-2.620	3.038	2.175	0.060	43.962	0.001	0.065
				avg	0.167								0.106
	403/8.0	20	Weak brine	51.000	0.07	0.9989	-3.885	9.947	0.081	0.863	81.643	0.021	1.75
	407/8.0	20	Weak brine	81.900	0.01	1.0000	-36.683	21.650	0.017	0.584	571.5	0.014	8.28
				avg	0.04								5.02
	N3/10	6	Weak brine	104.000	<0.01	0.9970	-80.852	33.772	0.0021	4.736	571.5	0.118	67.2
	N5/10	10	Weak brine	49.477	<0.01	0.9995	-41.415	16.563	0.0146	0.683	571.5	0.017	9.7
				avg	<0.01								38.5

[a] r^2 indicates fit of the linear regression to membrane filtration data. A perfect fit is $r^2 = 1.0$.

[b] $T_{1/2} = F \times G_{1/2}$; $T_{1/2}$ is based on a brine viscosity of 2.4 cp corresponding to an injection temperature of 50 C. At 100 F, $T_{1/2}$ is ~50% lower.

TABLE 4-5. Continued.

Vendor	Run/filter, µm	ΔP, psi	Source	Filtrate volume, ℓ	Suspended solids, mg/ℓ	r^2	Intercept, ℓ	Slope, $\ell/\sqrt{min}$	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
Baker	27/0.45	50	Weak brine	8.820	0.17	0.9914	3.9950	0.874	26.274	0.0065	33.62	0.0032	0.108
	32/0.45	50	Weak brine	6.200	0.25	0.9982	2.973	0.711	39.702	0.0063	22.86	0.003	0.072
	71/0.45	50	Weak brine	5.284	0.14	0.9999	1.103	0.928	23.305	0.006	40.82	0.003	0.122
	37/0.45	50	Weak brine	9.400	0.18	0.9998	-0.813	2.272	3.888	0.046	31.75	.001	0.037
	44/0.45	50	Weak brine	10.225	0.16	0.9994	1.981	1.437	9.719	0.017	35.72	0.0082	0.293
	53/0.45	50	Weak brine	6.700	0.15	0.8744	0.382	1.529	8.585	0.018	38.10	0.0087	0.331
	58/0.45	50	Weak brine	6.350	0.17	0.9830	1.602	0.878	26.035	0.0065	33.62	0.0032	0.109
	67/0.45	50	Weak brine	7.975	0.16	0.9818	2.669	0.958	21.868	0.0073	35.72	0.0036	0.130
				avg	0.17								0.150
	404/8	20	Weak brine	43.880	0.17	0.9926	-6.793	9.155	0.096	1.775	33.618	0.0441	1.48
	408/8	20	Weak brine	73.000	0.03	0.9921	-5.242	14.295	0.039	0.764	190.500	0.0190	3.61
				avg	0.10								2.55
	BD-10/10	6	Weak brine	112.000	0.02	0.9999	-70.654	33.196	0.0022	9.151	285.750	0.2272	64.9
	4/10	10	Weak brine	67.859	<0.01	0.994	-56.544	22.653	0.0078	1.278	571.500	0.017	18.1
												avg	41.5
L'Eau Claire	79/0.45	50	Weak brine	1.950	0.17	0.9843	0.732	0.455	96.945	0.0018	33.618	0.0009	0.029
	81/0.45	50	Weak brine	1.940	0.22	0.9965	0.708	0.440	103.667	0.0021	25.997	0.0011	0.027
	105/0.45	50	Weak brine	2.600	0.16	0.9762	0.711	0.598	56.124	0.0029	35.719	0.0014	0.051
				avg	0.18								0.036
	8A/10	10	Weak brine	44.000	<0.01	0.9979	-31.183	13.726	0.0213	0.469	571.500	0.0117	6.66
	8/10.0	10	Weak brine	143	<0.01	0.9975	-105.384	45.392	0.009	2.567	571.500	0.0637	36.42
	N6/10.0	10	Weak brine	34.019	<0.01	0.9967	21.318	2.330	1.4788	0.0068	571.500	0.0034	1.92
				avg	<0.01								15.00
	N1/0.45	50	Lake water	12.300	0.18	0.9929	5.982	1.161	28.030	0.0064	31.750	0.0032	0.102
	N10/10	6	Lake water	163.860	0.01	0.9995	-103.298	049.298	0.0019	5.360	571.500	0.133	76.05

TABLE 4-6. Summary of Bryan Mound injectivity test results.[a,b]

Run	Filter	Date	Source	Filtrate volume, ℓ/psi	Suspended solids, mg/ℓ	r^2	Intercept, ℓ	Slope, $\ell/\sqrt{min}$	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
1BM	0.4	2/23/79	Recirculated raw pond brine	9.35/50	2.78	0.9998	-0.748	1.8364	5.95	0.467	2.06	0.0116	0.024
2BM	0.4	2/24/79	Raw pond brine	7.16/50	3.17	0.9999	0.198	1.2669	12.50	0.254	1.80	0.126	0.23
7BM	0.4	2/26/79	Raw pond brine	6.23/50	6.33	0.9999	-1.422	1.4110	10.08	0.628	0.90	0.0156	0.014
11BM	0.4	2/27/79	Raw pond brine	5.96/50	5.54	0.9957	-0.296	1.110	16.26	0.341	1.03	0.085	0.009
17BM	0.4	2/28/79	Raw pond brine	7.31/50	-	-	-	-	-	-	-	-	-
				avg	4.46								0.069
3BM	10.0	2/23/79	Recirculated raw pond brine	9.36/6	0.214	0.0090	6.455	0.5281	8.64	0.0248	26.71	0.0123	0.33
4BM	10.0	2/24/79	Raw pond brine	7.00/6	0.443	-	-	-	-	-	-	-	-
5BM	10.0	2/26/79	Raw pond brine	3.75/6	0.293								
6BM	10.0	2/27/79	Raw pond brine	3.01	1.03				Filters Plugged				
8BM	10.0	2/28/79	Raw pond brine	2.35/6	1.11								
				avg	0.618								
9BM	0.4	2/27/79	Injection Pad 3	5.488/50		0.9999	-0.763	1.1406	12.41				
14BM	0.4	2/28/79	Injection Pad 3	2.250/50	6.75	0.9869	-0.138	0.4296	108.75	0.0621	0.85	0.0015	0.0013
				avg	6.75								

[a] r^2 indicates fit of best line through the linear portion of a membrane filtration curve. A perfect fit is $r^2 = 1$.

[b] $T_{1/2} = F \times G_{1/2}$; $T_{1/2}$ is based on a brine viscosity of 2.4 cp corresponding to an injection temperature of 50 C. At 100 F, $T_{1/2}$ is ~50% lower.

TABLE 4-6. Continued.

Run	Filter	Date	Source	Filtrate volume, ℓ/psi	Suspended solids, mg/ℓ	r^2	Intercept, ℓ	Slope, ℓ/$\sqrt{min}$	W/K_c, ppm/md	K_c, md	F	$G_{1/2}$, yr	$T_{1/2}$, yr
10BM	10.0	2/27/79	Injection Pad 3	4.100/6	0.24								
12BM	10.0	2/28/79	Injection Pad 3	5.030/6	0.159	0.9983	4.191	0.1532	102.62	0.0015	35.94	0.0010	0.0008
				avg	0.092								
13BM	0.4	2/26/79	Ultrafilter	23.484/50	0.042	0.9988	8.035	2.8455	2.48	0.0169	136.07	0.0084	1.15
15BM	0.4	2/27/79	Ultrafilter	23.932/50	0.013	0.9885	10.424	2.4364	3.38	0.0038	439.62	0.0019	0.84
				avg	0.028								
16BM	10.0	2/26/79	Ultrafilter	68.129/6	0.006	0.994	-56.3385	22.6712	0.0047	1.28	952.50	0.0318	30.28
18BM	10.0	2/27/79	Ultrafilter	67.363/6	0.004	0.9993	-47.9477	20.9953	0.0055	0.732	1428.75	0.0182	25.97
				avg	0.005								28.13
20BM	0.4	2/28/79	Granular-media	2.500/50	0.360	0.9996	0.9475	0.2832	250.2	0.0014	15.88	0.0007	0.0114
21BM	0.4	2/28/79	Granular-media	4.785/50	0.251	0.9989	2.4828	0.4216	112.9	0.0022	22.77	0.0011	0.025
				avg	0.036								0.018
22BM	10.0	2/27/79	Granular-media	121.556/6	0.0016	0.9996	-102.284	28.8687	0.0029	0.554	3571.88	0.0138	49.1
23BM	10.0	2/28/79	Granular-media	125.041/6	<0.001	0.9997	-104.057	29.5530	0.0028	0.363	5715.00	0.0090	51.5
24BM	10.0	2/28/79	Granular-media	67.174/6	<0.001	0.9994	-51.122	21.5424	0.0052	0.193	5715.00	0.0048	27.3
				avg	<0.0012								42.6
25BM	0.4	2/27/79	Injection Pad 3	6.147/50	0.456	-0.9999	-0.9128	1.2886	12.09	0.038	12.53	0.0009	0.0117
26BM	10.0	2/27/79	Injection Pad 3	120.281/6	<0.001	0.9998	-105.845	29.9464	0.0027	0.372	5715.00	0.0092	52.8

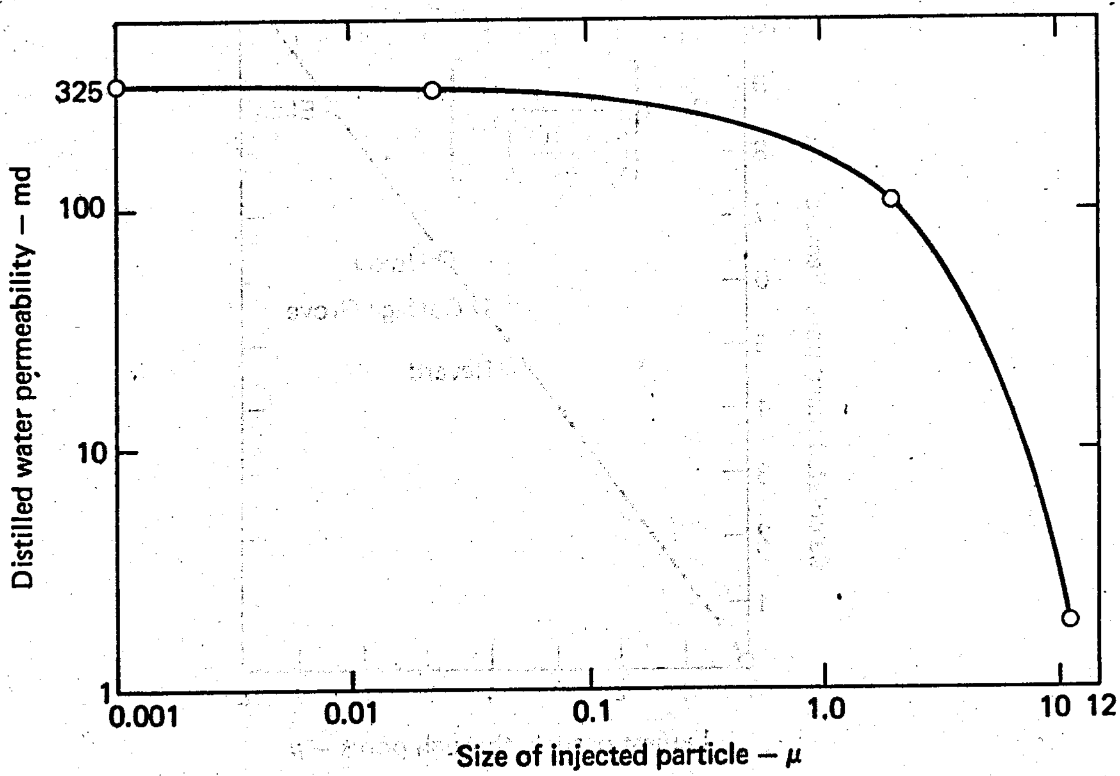


FIG. 4-1. Effect of particle injection on the permeability of selected sandstone cores (from Ref. 23).

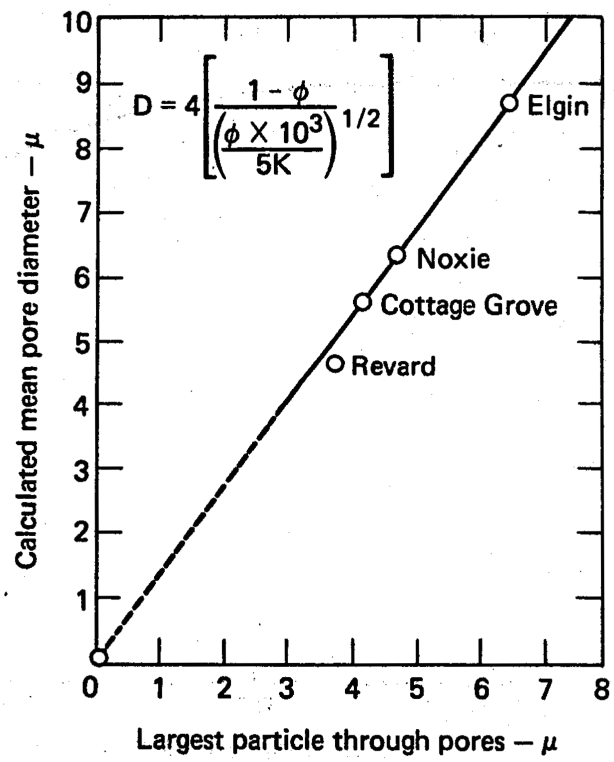


FIG. 4-2. Relationship of calculated pore diameter to the largest particle passed through selected core samples (from Ref. 23).

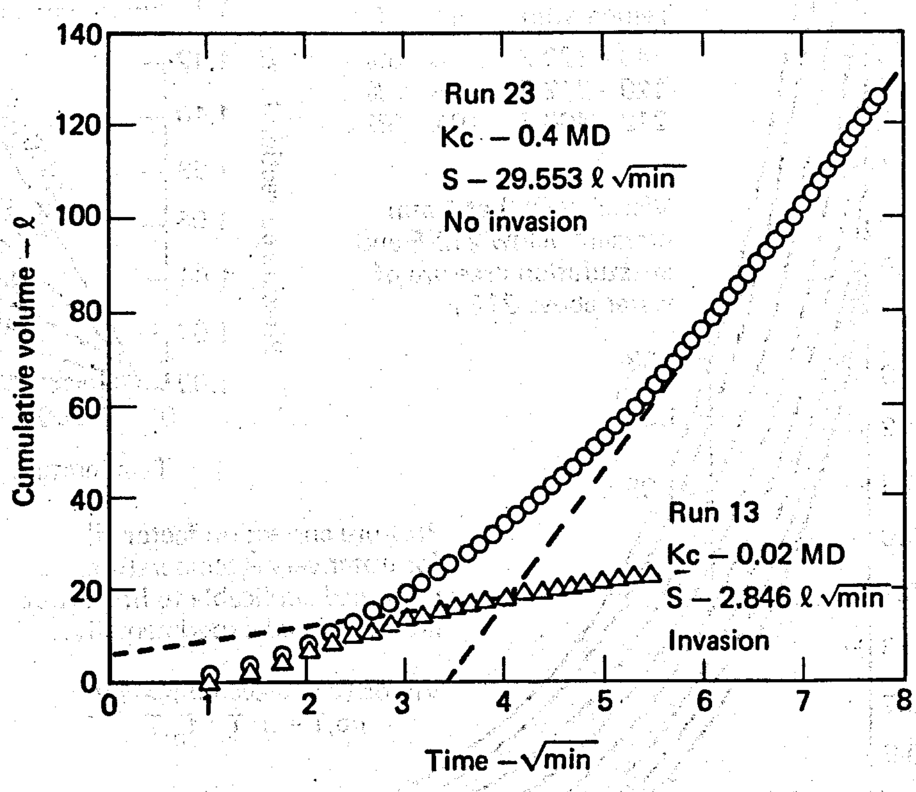


FIG. 4-3. Example of Barkman and Davidson (1972) type filtration curve (from Bryan Mound SPR site).

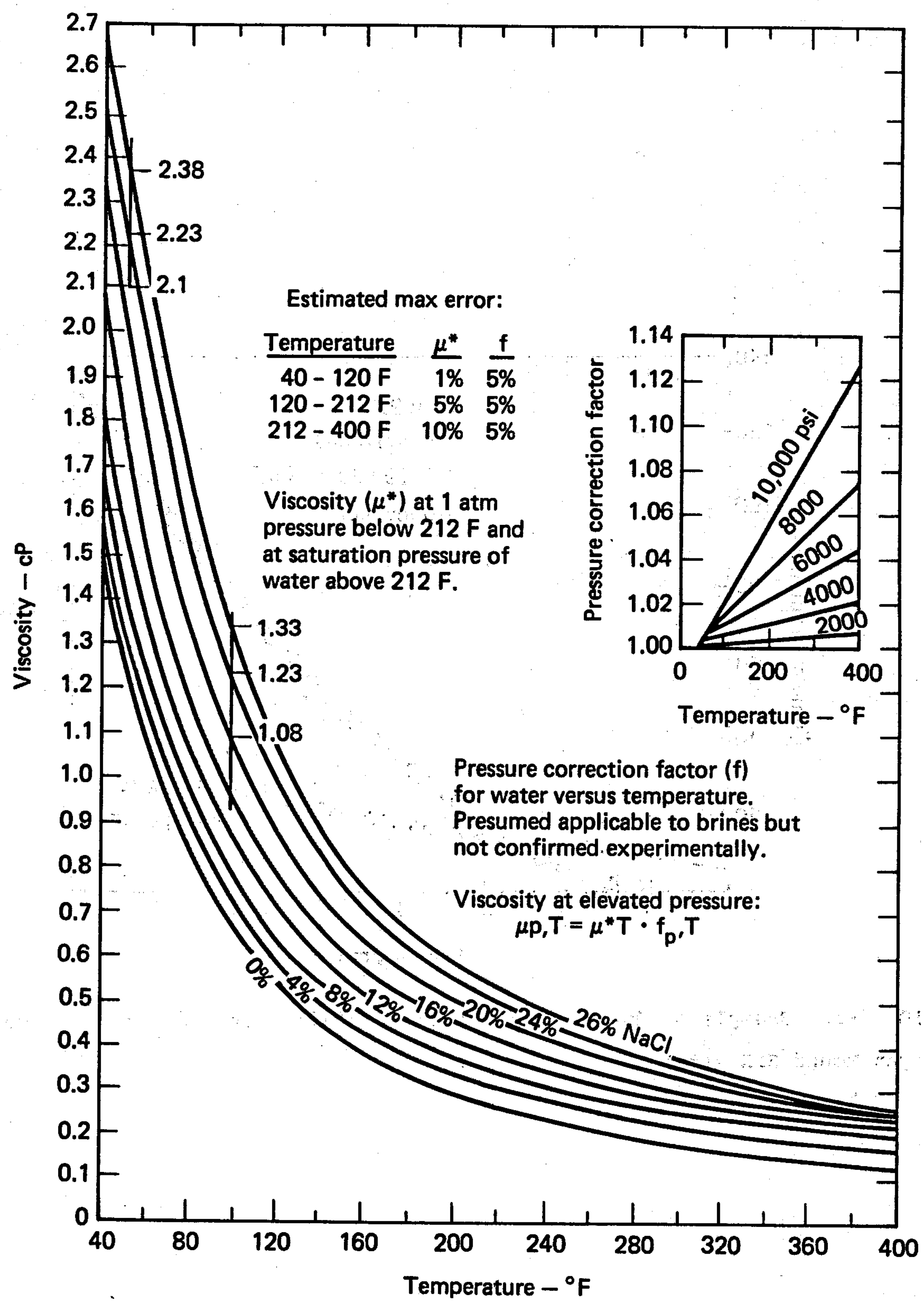


FIG. 4-4. Water viscosities for various salinities and temperatures (from Ref. 18).

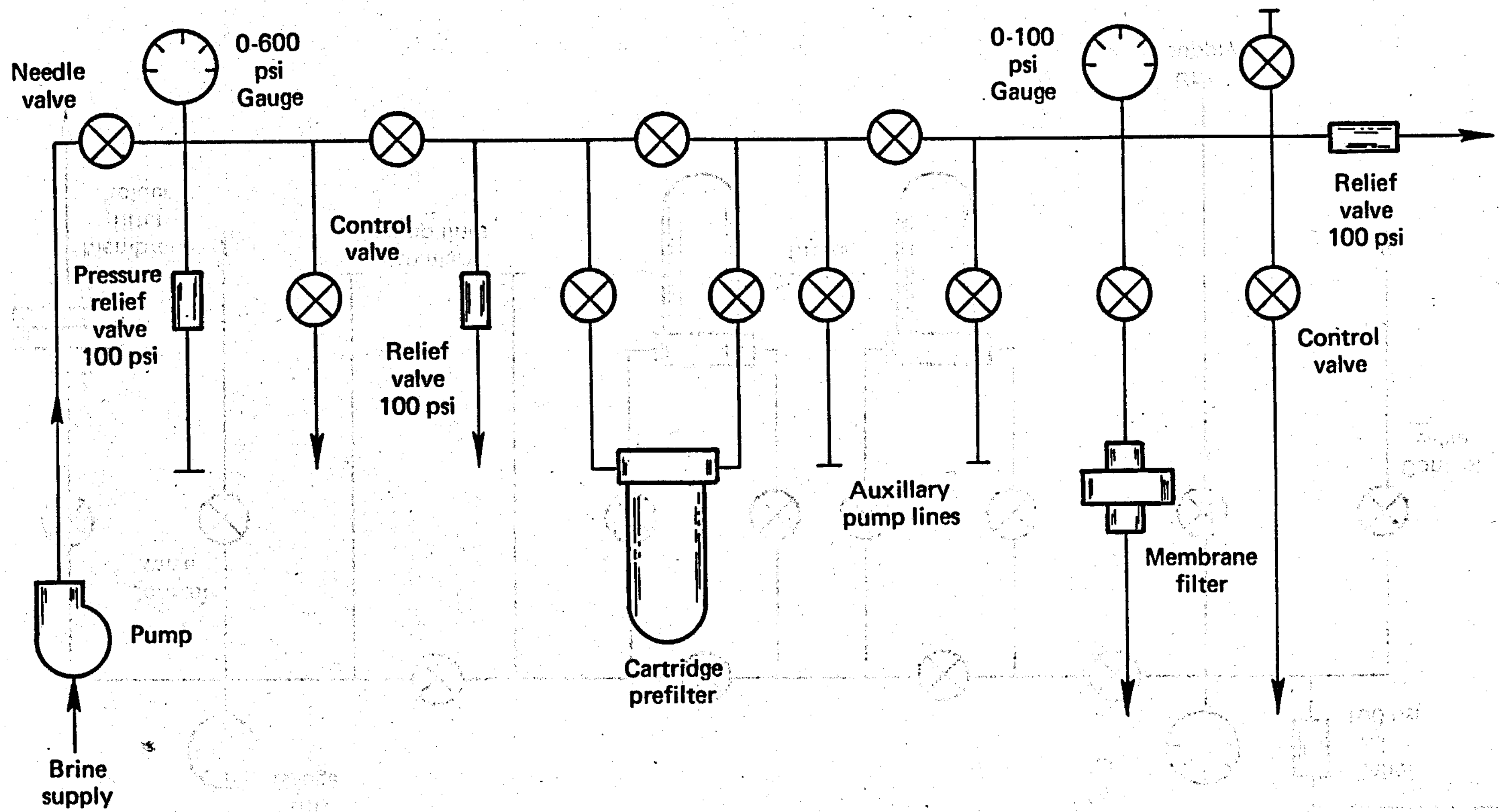


FIG. 4-5. Injectivity test apparatus for the membrane filtration system used in the LLL experimental trailer.

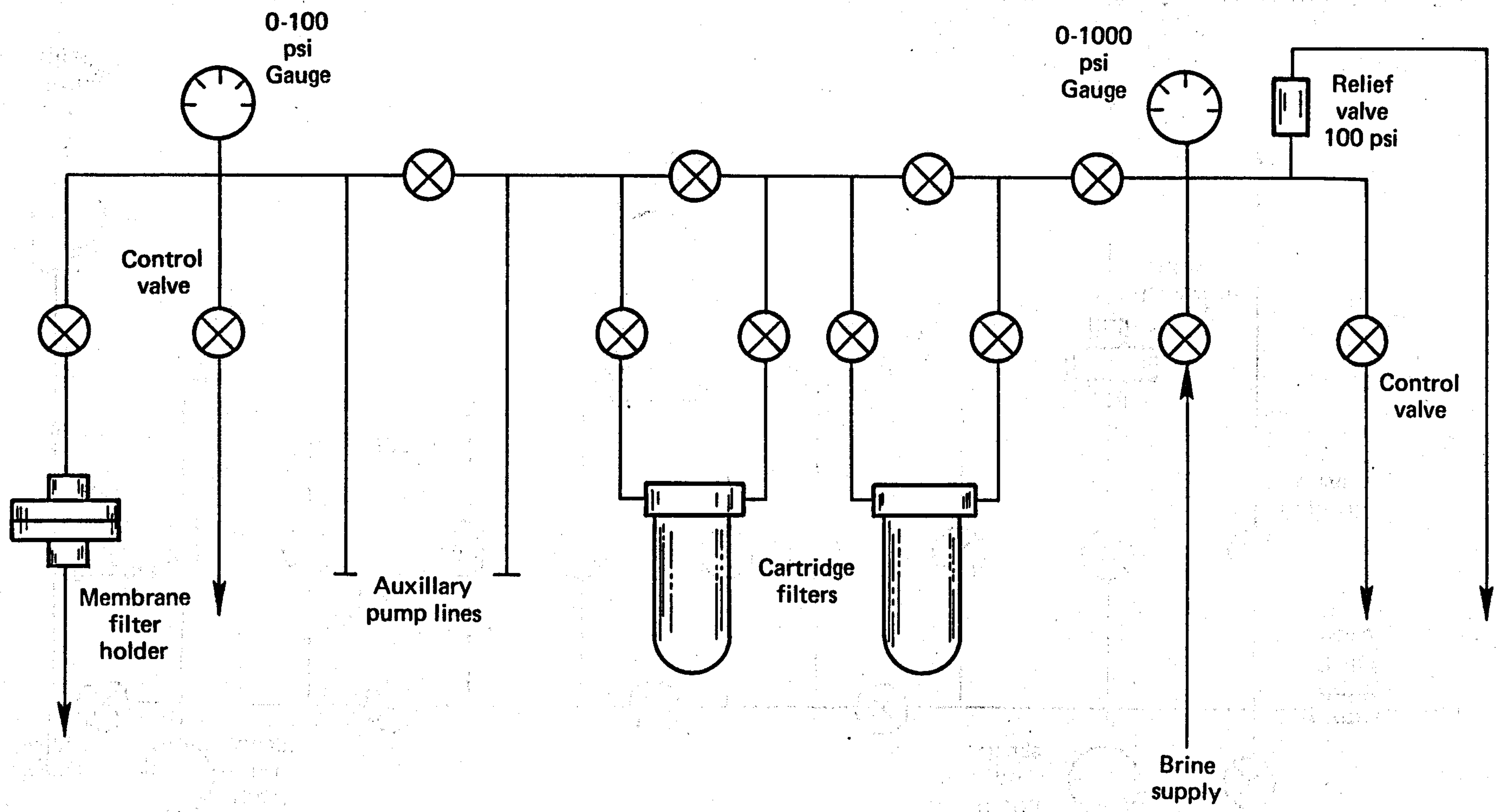


FIG. 4-6. Injectivity test apparatus for the membrane filtration system used in the LLL step van.

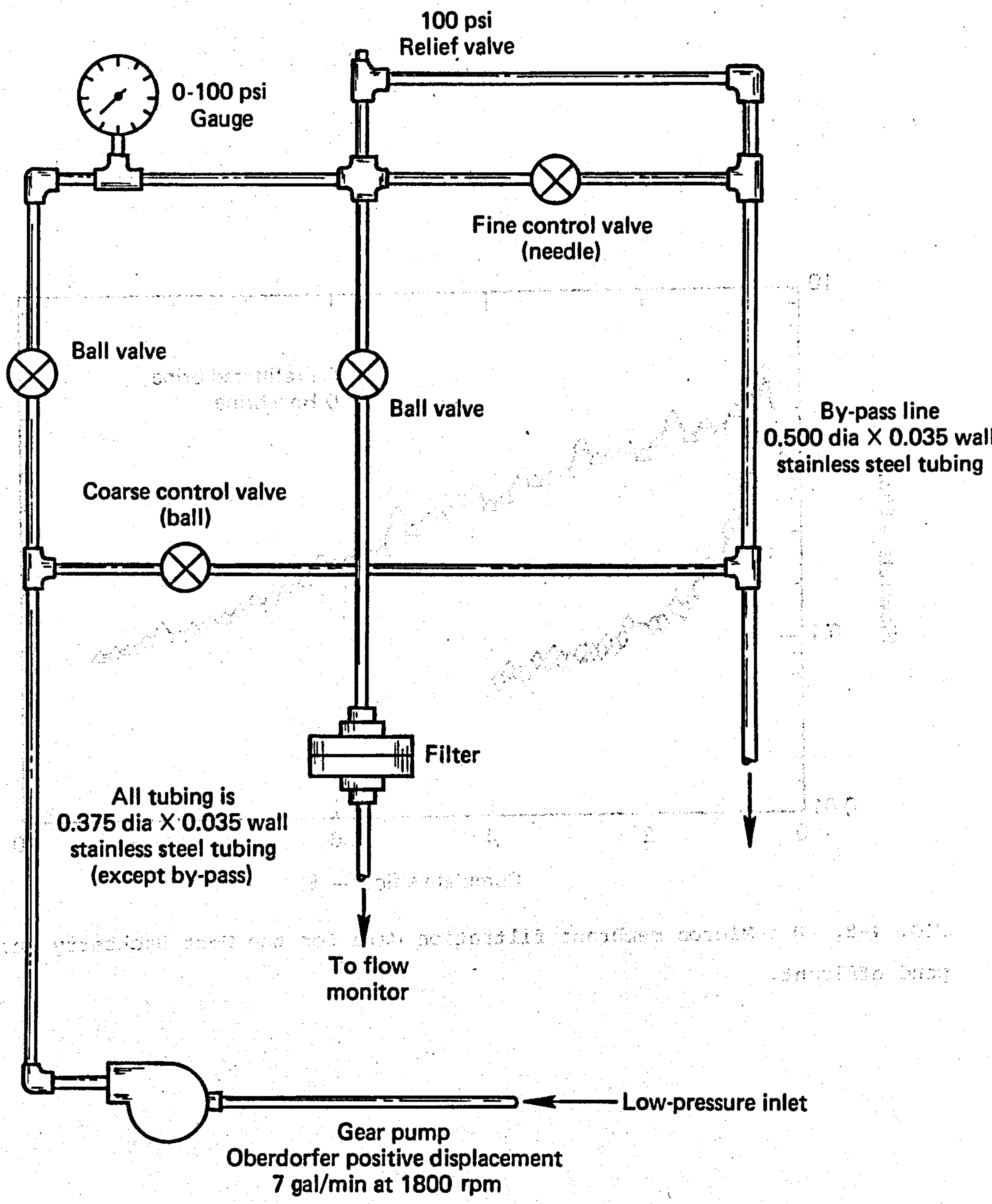


FIG. 4-7. Filter vendor effluent injectivity test apparatus.

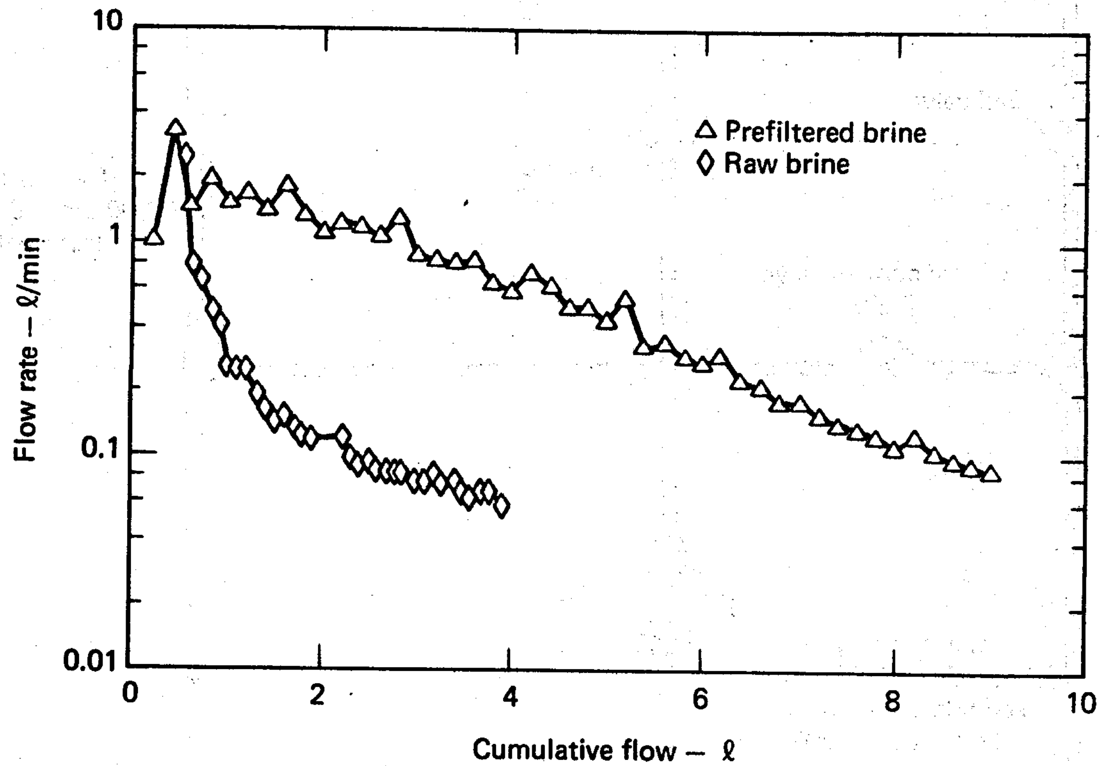


FIG. 4-8. 0.4-Micron membrane filtration data for the West Hackberry surge pond effluent.

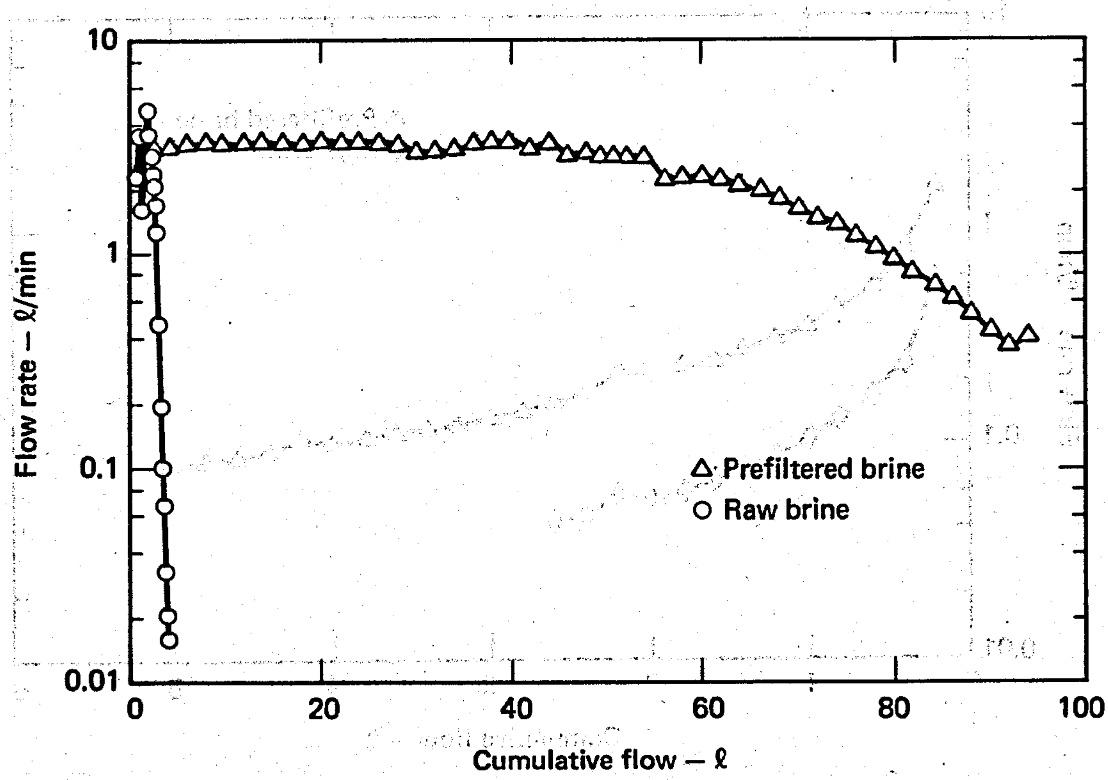


FIG. 4-9. 10-Micron membrane filtration data for the West Hackberry surge pond effluent.

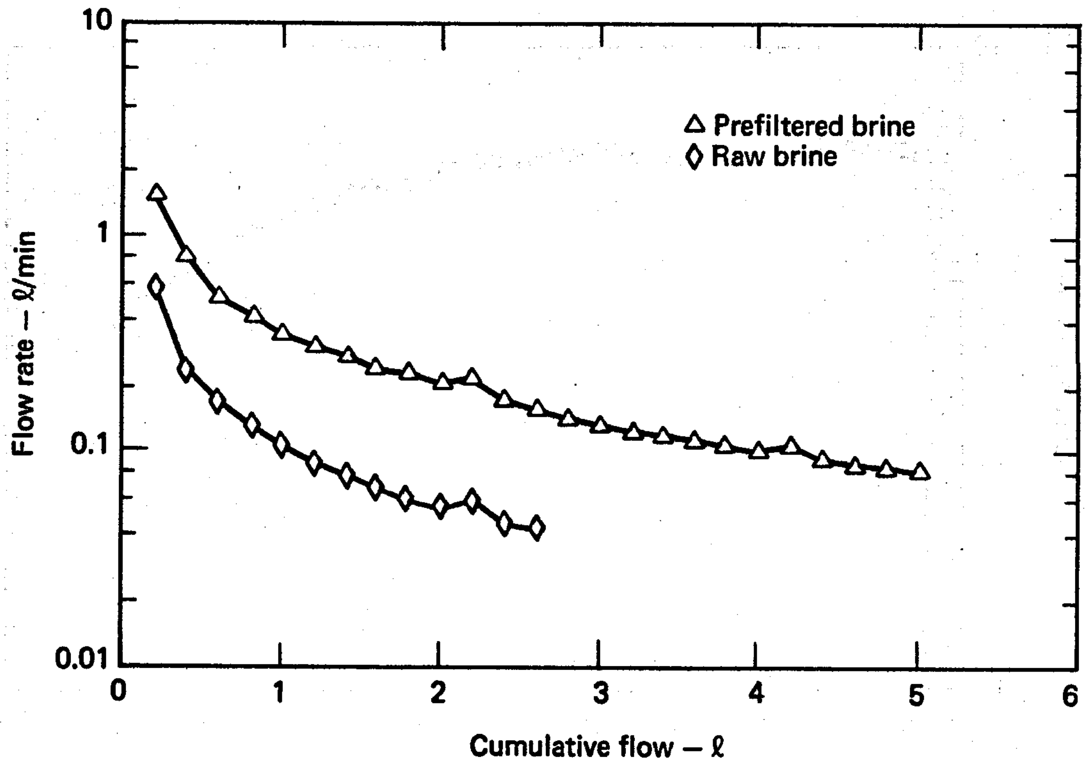


FIG. 4-10. 0.4-Micron membrane filtration data for the West Hackberry injection pad.

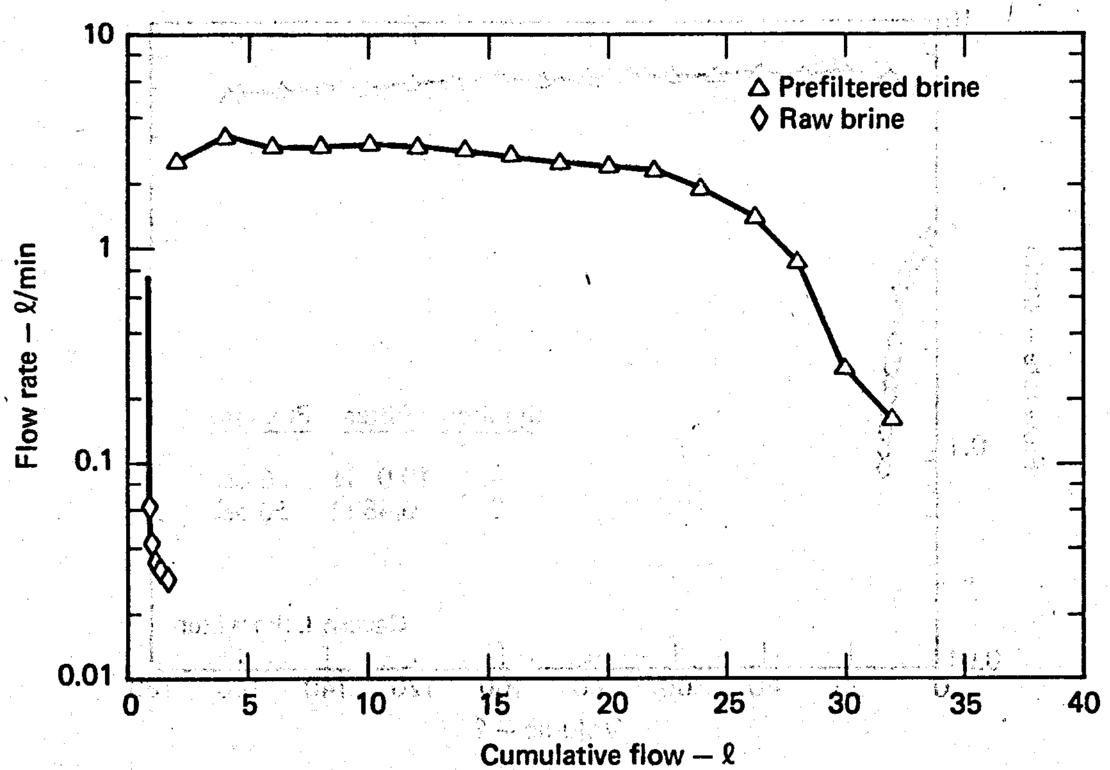


FIG. 4-11. 10-Micron membrane filtration data for the West Hackberry injection pad.

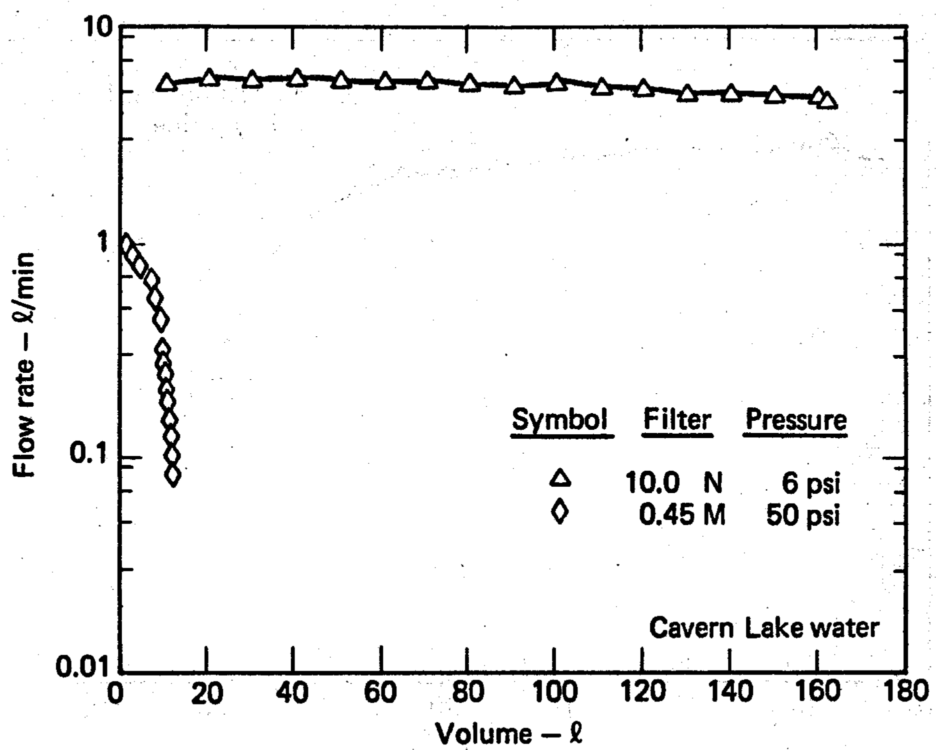


FIG. 4-12. Injectability test data for the L'Eau Claire upflow filter effluent at the Bayou Choctaw SPR site.

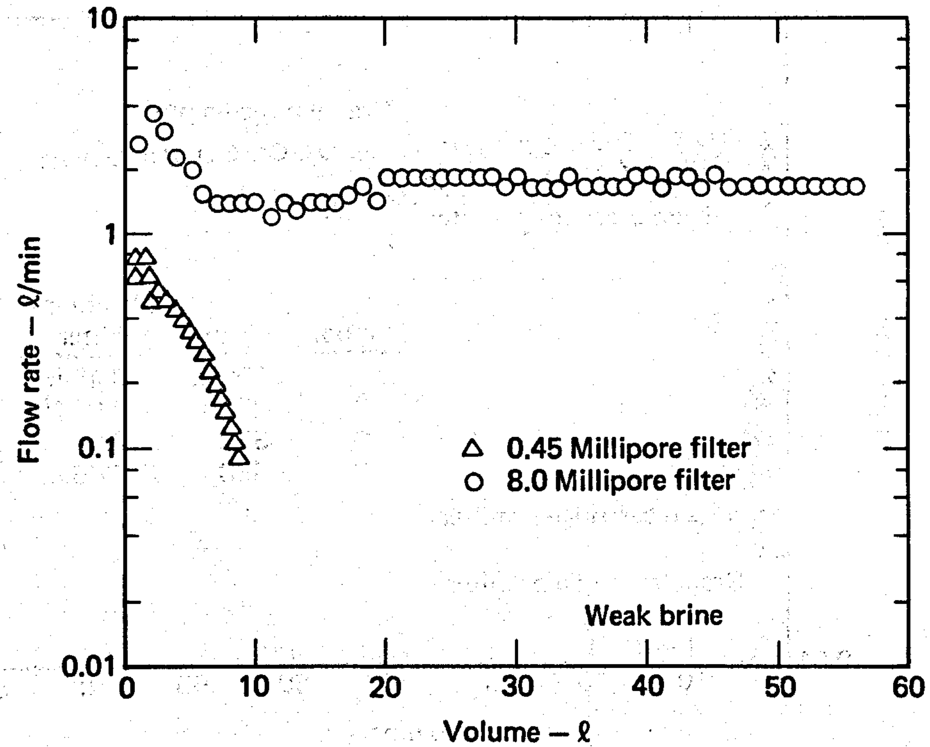


FIG. 4-13. Injectability test data for the 50K ultrafilter effluent at the Bayou Choctaw SPR site.

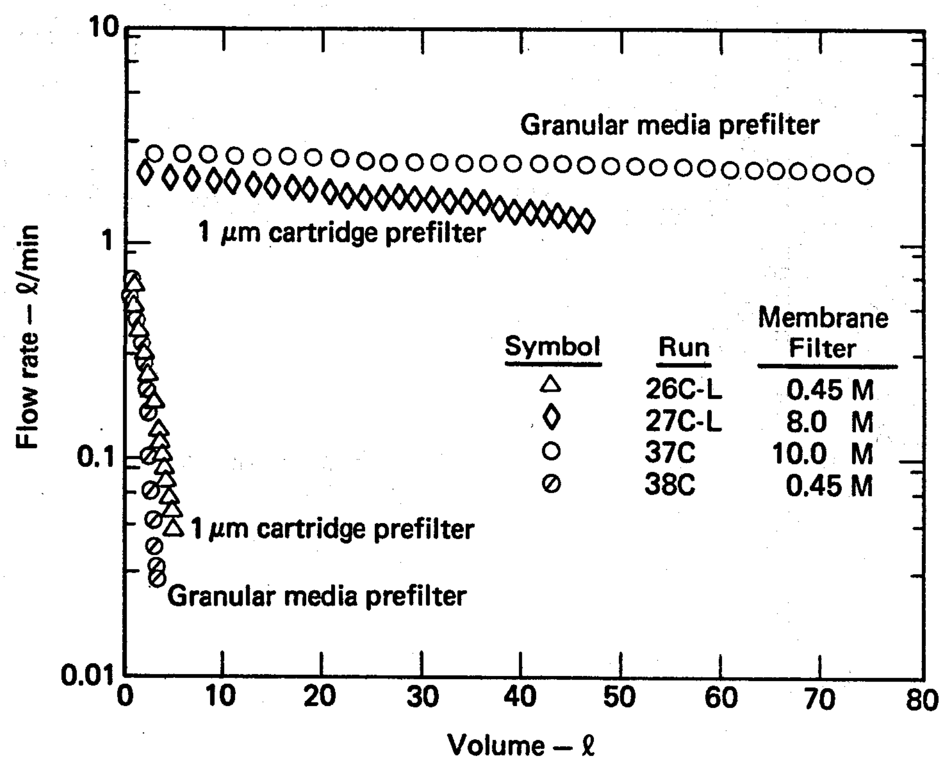


FIG. 4-14. Injectability test data for the prefiltered weak brine at the Bayou Choctaw SPR site.

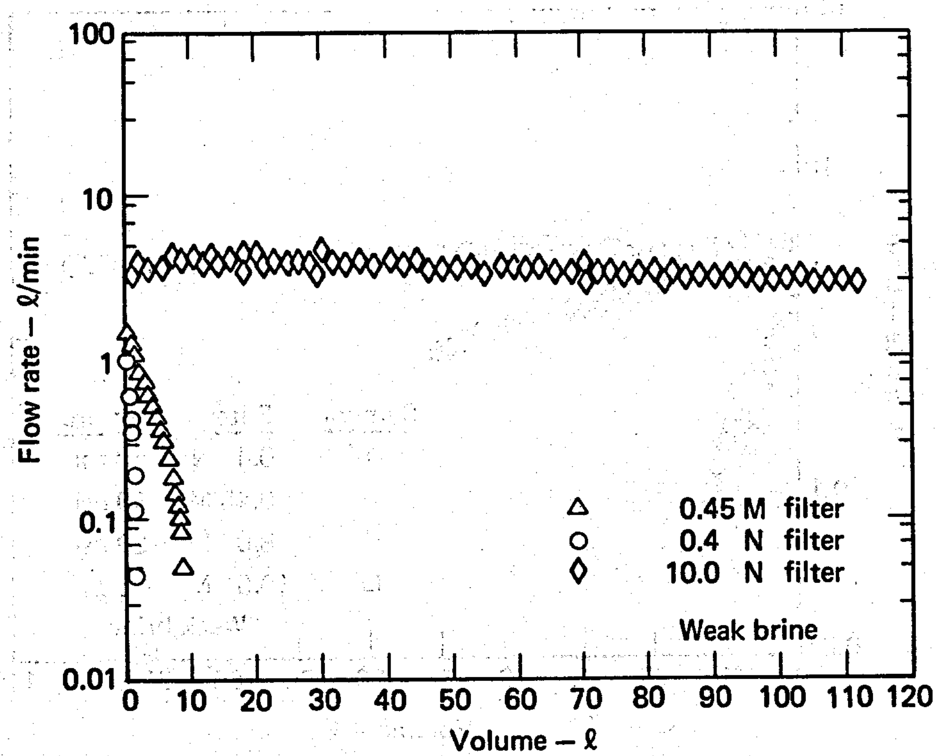


FIG. 4-15. Injectability test data (January 29, 1979) for the Baker downflow filter effluent at the Bayou Choctaw SPR site.

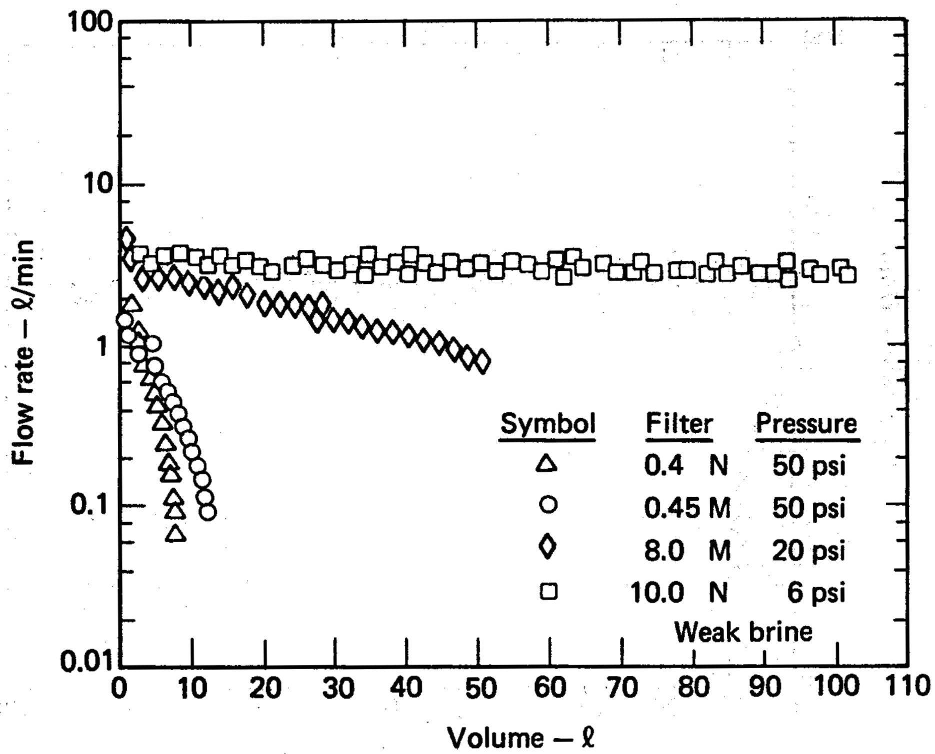


FIG. 4-16. Injectability test data (January 29, 1979) for the C. E. Natco upflow-downflow filter at the Bayou Choctaw SPR site.

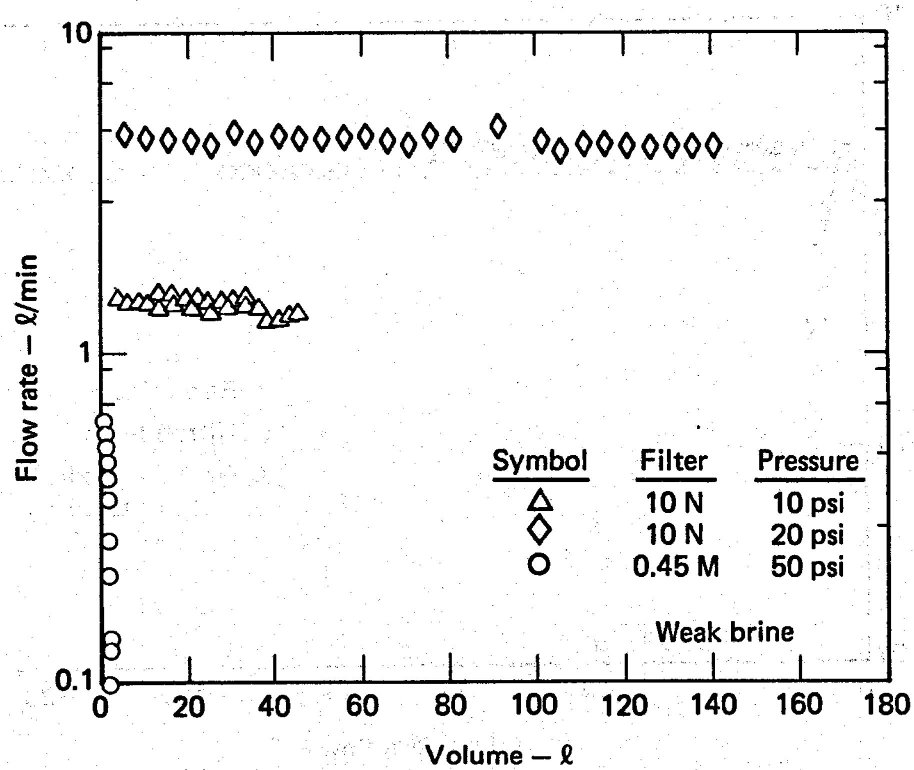


FIG. 4-17. Injectability test data for the L'Eau Claire upflow filter effluent at the Bayou Choctaw SPR site.

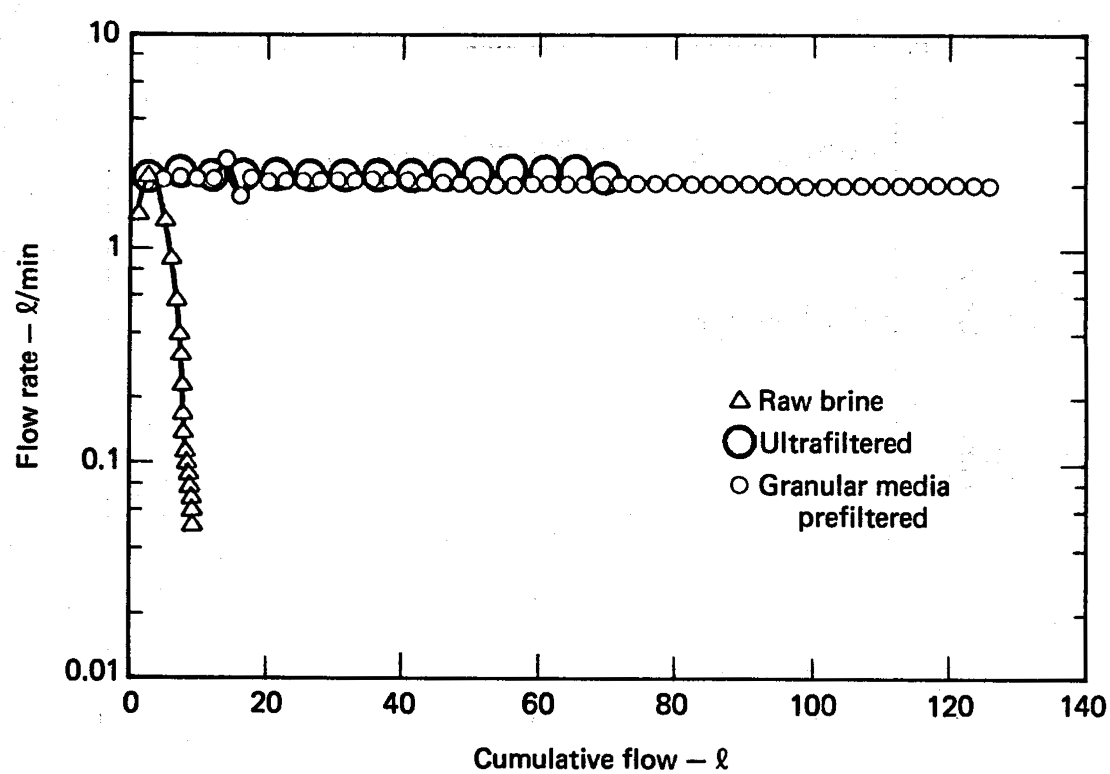


FIG. 4-18. 10-Micron membrane filtration test data for surge pond effluent at the Bryan Mound SPR site.

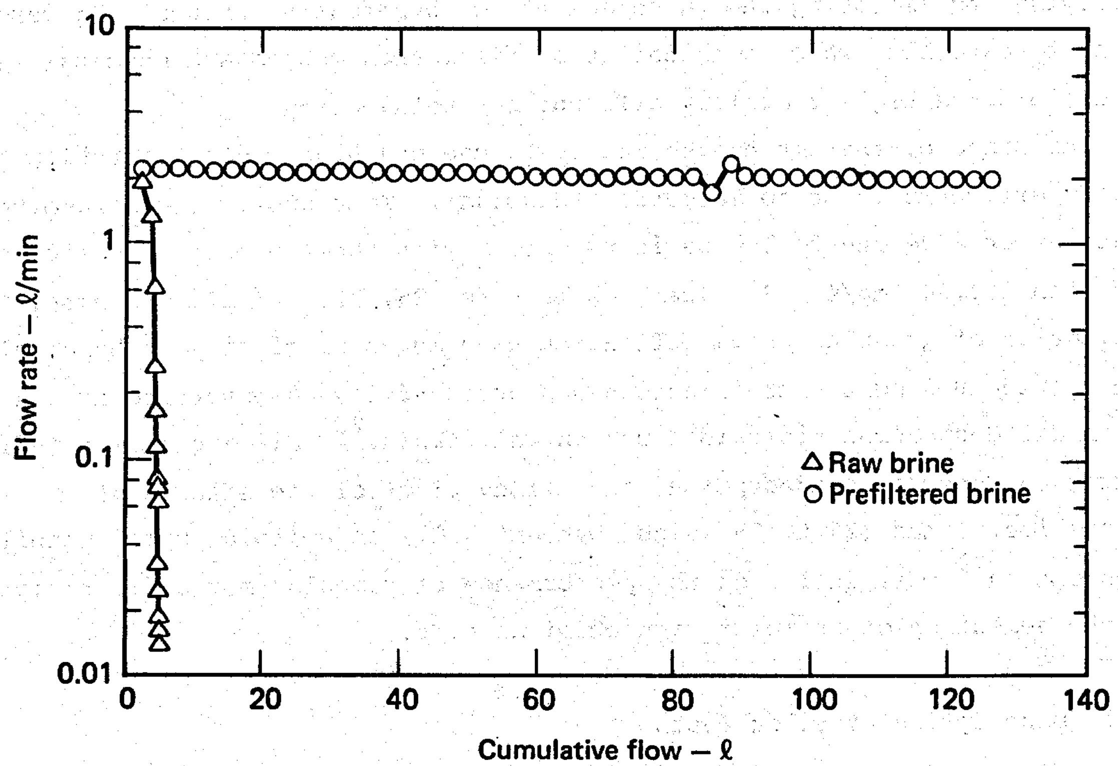


FIG. 4-19. 10-Micron membrane filtration test data for injection pad effluent at the Bryan Mound SPR site.

CHAPTER 5

BRINE CLARIFICATION

E. Raber, R. E. Thompson,* R. Quong, L. B. Owen,
W. H. Stringfellow,* and A. Robinson*

5.1 GRANULAR MEDIA FILTRATION SYSTEMS

Various filtration methods were evaluated as a possible means of clarifying and improving the injectability of hypersaline brines. It was our intent to establish which combination of filtration method and chemical feed would yield the highest quality effluent for reinjection.

The state-of-the-art convention is to use granular-media filtration to clarify effluents prior to subsurface disposal. Most applications involve treatment of moderate to low salinity waters with total dissolved solids of less than 100,000 mg/ℓ. See examples in Refs. 25, 26, and 27. However, application of granular media filtration as a means of clarifying hypersaline brines (>200,000 mg/ℓ) for injection was successfully demonstrated at the Salton Sea Geothermal Field in southern California.[28] Since granular-media filtration depends on adsorption, the strong electrolytic effects of hypersaline brines (26 to 28 weight percent NaCl) on colloid charge stability, and sorption[29] will influence the performance of granular-media filtration and the selection of prefiltration chemical aids.

5.1.1 Description of Pilot Tests

5.1.1.1 Test Procedure. The test procedure at each of the three sites was divided into three parts:

1. Pilot tests of direct filtration without chemical coagulants were performed with downflow granular media (combinations of sand, coal, and/or garnet) filters, ultrafilters, and cartridge filters;

---

* National Technical Services, Corvallis, Oregon

2. Inorganic salts and polymers were evaluated as coagulants/flocculants by a combination of jar testing and bench-scale filtration to identify the chemicals that significantly improve granular-media filtration; and
3. The performance characteristics of downflow granular media filters were evaluated with brines that were pretreated with chemicals that were found in jar tests to be effective in coagulating particulates contained in these hypersaline brines.

Follow-up laboratory studies were also completed to evaluate the possible effects of residual chemical additives on brine injectability. Based on the results from these field and laboratory studies, specific recommendations were made for brine processing requirements at the SPR sites (Chapter 1).

5.1.1.2 Filter Constructions. Six combinations of filter media were evaluated at the three sites. The construction of these pilot filters is given in Table 5-1. Listed media sizes were determined by standard sieve analyses. A constant feed rate of 8 $gal/min/ft^2$ was usually maintained for all granular-media filter runs, and filters were restored to normal conditions by backwashing at a rate of 16 $g/min/ft^2$ for 5 to 8 minutes. Figure 5-1 is a schematic diagram of our subpilot (4-inch-diameter) filters. Many full-scale granular-media filtration plants have been successfully designed utilizing test data from similar subpilot filters.[30-33] In addition to the granular-media filters, we also evaluated hollow fiber ultrafilters (Fig. 5-2) and disposable cartridge filters (Fig. 5-3) for use at SPR sites.

5.1.1.3 Salt Precipitation. Precipitation of NaCl from surge pond effluent complicated evaluation of brine filtration systems at Bayou Choctaw and Bryan Mound. At these sites, Cavern Lake water and Brazos River water, respectively, were used to dilute cavern brines prior to injection to prevent salt precipitation (Chapter 4). Preliminary tests at Bayou Choctaw established that turbid dilution water can be clarified by either granular media filtration or chemical flocculation and settling. We also established that a mixture consisting of 90 percent raw brine and 10 percent raw dilution water could be adequately conditioned by granular-media filters directly without the need for pretreatment of the dilution water. Based on these results and the fact that raw brine must be filtered in either case, we concluded that the combined filtration is probably more cost-effective.

However, at some sites, it may be desirable to pretreat dilution water with coagulants to enhance removal of the bulk of particulates by settling prior to mixing and filtering. For instance, Cavern Lake (Bayou Choctaw) is a deep (80 feet) surface depression caused by the collapse of a salt dome cavern. This water could be chemically treated (if environmental standards can be satisfied) and coagulated particles would then settle to the bottom. Removal of sludge would be much less frequent than it would be if dilution water were treated in the surge pond.

The most effective coagulants for use at Bayou Choctaw and Bryan Mound are listed in Table 5-2.

5.1.1.4 Effluent Quality and Particle-Size Distribution. Particle count data, absolute suspended solids concentration, turbidity, and injectability test results provided the necessary information on effluent quality for assessing filter performance. A Prototron particle counter, Model ILI 1000, with a particle profile attachment, both made by Spectrex Corporation, was used to count particles over a range of 1 to 25 μm in raw and processed fluids. The particle counter is based on detection of scattered light from suspended particulates, which intercept a scanning laser light source. The instrument is internally set to scan 10 mℓ of sample over a prescribed time interval. The particle profile attachment allows the option of a longer count time interval by either extending the count time or by selecting a large fixed number of total counts. In addition, the pulses, proportional to the size of the particles, are sorted by amplitude and stored in 15 channels available for recall. Effluent quality measurements are discussed in this section and in Chapter 4.

5.1.2 Evaluation of Pilot Tests without Chemical Pretreatment

In evaluating filter performance, flow rate and head loss (ΔP) are considered in addition to effluent quality. Due to various degrees of contamination from oil, minor differences in brine chemistry, and variable brine dilutions, each site must be considered separately. No one filtration scheme is suitable for all three sites. The results from each site will be discussed separately.

Filter tests at several flow rates were also performed to assess the impact on effluent quality of changes in the flow rate to sludge contact time within the filter media. Figure 5-4 illustrates that increased flow rate does not in itself improve the effluent quality. However, effluent quality is improved by a steady buildup of solids within the filter media.

Ultrafiltration produced acceptable quality brine effluent without chemical pretreatment, and quality was not significantly degraded by changing brine conditions or contamination.

Disposable cartridge filters are effective, but they plug too rapidly. Frequent renewal would not be practical for treatment of large quantities of brine.

Granular-media direct filtration tests of strong brines sometimes produced an acceptable quality effluent without the use of coagulants. This suggests that the high concentration of ions in the solution has sufficiently altered both the thickness and charge characteristics of the double layer around the particle surface. This reduces the zeta potential, allowing some coagulation without chemical additives.[29] However, changing brine conditions would severely tax the performance of all granular-media filters operating without chemical feeds. Therefore, further evaluations were done with chemical pretreatments and are discussed in Section 5.3.

5.1.3 Evaluation of Granular Media Filtration with Chemical Pretreatment

5.1.3.1 Jar Tests of Coagulants and Flocculants. Bench-scale experiments were run on cationic, anionic, and nonionic polymers as well as on inorganic salts at various concentrations. These experiments included tests on stagnant recirculated brine, strong diluted brines (5 to 10 percent) and leach brines. The results are listed in Table 5-3.

In addition, tests were conducted on lake and river waters to determine if chemical clarification and subsequent gravity settling prior to strong brine dilution and filtration would be useful. As indicated by the data in Table 5-2, clarification of lake and river waters can be effectively accomplished with chemical treatment.

A jar testing apparatus was used for these experiments. Samples were mixed at ambient temperature for 2 minutes at a constant speed of 100 rpm and then at 20 rpm for 10 minutes. This procedure permitted particle destabilization and flocculation. Turbidity measurements (Hach Model 2100A) were made on the supernatant, which was prefiltered by gravity through Whatman #2 paper. This technique has been shown to produce effluent quality similar to that produced by the mixed media filters.[32]

Jar tests showed initially that alum (or alum + nonionic polymers) or other moderately charged high-molecular-weight anionic polymers were the most effective with regard to treatment of hypersaline ponded brines. The highly charged anionic polymers often caused dispersion of suspended particulates and cationic polymers were not found to be very effective. In addition, long-chained nonionic polymers sometimes coagulated particulates in strong brines, supporting the theory that a high degree of particle coagulation already exists and further filter enhancement can be provided by a bridging agent.

5.1.3.2 Granular Media Pilot Tests. Granular media filtration is an effective means for hypersaline (leach/strong) brine clarification with the correct chemical pretreatment. Field tests show that triple media (coal-sand-garnet construction C in Table 5-1) is the most effective. This media construction, with the use of proper chemical treatments, was as effective as ultrafiltration although more sensitive to changing brine conditions.

Jar tests and filtration through Whatman #2 filter paper provide data on the optimum chemical dosages for coagulation. However, these procedures must be followed by tests on different granular media filters to assess pressure loss versus time, effluent quality, and length of filter cycle with respect to media design.[35] In the pilot filter tests, these prescreened chemicals were injected into the influent stream. While jar testing had indicated that several chemicals would coagulate particulates, only alum or the high-molecular-weight anionic polymers produced acceptable quality effluents when actually applied to granular media filters.

It can also be concluded that a prescribed chemical pretreatment could be made ineffective under changing brine conditions. Preliminary evidence suggests dilution of brines affects polymer coagulation performance, but further studies are needed. At the West Hackberry and Bryan Mound sites, coagulation tendencies of anionic and nonionic polymers were inhibited by oil contamination. Since oil analyses were infrequent, the cause-and-effect relationship was not uniquely established. However, at both sites when brine became oil contaminated, inorganic salts were the only effective filtration additives. These inorganic salts were not as effective at Bayou Choctaw where oil contamination was not a problem. It was the only site where polymers alone were effective.

Inorganic salts can be used in conjunction with long-chained nonionic polymers to increase floc shear strength to reduce filter penetration.

5.1.4 Problems Associated with Chemical Pretreatment

5.1.4.1 Postprecipitation Potential. Incubation tests were run on chemically clarified effluents at 35 C for periods ranging from 1 to 24 hours. Samples were filtered through 1.0 μm Nuclepore filters to determine the tendency for postprecipitation. Discussions with leading chemical companies suggested that problems of downhole postprecipitation due to chemical additives were especially likely in the presence of either Fe^{2+} (as little as 0.2 ppm) or Ca^{2+} (200 ppm).

Bryan Mound brine, which contained the highest concentrations of these ions, was used for these experiments. The test results show that postprecipitation is <0.1 ppm in the presence of excess alum (at 3 ppm), excess alum + Cyfloc 4500N (at 10 ppm alum + 0.2 ppm nonionic polymer), or excess Anionic Polymer Visco 3340 (at 3 ppm). If chemicals are employed in filtration operations, incubation tests must be done on the filtered effluents to determine the potential for downhole postprecipitation.

5.1.4.2 Residual Polymer. Field observations indicated that residual polymers contribute to the plugging of 0.4 μm Nuclepore membrane filters. Follow-up laboratory studies were conducted with prefiltered brine, and additional injectability tests were performed. The injectability test apparatus was similar to the equipment used in the field (Chapter 4). A relationship was observed between residual polymer concentration and loss of filter permeability (Figs. 5-5 and 5-6). Figure 5-5 shows the change in permeability of 0.4 μm membrane filters with polymer concentration after 30 minutes of flow. Figure 5-6 illustrates permeability differences of 0.4, 1.0, 5.0, and 10.0-micron filters after the passage of brine with and without polymer (0.5 mg/ℓ) additions. Observed permeability changes of the filters depended on the molecular weight of the polymer. Table 5-4 shows that residual high-molecular-weight polymers have the greatest effect on the rate of filter plugging. However, polymer charge does not seem to have any effect, possibly because of the already high electrolytic nature of the solution.

The membrane filter plugging mechanism may be due to either direct adsorption of polymer (enhanced by polymer bridging) or interaction of polymer and trace (<0.3 ppm) amounts of submicron suspended solids. Additional laboratory work would be required to unequivocally establish the plugging mechanism. Such studies would be desirable since injection wells could be impaired by the deposition of residual polymers or by the coagulation of trace particulates in post-filtered effluents.

5.1.5 Specific Site Evaluations

A summary of the most effective systems for brine clarification at each of the three sites is given in Table 5-5. The specific pilot tests and other evaluations conducted at each site are described in the following sections. Bench-scale tests at all sites demonstrated that sedimentation alone is not satisfactory as a possible short-term solution for producing adequate brine clarity. In addition, plugging factor tests show that even with chemical pretreatment, settling does not yield good quality brine effluent for injection (Fig. 5-7).

5.1.5.1 West Hackberry. Three granular media filters as well as cartridge filtration were evaluated. The filter constructions are described in Table 5-1. Table 5-6 compares the mean turbidities (NTU) and head loss (ft H_2O) for granular media filters with and without chemical feeds. Head loss or effluent turbidity are plotted versus time in Figs. 5-8 through 5-11 for several direct filtration (no chemical additives) tests. Table 5-7 summarizes the particle-size measurements on selected filter runs. Data are also included for the filter influent (pond output). The few particle count data collected at West Hackberry did not adequately show the effectiveness of the filters. Turbidity and injectability measurements, however, were satisfactory indicators of effluent quality. Particle-size measurements at Bayou Choctaw and Bryan Mound were more definitive.

Figure 5-8 shows that head loss (ΔP) is strongly dependent on the type of filter media used. For West Hackberry brines, Filters B and C, a dual-media filter and a triple-media filter, respectively, show the least amount of head loss over time. This occurs, as illustrated in Figs. 5-9 through 5-11, without any sacrifice in effluent quality compared with other filters having higher head losses.

It is important to note that initial filtration of these strong brines did produce an acceptable quality without the use of coagulants. Mean turbidity values of 0.20 ± 0.05, 0.20 ± 0.08, and 0.18 ± 0.07 were observed for Filters A, B, and C, respectively. However, direct filtration of brines during changing brine conditions would severely tax the performance of granular media filters operating without chemical feed.

As demonstrated in jar tests, aluminum salts alone produced acceptable effluent quality under changing brine conditions. Changes in input turbidity did require a slight increase in alum dosage to maintain filter effluent water quality. However, the length of the filter cycle was reduced with increasing aluminum salt dosage as illustrated in Fig. 5-12.

At West Hackberry, the optimum alum concentration is about 3 mg/ℓ, without unacceptable head loss. Overall, it can be concluded that triple-media Filter D produced the best fluid for injection although there is a larger head loss than with dual-media filters.

Although cartridge filters produced an excellent effluent quality they inevitably plug too rapidly and are therefore not practical (Chapter 4).

5.1.5.2 Bayou Choctaw. The information obtained from the West Hackberry filter evaluation test was used to select the following conditions for pilot filter evaluation: two 4-inch-diameter granular media filter configurations, one ultrafiltration hollow fiber cartridge unit, and disposal cartridge filters. In addition, based on information obtained during this pilot test, a third media configuration was designed later. The construction of these filters is given in Table 5-1 and Figs. 5-1 and 5-2. Results from pilot filter tests are given in Table 5-8.

The size distribution of particles in the test brines, dilution water, and filter effluents is given in Table 5-9. With proper filtration, essentially all particles above 5 μm and >99 percent of particles above 1 μm are removed. The particle-size distribution before and after filtration (Run D-3) of the leach brine is illustrated in Fig. 5-13.

Direct granular media filtration without chemicals produced an unacceptable effluent quality in both weak and diluted strong brine. Effluent turbidity values were high, on the order of 3.0 to 4.0 NTU. Therefore, any additional evaluation of filter performance included chemical treatment.

The ultrafiltration unit, which does not require chemical pretreatment of the brine, produced a very acceptable effluent with turbidities of 0.1 NTU and excellent plugging factor results (i.e., fluid injectability based on membrane filtration tests).

Evaluation of weak brine was difficult during the first half of this test period due to contamination of the brine by vendor-operated pilot filters. All three vendor filters were being backwashed into the weak brine storage tank. This meant that the vendor filters, as well as the LLL test trailer, received polymer-contaminated weak brine. Therefore, several days were spent testing this nonrepresentative weak brine until a separate backwash tank became available. However, the vendor filter effluents continued to be discharged back into the weak brine holding tank and recirculated.

Anionic polymers were the most effective in clarifying ponded brines at Bayou Choctaw and they were the most stable under changing brine conditions. The anionic polymer that seemed to yield the best results with regard to turbidity decrease was Visco 3340, a long-chain high-molecular-weight polymer. The optimum concentrations for turbidity reduction were 2 to 4 mg/ℓ.

Although filter alum $[Al_2(SO_4)_3 \cdot 14H_2O]$ also yielded good jar test results, much higher concentrations were required over those concentrations for West Hackberry brine. This resulted in a much more rapid head loss rate. In addition, flocs formed with alum in Bayou Choctaw brines were weaker than flocs formed by Visco 3340 and, therefore, penetrated through granular media at much lower ΔP.

The average turbidity and rates of head loss (ΔP) for different filter media using various chemical dosages of Visco 3340 were tested and evaluated. It was determined that filters containing a fine-garnet media improved effluent quality and filter run time. Based on the above information, Filter A1 was constructed and tested at a flow rate of 11 gal/min/ft^2 to approximate the dual-media downflow filters being tested on-site by the filter vendors. Figure 5-14 compares the length of run and average turbidity of the dual-media (garnet-coal) Filter A1 with those of the triple media (coal-silica sand-garnet) Filter D.

The mean turbidities, 0.24 and 0.23, for these two filters are not significantly different. However, filter run time and related head loss (ΔP) did show a significant difference. Filter D performed effectively for 19 hours compared with 10 hours for Filter A1. Both filters were run in parallel and each was terminated when flow rate through the filter could not be maintained. Filter D had a total acceptable throughput of 1.4 times that of Filter A1. Therefore, we conclude that triple media (coal-sand-garnet) seems to be the most effective granular media filter at Bayou Choctaw.

Comparative filter runs were performed to determine what effect, if any, various chemical additives have when used in conjunction with Visco 3340. Figure 5-15 compares the Visco 3340 with the Visco 3340 plus NaOCl. It shows that the effluent turbidity deteriorated with the introduction of NaOCl. NaOCl was evaluated because it is an inexpensive biocide, should a biocide be necessary to control biological activity. The detrimental effect of NaOCl may be due to destruction of Visco 3340 by oxidation. Figure 5-16 compares Visco 3340 with Visco 3340 plus alum. The introduction of alum also caused a significant deterioration of effluent quality with respect to turbidity and plugging factor.

A low-quality effluent was obtained in the plugging factor tests on filter effluent from granular media filters where 2 ppm Visco 3340 was used as a pretreatment. The effluent quality was low even though turbidity and particle count tests indicated an unusually good quality effluent. Data from bench-scale filtration studies with polymers (Section 5.1) indicate that long-chain anionic polymers, such as Visco 3340, may adsorb/bridge the 0.40 µm Nuclepore/0.45 µm Millipore membrane filter contributing to eventual plugging. Therefore, 0.5 mg/ℓ of Magnafloc 507C, a short-chain cationic polymer, was added along with 2 mg/ℓ Visco 3340. The 507C appeared to help, possibly by destabilizing the excess anionic charge for better granular filter bed retention. The effluent quality as measured by membrane filter tests was improved by about 50 percent when Magnafloc 507C was used.

5.1.5.3 <u>Bryan Mound</u>. The results of the filter evaluation tests at the two previous SPR sites were used to select the following conditions for pilot filter runs: two 4-inch-diameter triple-media configurations, one ultrafiltration hollow fiber cartride unit, and disposable cartridge filters. The construction of these filters is given in Table 5-1 and Figs. 5-1 and 5-2. Evaluation of pilot filters during the first part of the test was based on static ponded brine. This brine was more saline and therefore had slightly different coagulation characteristics.

As shown in Table 5-10, only the ultrafilter produced acceptable quality effluent without benefit of chemical feeds. Mean turbidities ranged from 0.13 to 0.10, and plugging factor tests showed excellent results. Jar tests, in the first few days of testing, indicated that several anionic polymers (Visco 3340, Visco 741, and Magnafloc 834A), as well as $AlCl_3$ and $Al_2(SO_4)_3 \cdot 14H_2O$ would produce acceptable quality effluent. However, due to the changing brine conditions, $Al_2(SO_4)_3 \cdot 14H_2O$ plus Cyfloc 4500N were the only chemicals that produced acceptable quality effluent when applied to granular media filters. Figure 5-17 compares filter effluent turbidity with alum plus Cyfloc 4500N and no chemical feed. Figure 5-18 gives head loss (ΔP) as a function of time. The head loss rate is acceptable for filter runs with chemical feed. Table 5-9 compares the mean turbidities taken (a) on effluents from granular media filters with and without chemical feeds, and (b) on ultrafilter effluent. Table 5-10 gives the particle-count data on these same streams plus data on fluids at other locations. The decline and shift in particle-size distribution after filtration is similar to results at Bayou Choctaw.

Although mean turbidities were approximately 0.18 NTU for filter runs with alum plus Cyfloc 4500N chemical feeds, and plugging factor test results showed in excess of 65 liters through 10 μm membrane filters in 30 minutes, only 2.7 liters passed through a 0.4 μm membrane filter in 30 minutes. This again may be indicative of a plugging problem resulting from either direct deposition of long-chained high molecular weight polymers such as Cyfloc 4500N on the membrane filter or interaction of the polymer with trace amounts of suspended solids.

5.1.6 Summary

5.1.6.1 Supersaturated (Strong) Brine.

1. Filtration of strong brine is not possible due to salt precipitation.
2. Dilution of the brine is necessary to prevent salt precipitation.

3. Hypersaline brine diluted with untreated lake/river water is more difficult to clarify than brine diluted with chemically treated and clarified lake/river water.
4. Lake/river water can be clarified and settled, using alum and Cyfloc 4500N or Visco 3317 prior to use as a diluent. However, separate clarification of lake/river water may not be cost-effective since the diluted brine must still be clarified.

5.1.6.2 Filtration without Chemical Pretreatment.

1. Granular media filtration without chemical treatment is generally unacceptable for both strong and weak hypersaline brines, unless the brine solids are precoagulated and brine properties remain stable.
2. Ultrafiltration produces acceptable quality brine effluent without chemical pretreatment. Although more expensive to install, this process is not as sensitive to changing brine conditions. However, there is scant industrial experience with ultrafilters having capacities of 150,000 to 200,000 bbl/d.
3. The 1 µm pore size cartridge filters produce acceptable quality effluents without chemical aids, but these filters irreversibly plug too rapidly to be practical for treatment of large quantities of brine.

5.1.6.3 Filtration with Chemical Pretreatment.

1. Dual- and triple-media filtration of both weak and diluted strong brines with proper chemical treatment produces a high-quality injectable effluent, as long as conditions remain constant.
2. Triple-media filters (coal-sand-garnet) with chemical treatment were superior to all other granular-media configurations tested with respect to effluent quality, head loss, and cycle time.

5.1.6.4 Chemicals and Chemical Pretreatment.

1. High-molecular-weight polyacrylamide polymers exhibited the most versatility in coagulating brine for filtration through granular-media filters, but are not as effective with oil-contaminated brines.
2. Alum or alum plus a nonionic, high-molecular-weight polyacrylamide polymer produces acceptable quality effluent when used with granular-media filters during periods of oil contamination.

3. Nonionic, long-chained polymer additives used in conjunction with alum strengthen the flocculated material and prevent premature filter penetration.
4. Incubation tests at 35 C of Bryan Mound brines show no evidence of postprecipitation with use of alum, alum + Cyfloc 5400 (nonionic polyer) or anionic polymer Visco 3340.
5. Injectability tests with membrane filters show that polymers in highly electrolytic solutions containing trace amounts of suspended solids eventually plug membrane filters with pore sizes from 0.4 to 5 µm. Furthermore, the effect is proportional to polymer chain length. Residual polymers in filter effluents, therefore, could lead to a potentially serious downhole problem. The significance of residual polymer concentration with respect to potential injection well impairment merits further study.

5.2 INTERIM CLARIFICATION SYSTEMS

F.H. Smith*

The SPR sites were experiencing continuing difficulties with the disposal of untreated brine at disposal rates of up to 200,000 bbl/d. An assessment was, therefore, made of provisional clarification and filtration systems that could be quickly implemented at the three sites. Accordingly, engineering studies were made on (1) modification of the brine holding ponds to optimize removal of brine particulates by settling; (2) the use of "packaged" or cartridge filtration systems amenable to rapid construction and installation; and (3) the use of in-place or pool-type granular media filters in lieu of on-site concrete fabrication or factory manufactured tankage. Subsequently, we determined that cartridge filtration systems are not viable at SPR sites owing to rapid and irreversible plugging.

5.2.1 Brine Holding Ponds

The existing holding ponds have been considered for use as settling basins to clarify the brines before reinjection. Two basic aspects are

*National Technical Service, Corvallis, Oregon.

reviewed: the settleability of particles in the brine and the design of the ponds for use as clarification basins.

Principles of sedimentation have been studied for many years. Many theoretical parameters have been verified in laboratory work, and some have been verified by observations in the field of full-sized clarifiers. Discrepancies between theoretical settling values and actual values often occur because theoretical settling equations have been based on spherical particles (seldom found in actual conditions) or one or more types of currents that hinder the settling of the particles. Four types of currents are responsible for most of the problems in comparing theoretical settling values with actual conditions: (1) surface currents caused by wind movement across an uncovered basin; (2) convection currents caused by temperature differentials in and around a basin; (3) density currents caused by differential temperature and/or suspension loading values between incoming water and water in a basin; and (4) eddy currents produced when incoming water enters a basin.

Regardless of the type of discrepancy, the end result is to prolong settling times established by mathematical equations for theoretical spherical particles falling through water in a basin without any hindering currents. Therefore, a look at the theoretical settling values of particles in the brine at West Hackberry, Louisiana, is presented first, followed by a general description of the holding basins at each of the three SPR sites.

Preliminary field analyses at West Hackberry established that the average brine exiting the pond contained the following particle size distribution:

1 to 2-micron particle size	46 percent
2 to 5-micron particle size	34 percent
5 to 10-micron particle size	15 percent
>10-micron particle size	5 percent

Since 95 percent of the particles are smaller than 10 microns, the following analysis of settling velocities is based only on these very small particles.

A very useful equation for establishing settling velocities of spherical particles in ideal settling basins is given by

$$v = \frac{g(\rho_s - \rho)}{18\mu} d^2$$

where v is the velocity of the particle, g is the gravity constant, ρ_s and ρ

are the specific gravities of the particle and fluid, respectively, ρ is the dynamic viscosity of the fluid, and d is the diameter of the particle.

The specific gravity of most suspended particles found in water varies between 2.1 and 2.9, and the specific gravity for the brine is approximately 1.18. Analysis at the site indicates that the viscosity of the brine is approximately twice that of water, or about 3.14 cP for a temperature of 4 C (40 F). Substitution of these values in the previously described equation provides two factors which can be multiplied by various diameters of particles, to establish settling velocities, as follows:

$$v = \frac{(981)(2.1 - 1.18)}{(18)(3.14)} d^2 = 15.97\ d^2$$

$$v = \frac{(981)(2.9 - 1.18)}{(18)(3.14)} d^2 = 29.85\ d^2$$

Settling velocity of particles 1 micron in diameter:

$$\text{Minimum } v = (15.97)(0.0001)^2 = 1.6 \times 10^{-7} \text{ cm/sec}$$

$$\text{Maximum } v = (29.85)(0.0001)^2 = 3.0 \times 10^{-7} \text{ cm/sec}$$

Settling velocity of particles 5 microns in diameter:

$$\text{Minimum } v = (15.97)(0.0005)^2 = 4.0 \times 10^{-6} \text{ cm/sec}$$

$$\text{Maximum } v = (29.85)(0.0005)^2 = 7.5 \times 10^{-6} \text{ cm/sec}$$

Settling velocity of particles 10 microns in diameter:

$$\text{Minimum } v = (15.97)(0.001)^2 = 1.6 \times 10^{-5} \text{ cm/sec}$$

$$\text{Maximum } v = (29.85)(0.001)^2 = 3.0 \times 10^{-5} \text{ cm/sec}$$

It has been established by various analysts in the past that the settling velocity of a particle is equal to the surface loading of a settling basin; therefore by dividing each of the previously established settling velocity values by the factor 4.7×10^{-5} we can establish the theoretical overflow rate required for good settling. When the overflow rates are divided into the generalized flow values for each of the three SPR sites (approximately

10,500,000 gal/d), the theoretical settling areas are established. Table 5-12 shows these values and their relationships.

Since 80 percent of the suspended particles in the brine are smaller than 5 microns, direct settling of these particles is impractical if at all possible. The values shown in Table 5-12 are based on settling basins that are completely quiescent and do not take into account hindering currents. These currents, if present, can cause the size of the basin to be increased significantly in order to reduce their effect on the settling particles.

A prime design factor that can significantly affect the settling of discrete particles is the shape of the settling basin. This parameter has a major effect on the amount of short circuiting encountered, which partially establishes the amount of solids leaving the basin through the effluent line rather than accumulating on the basin bottom. By far, the most effective shape is a long, narrow, rectangular tank, with bends to reduce the effect of the velocity head of the entrance water. The existing holding ponds can be modified into long settling ponds by installing floating baffle curtains and relocating the entrance and exit pipes. This design change would optimize their shape, thus allowing an analysis of the size of particle that would theoretically settle in them. Part of the basin depth must be utilized for sludge accumulation and, for purposes of this report, the bottom one foot of pond depth is so utilized.

At West Hackberry, two basins are connected together with a transfer pipe. By using the two basins in series, relocating the influent pipe, and modifying the transfer pipe to a pass-through channel, a settling basin with the following characteristics is established:

Width of basin = 304 ft (not including sloped surfaces of berms)
Length of basin = 1,008 ft (not including sloped surfaces of berms)
Usable settling depth = 4 ft (1 ft allowed for sludge accumulation)
Length-to-width ratio = 3.3:1
Length-to-depth ratio = 252:1
Horizontal velocity at 250,000 bbl/d flow = 0.01 ft/sec (16.25 ft^3/sec)
Overflow rate at 250,000 bbl/d = 34 gal/d/ft^2 flow (10.5 million gal/d)
Detention time at 250,000 bbl/d flow = 21 hours.

These modified basin criteria are conducive for good removal of discrete particles as small as 5 microns (0.005 mm) from water, based on field analysis of water treatment plant sedimentation basins at St. Louis, Kansas City, and

Washington, D.C. By installing floating baffles and using the long, round-the-end design for the basin, short circuiting is minimized. Data accumulated at existing facilities show that this type of design has no short circuiting problems.

Similarly, at Bayou Choctaw two basins are connected together with a transfer pipe. By using the two basins in series, relocating the influent pipe, and modifying the transfer pipe to a pass-through channel, a settling basin with the following characteristics is established:

Width of basin = 201 ft (not including sloped surfaces of berms)

Length of basin = 1,056 ft (not including sloped surfaces of berms)

Usable settling depth = 10 ft (1 ft allowed for sludge accumulation)

Length-to-width ratio = 5.25:1

Length-to-depth ratio = 105:1

Horizontal velocity at 250,000 bbl/d = 0.01 ft/sec flow (16.25 ft^3/sec)

Overflow rate at 250,000 bbl/d = 49 gal/d/ft^2 flow (10.5 million gal/d)

Detention time at 250,000 bbl/d flow = 36 hours

By changing the shape of the basin and making it into a round-the-end design, short circuiting is significantly reduced. The horizontal velocity is still within the range of values indicative of good removal of small particles. This modified design produces a basin conducive for good removal of discrete particles as small as 5 microns (0.005 mm) from water.

Bryan Mound has one basin. At this site, it appears that the influent and effluent pipes are located at the farthest points possible from each other. This basin is significantly smaller than either of the previously described basins and has the following characteristics:

Width of basin = 193 ft (not including sloped surfaces of berms)

Length of basin = 297 ft (not including sloped surfaces of berms)

Usable settling depth = 6 ft (1 ft allowed for sludge accumulation)

Length-to-width ratio = 1.54:1

Length-to-depth ratio = 50:1

Horizontal velocity at 250,000 bbl/d = 0.01 ft/sec flow (16.25 ft^3/sec)

Overflow rate at 250,000 bbl/d = 183 gal/d/ft^2 flow (10.5 million gal/d)

Detention time at 250,000 bbl/d flow = 6 hours

In this case almost none of the characteristics of this pond meets the desired criteria conducive for removal of discrete particles from water in the desired range of 1 to 10 microns. However, it is possible to improve some of the pond characteristics by installing a floating baffle in the center of the basin to form a long basin with round-the-end flow design. If this is done, the pond characteristics are as follows:

Width of basin = 96 ft (not including sloped surfaces of berms)
Length of basin = 594 ft (not including sloped surfaces of berms)
Usable settling depth = 6 ft (1 ft allowed for sludge accumulation)
Length-to-width ratio = 6.2:1
Length-to-depth ratio = 99:1
Horizontal velocity at 250,000 bbl/d = 0.03 ft/sec flow (16.25 ft^3/sec)
Overflow rate at 250,000 bbl/d = 183 gal/d/ft^2 flow (10.5 million gal/d)
Detention time at 250,000 bbl/d flow = 6 hours

Comparing the design criteria of the modified basin with that of existing basins indicates that particle sizes in the range of 15 to 20 microns (0.015 mm to 0.020 mm) can be settled in water. These particle sizes are larger than those which require removal from the brines being reinjected.

When comparing the sedimentation of various particle sizes in the previous paragraphs, the carrying fluid was water with a specific gravity of 1.00 and an approximate 1.6 cP viscosity. When these values are used in the equation to determine settling velocities, we find that particles of approximately 5 microns in size have a settling velocity, in water, of 9.4×10^{-6} cm/sec when the particles have a specific gravity of 2.1. The settling velocity increases to 1.6×10^{-5} cm/sec for particles with a 2.9 specific gravity. Substitution of this value in the same equation using specific gravity and viscosity values for brine establishes particle diameters between 7 and 8 microns which have the same settling velocities in brine.

Based on the previous calculations and comparisons with existing water clarification basins, it appears that modifying the holding ponds at West Hackberry and Bayou Choctaw to make them into long, rectangular basins with round-the-end flow patterns will provide good settling characteristics so that discrete particles as small as 7 microns can be removed from the brine. The modifications are not extensive in either case with the exception of modifying the separating berm between the two basins.

Although the majority of the discrete particles in the brine at West Hackberry were less than 5 microns in size, any modification to improve the settling characteristics of these two ponds will improve the turbidity loading to any filter system which may be installed.

At this time, prior to any testing being performed, it appears that there is no way to easily improve the settling characteristics of the holding pond at Bryan Mound site, with the exception of adding floating baffles and modifying the inlet piping to optimize distribution of the flow. An additional pond, built to operate in series with the existing pond, may be required to obtain pond characteristics similar to those obtained when the ponds at West Hackberry and Bayou Choctaw are modified.

5.2.2 Cartridge Filtration Systems

A prime reason for investigating the use of cartridge filtration systems in treating brine wastewaters is the hope of installing the systems in a short time period. For this reason, various package-type filter systems, which are readily available, were reviewed. Four systems were compared for size, flexibility of operation, and price.

The four systems investigated can be separated into three types of treatment approaches. One approach, consisting of one of the five systems reviewed, is based on provided multiple pressure downflow granular filters, manifolded together with appropriate piping so that they act as one filter (Fig. 5-19). The second approach is based on the utilization of ultrafiltration cartridges and treating the brine in a batch treatment process by recirculating the reject water back to the brine holding pond (Fig. 5-20). The third approach utilizes pressure filter vessels that house multiple disposable filter cartridges. Two cartridge filter systems were reviewed. These cartridges are available in various porosities, capable of removing particles down to 3 microns in size. Further discussion of each of the three approaches is contained in the following paragraphs. Table 5-13 shows some of the comparative factors for each of the three approaches when located at each of the three sites in Louisiana and Texas.

The downflow granular filter approach offers the most flexibility of all the investigated systems because it can operate effectively with or without chemical addition to the brine, and if conditions are right, without chemicals.

To provide a filter system that is versatile to install and use as well as easy to ship, a standard module is proposed consisting of a support frame 8 feet wide and 16 feet long. Each frame contains 12 vertical pressure filters, each 2 feet in diameter and approximately 5 feet high. Each filter tank is connected to the two main headers running the length of the assembly and can be individually isolated from both headers by operating manual valves. The upper header is used for raw water transfer to the top surface of the filter media during filtering mode of operation and for removal of backwash wastewater during backwashing mode. Two skid assemblies are manifolded together to form one "filter" for backwashing purposes. This reduces the number of valve stations required for automatic operation but still provides a reasonable size of filter for backwashing purposes so that piping sizes can be kept to a minimum. Multiple filters can be manifolded together as required to meet the desired flow rates at each SPR site. Automatic controls for this system are simple and consist of two automatic open-closed valves for each filter and one modulating automatic valve on the main plant effluent pipe. The two open-closed valves are used to divert the normal flow for each filter from filtering mode to backwashing mode, and the modulating final effluent valve is used to increase back pressure on the main effluent header so that the proper backwash flow is diverted to the particular filter requiring backwash and through the waste line back to the brine holding pond. Backwashing is initiated by high head loss across the filter or manually as desired by the operator. In addition, individual head loss indicators may be installed on all tanks of each filter for visual monitoring purposes. The estimated cost of this approach, not including the main piping system required to connect the necessary number of filters together to obtain a properly sized treatment plant, is shown on Table 5-13. Manufacturing time required for this approach appears to be approximately 8 to 10 weeks for a nominal plant capacity of 250,000 bbl/d.

The ultrafiltration approach provides the best potential quality of all the systems described. It was field-tested at Bayou Choctaw and Bryan Mound. The single ultrafiltration cartridge system that was tested can provide an effluent with all suspended particles removed down to a size of 0.1 micron. This system is easy to operate as no chemicals are required for optimum effluent qualities. This type of filter process is strictly a mechanical separation of clean water from dirty water through the utilization of pressure to force a varied percentage of the raw water through a semipermeable membrane. The reject water that does not pass through the membrane is returned to the brine pond. Periodic backflushing and chemical cleaning of the membranes is required and is accomplished in much the same manner as backwashing the granular filters previously described. The estimated cost for this approach, not including the main piping system, is shown in Table 5-13. Manufacturing time required for this approach is approximately 30 weeks for a nominal plant capacity of 250,000 bbl/d.

The final approach investigated was the use of disposable cartridge filters. Two manufacturer's sytems were reviewed, both using slightly different cartridges and piping arrangements. The factor common to the two manufacturers is the utilization of a 5-micron cartridge, which means that all suspended matter larger than 5 microns will be captured in the cartridge elements. These systems operate in a similar manner to the granular filter approach in that no "reject" water needs to be piped back to the holding pond. They also operate in a similar manner to the ultrafiltration system in that a pressure differential is used to mechanically separate the clean water from the dirty water by forcing the raw water through a membrane. A major drawback with this approach is that there is no flushing action on the membrane surface as occurs in the ultrafiltration process. Furthermore, chemical addition is not recommended as the heavier and more voluminous floc produced by chemical addition will quickly blind off the cartridge surface causing earlier replacement of the cartridges than should be necessary. Cartridge filter operation depends on the viscosity of the fluid being filtered: as the viscosity increases, less water can be forced through a cartridge using a given initial pressure. For this reason, the viscosity of the brine being filtered should be analyzed by laboratory means so that optimum operating conditions can be established. For calculation purposes in this paper, a kinematic viscosity between 20 and 50 Centistokes is assumed.

These values are reasonably based on published data for 25 percent brine and by comparisons with similar sugar concentration data. Based on these viscosity values and a desired initial pressure differential across the cartridge of one psid, the flow rate through each cartridge can vary between 0.5 and 1.2 gal/min. The estimated cost of the two disposable cartridge filter systems, not including the main piping system, is shown in Table 5-14. Manufacturing time required for either of the two systems is approximately 8 to 10 weeks for a nominal plant capacity of 250,000 bbl/d.

Our SPR field tests (Chapter 4) demonstrated that 5 μm cartridges produce a totally unsatisfactory effluent. Finer pore-sized cartridges (i.e., 1 μm) produce high-quality effluents, but plug in approximately 8 hours of operation (100 psi - ΔP max) at 1 gal/min/ft^2. The cost and inconvenience of such frequent replacement may be unacceptable.

The main piping system required to transmit the 175-bbl/min flow to the filter system used will not vary greatly in cost because the major piping size is similar. The layout of the filter system is assumed to be constant between the three SPR sites regarding to the location of the filter supply pumps and the filter building. The filter supply pump design for each site consists of three pumps, each capable of providing a flow of 60 bbl/min at a pressure of 30 psig. Using three pumps ensures that if one motor or pump becomes inoperable, the remaining pumps can still provide two-thirds of the desired flow rate to the filters. The estimated cost of a typical main piping system, including three pumps and appropriate valving, is shown in Table 5-14. Manufacturing time required for this system is approximately 8 to 10 weeks for a nominal plant capacity of 250,000 bbl/d.

5.2.3 In-Place Granular Media Filters

The use of in-place granular media filters is recommended only as a temporary approach to solve an immediate problem. Because it is desired to keep installation time to a minimum, the earthen basin design is selected in lieu of on-site concrete fabrication or factory manufactured tankage. This type of basin design, with sloped sides, is not advantageous in the operation of the filter as the portion of the media above the sloped berms is not properly cleaned during backwash. This will not be a major problem for a temporary installation, but it would be for a permanent one as dirt will continue to accumulate in the improperly washed portion of the media over an extended time period.

The operation of this filter design (Fig. 5-21) is similar to that of a conventional treatment plant. Basically, the water from the holding pond is collected in a pipe system and transferred to the filters by the differential head between these two basins, approximately 2 to 6 inches. Water is removed from the filter by a pump connected to the underdrain piping system installed below the filter media. The filter pump discharge piping is connected to the supply piping of the well injection pumps or to a holding tank between the two sets of pumps. If the pumps are connected directly together, the injection well pumps must be shut down when the filters are backwashed. A holding tank between the two sets of pumps would allow the injection well pumps to continue to operate during backwash times.

As the "dirty" water continues to pass through the filter, the spaces between the media particles become clogged with matter, thus reducing the available area for the water to use when passing through the filter. This increases the velocity and thereby the head loss across the filter media. To compensate for the variable head loss, a level controller is installed in the filter, which maintains a constant water level in the filter by increasing the opening of the filter pump discharge valve as the filter head loss increases. The filter pump has a flooded suction so the only restriction on the suction side of the pump is the increasing velocity head associated with the increasing filter head loss. This restriction is not a problem when operating the filter at a flow rate of approximately 8 gal/min/ft^2 and a terminal head loss of 15 to 18 feet of water.

The piping and equipment required for three filters, including automatic controls is estimated to cost $255,000, not installed. This cost is approximately the same whether a gunite liner or plastic liner is used. Table 5-14 shows basic comparative data for systems built with either liner.

Two means of construction were analyzed in preparing this report: an earthen basin with a 30-mil impervious liner, and an earthen basin with a gunite lining. Both types of basins will require a similar amount of piping and the same pumps and equipment, but construction details will be different.

The use of a gunite liner in an earthen basin has the following advantages:

1. It is quick to install. Depending on the natural ground at each site, it is possible to construct the earthen berms for three filters in about 3 to 4 days. An additional 2 days is required for installation of the steel mesh and gunite liner.
2. Care in construction of the berms is not critical. Because gunite can "mold" around virtually any protrusions in the earthen berm, elimination of protruding rocks and other materials is not necessary.
3. Gunite can be installed on any surface angle, thus eliminating the need to ensure a 2:1 or 3:1 sloped berm. Because the thickness of the gunite coating depends on the slope, a slope ratio of approximately 1:1 should be

used to keep the gunite thickness between 2 and 3 inches. Vertical walls would require a thickness of 6 or more inches.

A gunite liner has two disadvantages:

1. It is more expensive than a plastic impervious liner. Gunite in place, not including any earth work is between \$1.50 and \$2.00/ft^2 of area.
2. Gunite is not impervious, thus allowing a small amount of brine seepage to occur, and will probably stain and scale when used to contain brine solutions. If the basins were to be used for an extended time period (several years) it may be advisable to coat the lining with epoxy paint, but this would require additional time for application and curing.

Figure 5-22 shows a typical three-filter arrangement with gunite linings. The estimated cost for this arrangement is \$35,000, not including any piping or equipment.

The use of an earthen basin with a plastic impervious liner has two advantages:

1. A plastic liner is less expensive than a gunite liner. The cost of a plastic liner shipped to the job site is between 55 and 60¢/ft^2 of area. This is based on three men taking 3 days to install the liners in three filters at one site.
2. A plastic liner, if installed properly and protected with a layer of sand or similar "cushion," is impervious and does not react with the brine.

The use of a plastic liner has three disadvantages:

1. Because the liner can be punctured by sharp objects, it must be installed carefully and requires care in making the joints between membrane sections or where piping penetrates the liner. Because support gravel for the filter media is angular, the liner should have a sand covering to keep from having the support gravel puncture it. This sand "topping" requires additional time for installation. All the previously mentioned requirements mean that proper installation of a plastic liner takes more time than required for a gunite liner.
2. Construction of the berms is more critical than when using gunite. This is because protruding rocks and other material may puncture the plastic liner. These materials should be removed or covered with earth to prevent damage to the liner from occurring.
3. An earthen basin with a plastic liner should have a slope ratio no greater than 2:1 to ensure stability of the berm. This means a greater plan area

is required for the same filter bottom area and a greater amount of earth must be moved to construct the berms.

Figure 5-23 shows a typical three-filter arrangement with impervious plastic liners. The estimated cost for this arrangement is $54,000, not including any piping or equipment.

Because time is a very important element for the temporary solution at the two SPR sites in Louisiana and the one site in Texas, design and construction efforts will necessarily be performed simultaneously.

TABLE 5-1. Construction of pilot filters.

	Filter	Construction	Sites tested
A	4-in.-dia single-media	24 in. of silica sand 0.45-0.6 mm	West Hackberry
A_1	4-in.-dia dual-media	12 in. garnet 0.28-0.35 mm; 18 in. of anthracite coal 1.0-1.1 mm	Bayou Choctaw
B	4-in.-dia dual-media	12 in. of silica sand 0.48-0.6 mm; 18 in. of anthracite coal 1.0-1.1 mm	Bayou Choctaw and West Hackberry
C,D	4-in.-dia triple-media	3 in. garnet 0.28-0.35 mm; 9 in. silica sand 0.48-0.60 mm; 18 in. anthracite coal 1.0-1.1 mm	Bayou Choctaw, West Hackberry, and Bryan Mound
E	Ultrafilter	Romacon hollow fiber cartridge; 3 in. dia, 25 in. long with 525-mℓ volume; Polysufone shell	Bayou Choctaw and Bryan Mound
F	Disposable cartridge filters	Cuno, 1.0 µ cartridge filters	Bayou Choctaw, West Hackberry, and Bryan Mound

TABLE 5-2. Chemical treatment for dilution water.

Site	Method	Chemical treatment	Comments
Bayou Choctaw	Gravity settling	100 ppm Visco 3317 (Al chloride + cationic polymer)	Fastest settling rate
		80 ppm alum + 0.1 ppm Visco 985N (long-chained nonionic polymer)	
Bryan Mound	Gravity settling	50 ppm Visco 3317 (Al chloride + cationic polymer)	Fastest settling rate
		60 ppm alum + 0.1 ppm Visco 985N (long-chained nonionic polymer)	Causes pH decrease

TABLE 5-3. Coagulants and flocculants.

Coagulant or flocculant	Amount added, ppm	Description	Effect on turbidity at indicated site[a]		
			West Hackberry	Bayou Choctaw	Bryan Mound
Cationics					
Alum	1-300	Inorganic, short-chained, high-charged; used with Cyfloc 4500	E	R	E
$FeCl_3$	1-50	Inorganic, short-chained	R	--	--
Cat Floc-T Calgon	0.5-10	Low molecular weight (0.5 m)	N	N	--
Cyanamid Magnafloc 507C	0.5-3	Low molecular weight, high-charged; used with 3340	N	N	--
Cyanamid Magnafloc 581C	0.5-10	--	N	N	--
Cyanamid Magnafloc 1561C	0.5-10	--	--	N	--
Cyanamid Magnafloc 1563	0.5-10	--	--	N	--
Nalco Vx-740	0.5-5	High molecular weight (7-10 m)	--	--	N
Visco 3317	0.5-3	$AlCl_3$ cationic polymer; used with anionics (834A, 1820A, 3340)	N	R	R
Visco 3342	1-20	--	N	--	--
Visco 3347	0.5-10	Alum; cationic polymer	N	N	--
Visco 3349	0.5-10	--	N	N	--
Zimmite 2T68	1-20	--	N	--	--
Zimmite 2T653	0.5-20	--	N	--	--

[a]N = no change in turbidity;
R = reduced turbidity to some degree;
E = excellent turbidity reduction.

TABLE 5-3. (continued).

Coagulant or flocculant	Amount added, ppm	Description	Effect on turbidity at indicated site[a]		
			West Hackberry	Bayou Choctaw	Bryan Mound
Anionics					
Chlorine	1-5	--	N	N	N
Calgon M-570	0.5-3	Medium molecular weight (7 m)	N	--	--
Calgon M-580	0.5-20	Medium molecular weight (7 m)	R	--	--
Calgon M-590	0.5-10	Medium molecular weight (7 m)	N	R	--
Cyanamid Cypan	1-3	200,000 MW	--	--	--[b]
Cyanamid CY292	1-3	400,000 MW	--	--	--[b]
Cyanamid Cy-Guard 382	0.5-10	10,000 MW	--	--	--[b]
Cyanamid P-26	0.5-10	150,000 MW	--	--	--[b]
Cyanamid 5300	0.5.5	15 MW	--	--	R
Cyanamid Magnafloc 834A	0.5-10	High molecular weight (18 m)	--	R	R
Cyanamid Magnafloc 837A	0.5-10	High molecular weight (15 m)	--	R	--
Cyanamid Magnafloc 1820	0.5-10	High molecular weight (18 m)	--	R	--
Visco 741	0.5-5	15-20 million MW	--	--	R
Visco 743	0.5-5	10-15 million MW	--	--	N

[b]Dispersed.

TABLE 5-3. (continued).

Coagulant or flocculant	Amount added, ppm	Description	Effect on turbidity at indicated site[a] West Hackberry	Bayou Choctaw	Bryan Mound
Visco 3340	0.1-10	Long-chained, high molecular weight (15-20 m)	E	E	R
Tretolite FR-52	1-20	--	--	--	--[b]
Nonionics					
Cyanamid Cyfloc 4500	0.02-5	Long-chained, high molecular weight (15 m); used with alum, 3317, and 3340	E	N	E
Cyanamid Magnafloc 985N	0.1-10	Long-chained, high molecular weight	R	N	R
Cyanamid Magnafloc 990N	0.5-10	Medium molecular weight (4 m)	N	--	N
Mixed Polyethylene Amines	0.5-20	Low molecular weight	N	--	--
Polyglcol P.400	0.5-20	Low molecular weight	N	--	--

TABLE 5-4. Effects of polymer molecular weight on membrane filter (0.4 μ) flow rates.[a]

Polymer	Molecular weight	Charge	Flow rate, ℓ/min, after 30-minute test
Magnafloc 4500	15-20 m	Nonionic	0.067
Visco 3340	15-20 m	Anionic	0.056
Visco 742	15-20 m	Cationic	0.080
Magnafloc 990	4 m	Nonionic	0.067
Visco 3364	1 m	Cationic	0.118
Visco 3345	100,000	Cationic	0.100
Cyguard 294	80,000	Anionic	0.100
Carbowax 14,000	14,000	Nonionic	0.100
Blank (Ultrafiltered brine)	-	-	0.155

[a]0.005 mg/ℓ of polymer was used in each run; 0.4 μ Nuclepore membrane filters were used; and all polymers are polyacrylamide or copolymer polyacrylic acid.

TABLE 5-5. Recommended granular media clarification systems for SPR sites.

Site	Chemical additive	Concentration, mg/ℓ	Chemical Type	Media construction	Comments
West Hackberry	Alum, $Al_2(SO_4)_3 \cdot 14H_2O$	3	Inorganic Al salt	Triple media (coal, sand, garnet) or dual media (coal, sand)	1. Less alum is required during periods of strong brine flow. 2. Straining without chemicals is sometimes effective.
Bayou Choctaw[a]	Visco 3340	2-4	Anionic polymer	Triple media (coal, sand, garnet)	1. Polymer does not work in presence of oil contamination. 2. Dual media filter is effective, but at a lower total throughput. 3. During periods of strong brine injection, alum may be necessary in place of Visco 3340.
Bryan Mound[a]	Alum + Cyfloc 4500	10 + 0.2	Inorganic Al salt + nonionic polymer	Triple media (coal, sand, garnet)	

[a]Ultrafiltration without chemical aids was tested at these sites and was as effective and less sensitive to changing brine conditions.

TABLE 5-6. West Hackberry SPR pilot filter runs in ponded brine.[a]

Run	Date	Filtration method[b]	Chemical feed, mg/ℓ	Head loss rate, ft H_2O/hr	Effluent turbidity, NTU	Influent turbidity, NTU
A-1	1/6/79	Single media	None	0.40	0.20	1.36
B-1	1/6/79	Dual media	None	0.10	0.20	1.36
C-1	1/6/79	Triple media	None	0.15	0.18	1.36
D-1	1/9/79	Triple media	5.0 Alum	1.12	0.02	1.05
C-2	1/10/79	Triple media	0.5 Alum	0.35	0.31	0.35
D-3	1/10/79	Triple media	2.0 Alum	0.98	0.15	1.0
B-2	1/10/79	Dual media	3.0 Alum	0.94	0.09	1.33
C-3	1/10/79	Triple media	3.0 Alum	0.89	0.11	1.33
D-4	1/10/79	Triple media	3.0 Alum	1.17	0.11	1.33
B-3	1/11/79	Dual media	1.0 Alum	0.52	0.18	1.73
C-4	1/11/79	Triple media	1.0 Alum	0.75	0.16	1.73
D-4	1/11/79	Triple media	0.03 Cyfloc 4500N	0.25	0.84	1.73
A-2	1/13/79	Single media	None	0.65	1.2	7.68
B-4	1/13/79	Dual media	4.0 Alum	1.07	0.21	7.68
C-5	1/13/79	Triple media	4.0 Alum	1.32	0.15	7.68
D-5	1/13/79	Triple media	0.15 Cyfloc 4500N	1.82	0.22	7.55
C-6	1/14/79	Triple media	None	0.88	1.5	7.73
D-6	1/14/79	Triple media	3.0 Alum	0.94	0.19	7.13
B-5	1/14/79	Dual media	1.0 Calgon M580	0.65	1.0	4.4

[a]Brine density = 1.177 g/cc; Cl^- = 180,000 ppm.

[b]Filter media compositions: Single media--silica sand
Dual media--silica sand, anthracite coal
Triple media--silica sand, anthracite coal, garnet.

TABLE 5-7. Particle count results at West Hackberry.

Date	Source/run[a]	Chemical treatment	Counts/mℓ at indicated particle size		
			>1 μm	1-5 μm	5-10 μm
1/9/79	Pond input	-	461	364	43
	Pond output	-	793	658	107
	B-1 effluent	-	241	233	8
	C-1 effluent	-	126	118	6
	D-1 effluent	5 ppm Alum	34	33	1
1/10/79	Pond input	-	692	577	91
	Pond output	-	2063[b]	1249	550
	B-2 effluent	3 ppm Alum	258	239	17
	C-3 effluent	3 ppm Alum	281	252	28
	D-4 effluent	3 ppm Alum	295	268	24
1/11/79	Pond input	-	556	460	75
	Pond output	-	2089	1097	623

[a]Keyed to run numbers in Table 5-6.

[b]Counts >1000 are subject to coincidence errors. Actual counts are higher.

TABLE 5-8. Bayou Choctaw SPR pilot filter runs.

Run	Date	Brine type	Filtration method[a]	Chemical feed mg/ℓ	Head loss rate, ft H_2O/hr	Effluent turbidity, NTU	Influent turbidity, NTU
A-1	1/26/79	Strong[b]	Dual media	None	0.22	1.63	1.61
A-2	1/27/79	Diluted strong[c]	Dual media	None	0.30	1.98	1.9
B-1	1/27/79	Diluted strong	Dual media	25.0 Alum	0.32	1.9	1.9
UF-1	1/29/79	Leach[d]	Ultrafilter	None	--	0.12	18.0
C-1	1/30/79	Leach	Triple media	None	0.47	4.4	5.2
D-2	1/31/79	Leach	Triple media	4.0 Visco 3340 + 4.0 Cl_2	0.36	0.84	8.6
C-5	2/2/79	Leach	Triple media	2.0 Visco 3340 + 0.5 Magnafloc 507C	1.28	0.25	17.5
Al-1	2/1/79	Leach	Dual-A-media	2.0 Visco 3340	1.4	0.24	10.0
D-3	2/1/79	Leach	Triple media	2.8 Visco 3340	0.79	0.23	10.0
B-2	2/1/79	Leach	Dual media	2.0 Visco 3340 + 1.0 Alum	1.53	1.47	9.3
C-3	2/1/79	Leach	Triple media	2.0 Visco 3340 + 3.0 Alum	1.72	1.35	10.0

[a]Filter media compositions: Dual media--anthracite coal, silica sand
Dual-A-Media--anthracite coal, garnet
Triple media--Anthracite coal, silica sand, garnet

[b]Strong brine density = 1.196 g/cc; Cl^- 188,000 ppm.

[c]Strong diluted brine = 90% strong + 10% Cavern Lake water (unclarified).

[d]Leach brine density = 1.173 g/cc.

TABLE 5-9. Particle count results at Bayou Choctaw (Prototron Spectrex Model ILI 1000).[a]

Source	Chemical treatment	Date	Counts/mℓ at indicated particle size					
			>1 µm	1-5	5-10	10-15	15-20	20-25
Ponded strong brine (SB)	-	1/25/79	834	687	120	23		-
SB	-	1/27/79	935	812	126	13		-
Injection site	-	1/27/79	1069[a]	817	219	31		-
Weak brine (WB)[b]	-	1/29/79	1546	939	389	189		-
WB	-	1/30/79	2145	1079	680	199	83	50
WB	-	1/30/79	2204	1071	724	235	90	46
WB vendor's site	-	1/31/79	1928	1315	424	115	47	18
WB	-	2/2/79	2093	1271	591	142	54	22
Cavern Lake (CL)	-	1/30/79	2127	1194	709	167	41	12
Clarified CL (CCL)	80 mg/ℓ Alum + 0.1 mg/ℓ Am. Cyan. 985N	1/30/79	486	447	27	4	2	2
9:1 SB/CCL	-	1/30/79	1742	1250	323	101	<35	<17
9:1 SB/CCL B-1 filter[c] effluent	6 mg/ ℓAlum	1/30/79	79	70	5	2	<1	<1
9:1 SB/CCL B-1 filter effluent	12 mg/ℓ Alum	1/30/79	778	704	68	4	1	<1
WB-C-1-filter effluent	-	1/30/79	1738	1257	333	94	31	15
WB-D-1-filter effluent	4 mg/ℓ Visco 3340	1/30/79	135	131	4	<1	<1	<1
WB-D-2-filter effluent	4 mg/ℓ Visco 3340	1/31/79	72	64	4	1	<1	<1

[a]Counts >1000 are subject to coincidence errors. Actual counts are higher.

[b]Same as leach brine.

[c]Filter run numbers keyed to Table 5-8.

Table 5-9. Continued

Source	Chemical treatment	Date	Counts/mℓ at indicated particle size					
			>1 µm	1-5	5-10	10-15	15-20	20-25
Baker filter effluent	Yes	1/31/79	116	180	8	3	2	2
C. E. Natco filter effluent	Yes	1/31/79	34	26	4	2	1	<1
L'Eau Claire filter effluent	Yes	1/31/79	46	37	5	2	1	<1
L'Eau Claire effluent	Yes	2/2/79	53	49	3	<1	<1	<1
WB-Al-1-filter effluent	2 mg/ℓ Visco 3340	2/1/79	32	27	3	1	<1	<1
WB-Al-1-filter effluent	Same + 3 hours	2/1/79	170	151	11	3	2	<1
WB-Al-1-filter effluent	Same + 5 hours	2/1/79	50	42	4	2	1	<1
WB-D-3-filter effluent	2 mg/ℓ Visco 3340	2/1/79	152	134	10	3	2	2
WB-D-3-filter effluent	Same + 25 hours	2/2/79	157	156	<1	<1	<1	<1
WB-D-3-filter effluent	Same + 27 hours	2/2/79	39	35	3	<1	<1	<1
WB-D-3-filter effluent	Same + 28 hours	2/2/79	17	16	<1	<1	<1	<1
WB-B-2-filter effluent	2 mg/ℓ Visco 3340 + 1 mg/ℓ Alum	2/1/79	820	697	96	15	6	3
WB-C-3-filter effluent	2 mg/ℓ Visco 3340 + 3 mg/ℓ Alum	2/1/79	800	711	75	7	3	2
WB-C-4-filter effluent	2 mg/ℓ Visco 3340	2/2/79	59	56	1	<1	<1	<1
WB-C-5-filter effluent	2 mg/ℓ Visco 3340 + 0.5 mg/ℓ Magnafloc 507C	2/2/79	24	23	<1	<1	<1	<1
WB-Ultrafilter effluent	-	1/29/79	36	26	4	-	-	-
WB-Ultrafilter effluent	Same + 22 hours	1/30/79	54	48	5	1	<1	-
Deionized water	-	2/1/79	200	178	11	3	2	2
Bottled drinking water	-	2/1/79	11	9	1	<1	<1	1

TABLE 5-10. Bryan Mound SPR pilot filter runs in strong ponded brine.[a]

Run	Date	Filtration method[b]	Chemical feed, mg/ℓ	Head loss rate, ft H_2O/hr	Effluent turbidity, NTU	Influent turbidity NTU
C-1	2/23/79	Triple media	None	0.36	1.1	9.5
D-1	2/23/79	Triple media	None	0.29	1.2	9.5
UF-1	2/24/79	Ultrafilter	None	–	0.10	8.0
D-2	2/24/79	Triple media	3.0 Visco 3340	0.33	0.32	8.0
C-2	2/24/79	Triple media	None	0.32	0.71	8.0
UF-2	2/25/79	Ultrafilter	None	–	0.12	11.9
C-3	2/25/79	Triple media	None	0.33	1.40	11.9
D-3	2/25/79	Triple media	4.0 Visco 3340	0.52	0.69	11.9
UF-3	2/25/79	Ultrafilter	None	–	0.13	11.9
D-4	2/26/79	Triple media	3.0 Visco 3340	0.53	1.05	15.3
C-4	2/26/79	Triple media	None	0.32	1.54	15.3
D-5	2/26/79	Triple media	2.0 Visco 3317 + 2.0 Visco 3340	0.44	0.73	15.3
UF-4	2/27/79	Ultrafilter	None	–	0.13	14.8
C-5	2/27/79	Triple media	None	0.33	1.01	14.8
D-7	2/27/79	Triple media	10.0 Alum + 0.2 Cyfloc 4500N	0.85	0.18	14.8
D-8	2/28/79	Triple media	10.0 Alum + 0.2 Cyfloc 4500N	1.56	0.18	14.8

[a]Strong ponded brine density = 1.191 g/cc Cl^- ~190,000 ppm.

[b]Triple-media construction: anthracite coal, silica sand, garnet.

TABLE 5-11. Particle count results at Bryan Mound (Prototron Spectrex Model ILI 1000).

Source	Chemical treatment	Date	Counts/mℓ at indicated particle size >1 µm	1-5	5-10	10-15	15-20	20-25
Cavern 5 brine[a]	-	2/25/79	1176	868	251	44	7	2
Cavern 5 brine[a]	-	2/27/79	677	589	72	11	2	1
Cavern 4 brine[a]	-	2/27/79	431	381	41	6	1	<1
Ponded brine	-	2/23/79	2143[b]	1307	694	122	14	3
Ponded brine	-	2/24/79	1856	1139	580	114	15	3
Ponded brine	-	2/25/79	2000	1086	697	173	32	7
Ponded brine	-	2/25/79	2195	1186	778	192	29	6
Ponded brine	-	2/26/79	2093	1110	747	183	40	9
Ponded brine	-	2/27/79	2222	1006	854	277	66	15
Ponded brine	-	2/28/79	2000	1277	604	100	15	3
Ponded brine	-	2/28/79	2169	1038	812	255	53	9
Brine at injection site	-	2/26/79	2093	1014	792	224	53	9
Ultrafilter effluent	-	2/24/79	11	9+	1+	<1	<1	<1
Ultrafilter effluent	-	2/25/79	9	7+	<1	<1	<1	<1
Ultrafilter effluent	-	2/26/79	32	27	2+	1	<1	<1
Ultrafilter effluent	-	2/27/79	130	91	22	11	2	1
Ultrafilter effluent	-	2/27/79	96	88	6+	1	<1	<1

[a]Diluted 10% to prevent salt precipitation.

[b]Counts >1000 are subject to coincidence errors. Actual counts are higher.

TABLE 5-11. (continued).

Source	Chemical treatment	Date	Counts/mℓ at indicated particle size					
			>1 µm	1-5	5-10	10-15	15-20	20-25
A-column effluent[c]	-	2/24/79	634	600	28	4	1	<1
C-2-column effluent[c]	-	2/24/79	460	444	12	3	<1	<1
C-3-column effluent[c]	-	2/25/79	1000	856	100	26	7	3
C-4-column effluent[c]	-	2/26/79	918	818	65	21	5	3
C-5-column effluent[c]	-	2/28/79	63	61	1+	<1	<1	<1
C-5-column effluent[c]	-	2/28/79	77	73	2+	<1	<1	<1
D-2-column effluent[c]	3 ppm Visco 3340	2/24/79	466	446	15	4	1	<1
D-3-column effluent[c]	4 ppm Visco 3340	2/25/79	200	175	13	7	2	1
D-5-column effluent[c]	2 ppm Visco 3340 + 2 ppm Visco 3317	2/26/79	295	282	8	5	<1	<1
D-7-column effluent[c]	10 ppm Alum + 0.2 ppm Cyfloc 4500N	2/27/79	575	432	98	28	7	4
D-7-column effluent[c]	Same + 3 hours	2/27/79	8	6	<1	<1	<1	<1
D-8-column effluent[c]	10 ppm Alum + 0.2 ppm Cyfloc 4500N	2/28/79	6	5	<1	<1	<1	<1
River water	-	2/24/79	2338	701	917	410	191	70
Bottled deionized water	-	2/23/79	73	69	2+	<1	<1	<1

[c]Filter run numbers keyed to Table 5-10.

TABLE 5-12. Theoretical settling parameters.

Particle diameter, micron	Particle specific gravity	Theoretical settling velocity, cm/sec	Theoretical overflow rate, gal/d/ft^2	Theoretical settling area required	
				ft^2	acres
1	2.1	1.6×10^{-7}	0.0034	3.1×10^{9}	70,896
1	2.9	3.0×10^{-7}	0.0064	1.6×10^{9}	37,664
5	2.1	4.0×10^{-6}	0.0851	1.2×10^{8}	2,833
5	2.9	7.5×10^{-6}	0.1596	6.6×10^{7}	1,510
10	2.1	1.6×10^{-5}	0.3404	3.1×10^{7}	708
10	2.9	3.0×10^{-5}	0.6383	1.6×10^{7}	378

TABLE 5-13. Cartridge filter system comparisons.[a,b]

Parameter	Value at all sites
Granular filters:	
Estimated number of assemblies	24
Total area required for equipment, ft^2	4,400
Estimated cost of assembly	$534,000
Ultrafiltration:	
Estimated number of assemblies	25
Total area required for equipment, ft^2	1,240
Estimated cost of assembly	$1,898,000
Ronnigen Petter (disposable cartridge filter):	
Estimated number of assemblies	4
Total area required for equipment, ft^2	1,120
Estimated cost of assembly	$360,000
CUNO (disposable cartridge filters):	
Estimated number of assemblies	4
Total area required for equipment, ft^2	1,120
Estimated cost of assembly	$390,000

[a]Main piping and three supply pumps to pump the water through any of the above filter systems is estimated to cost approximately $60,000.

[b]To optimize manufacturing capabilities, the same size assembly is shown at each location. Although the reported flows are different at the three indicated locations, the difference between them is not great enough to cause a problem in using the same size plant.

TABLE 5-14. Comparative data for fabricated in-place filters.

Parameter	Value with gunite liner	Value with impervious plastic liner
Filter depth, ft	9	9
Filter bottom dimensions, ft	18 × 18	18 × 18
Plan area including outside edge of berms, ft^2	10,472	23,504
Earth volume required for berms, yd^3	2,490	5,620
Estimated costs:		
Earth work	$20,000	$45,000
Liner work	$15,000	$9,000
Total filter basin cost	$35,000	$54,000
Piping and equipment[a]	$255,000	$255,000
Total cost[a]	$290,000	$309,000

[a]Excludes costs of installing piping and equipment.

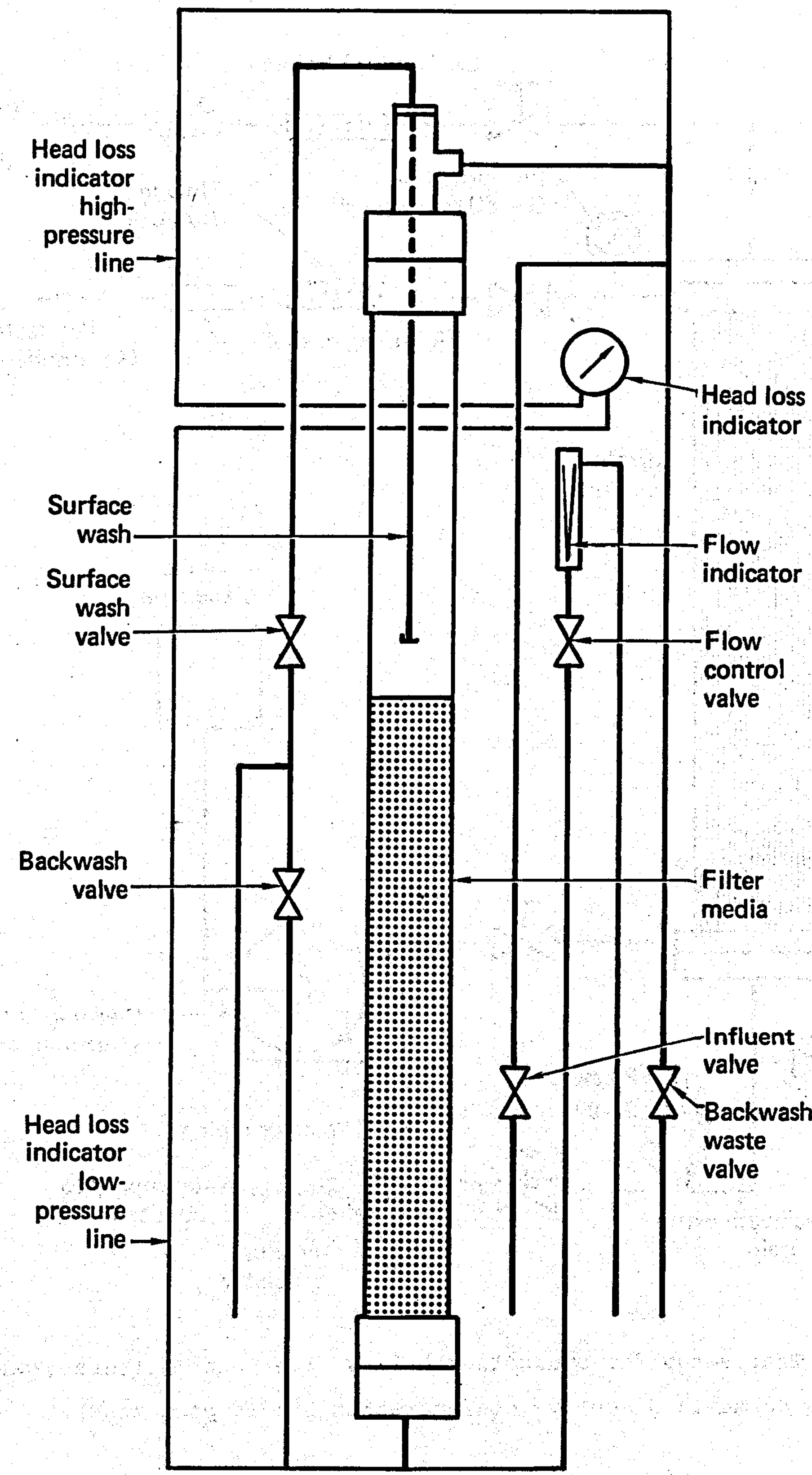


FIG. 5-1. Schematic diagram of the 4-inch-diameter pilot filter.

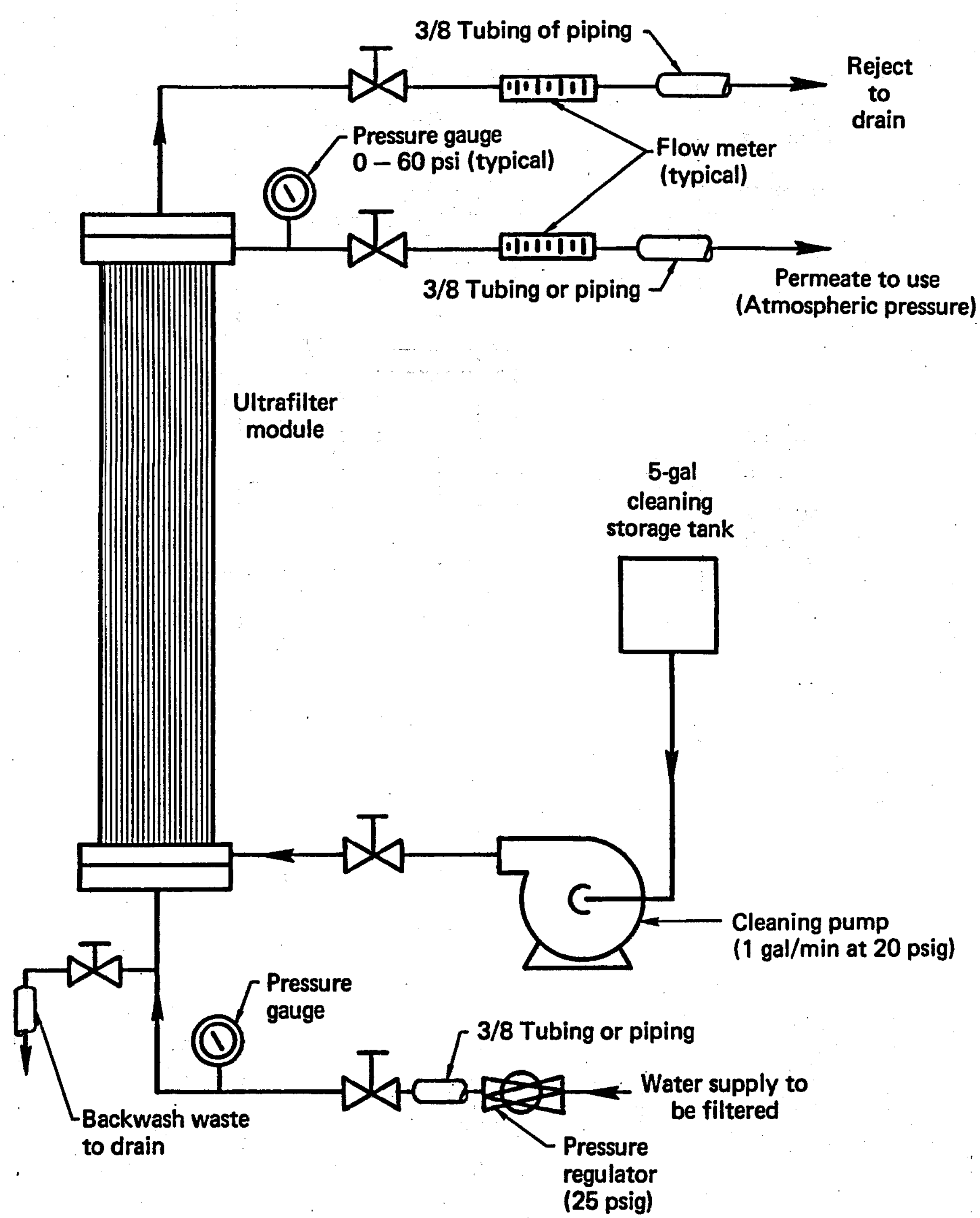


FIG. 5-2. Test setup for evaluating hollow fiber ultrafilters (Model 8001 CUF atmospheric permeate discharge configuration single-pass mode).

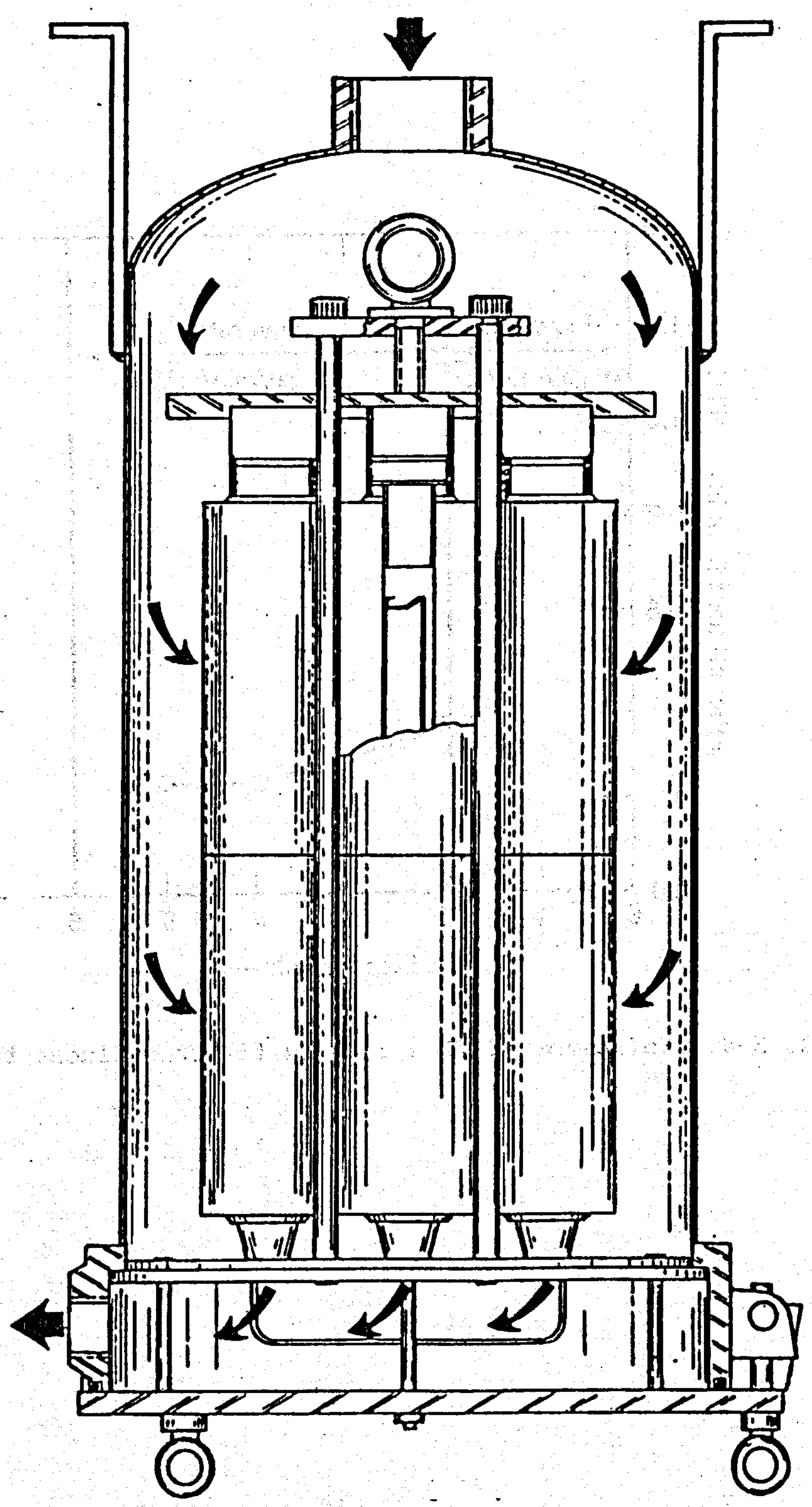


FIG. 5-3. Test setup for evaluating cartridge-type filters.

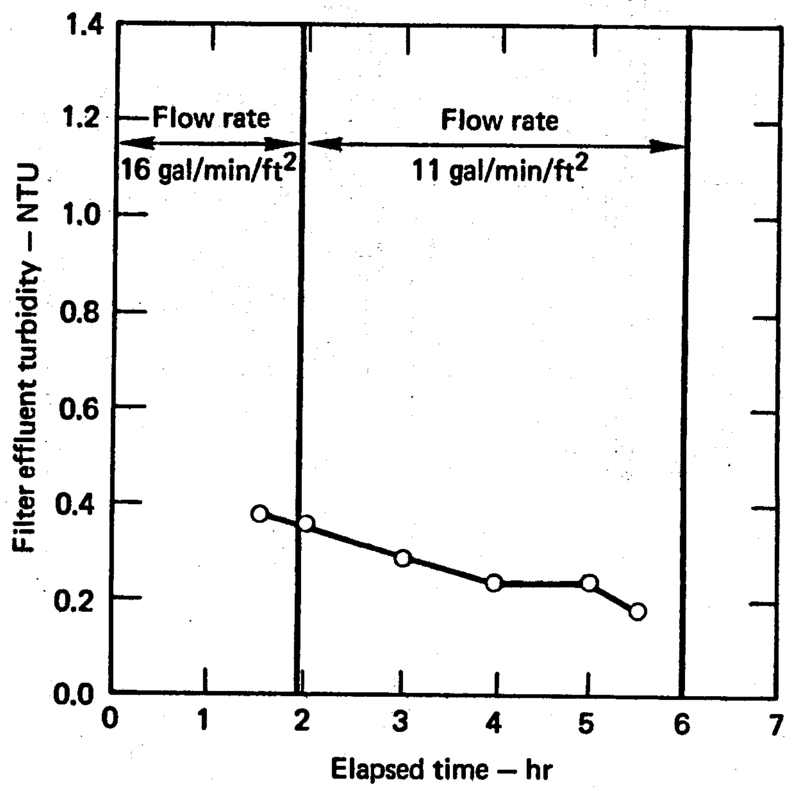


FIG. 5-4. Influence of flow rate on filter effluent turbidity.

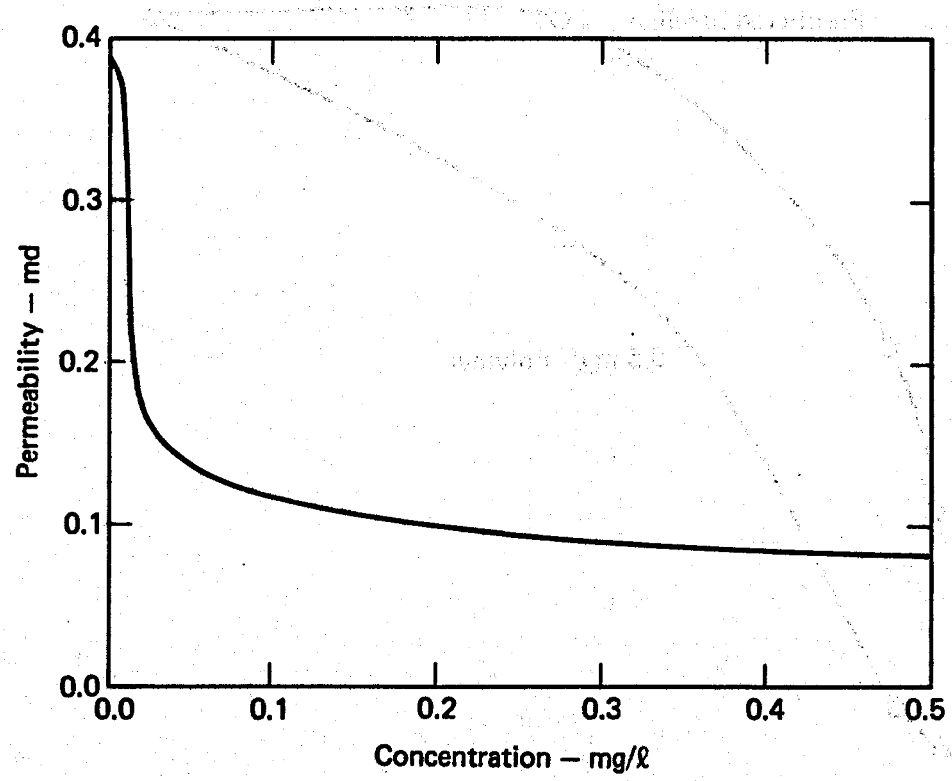


FIG. 5-5. Effect of residual polymer concentration on permeability (after 30 minutes of flow) of 0.4 μm Nuclepore membrane filters.

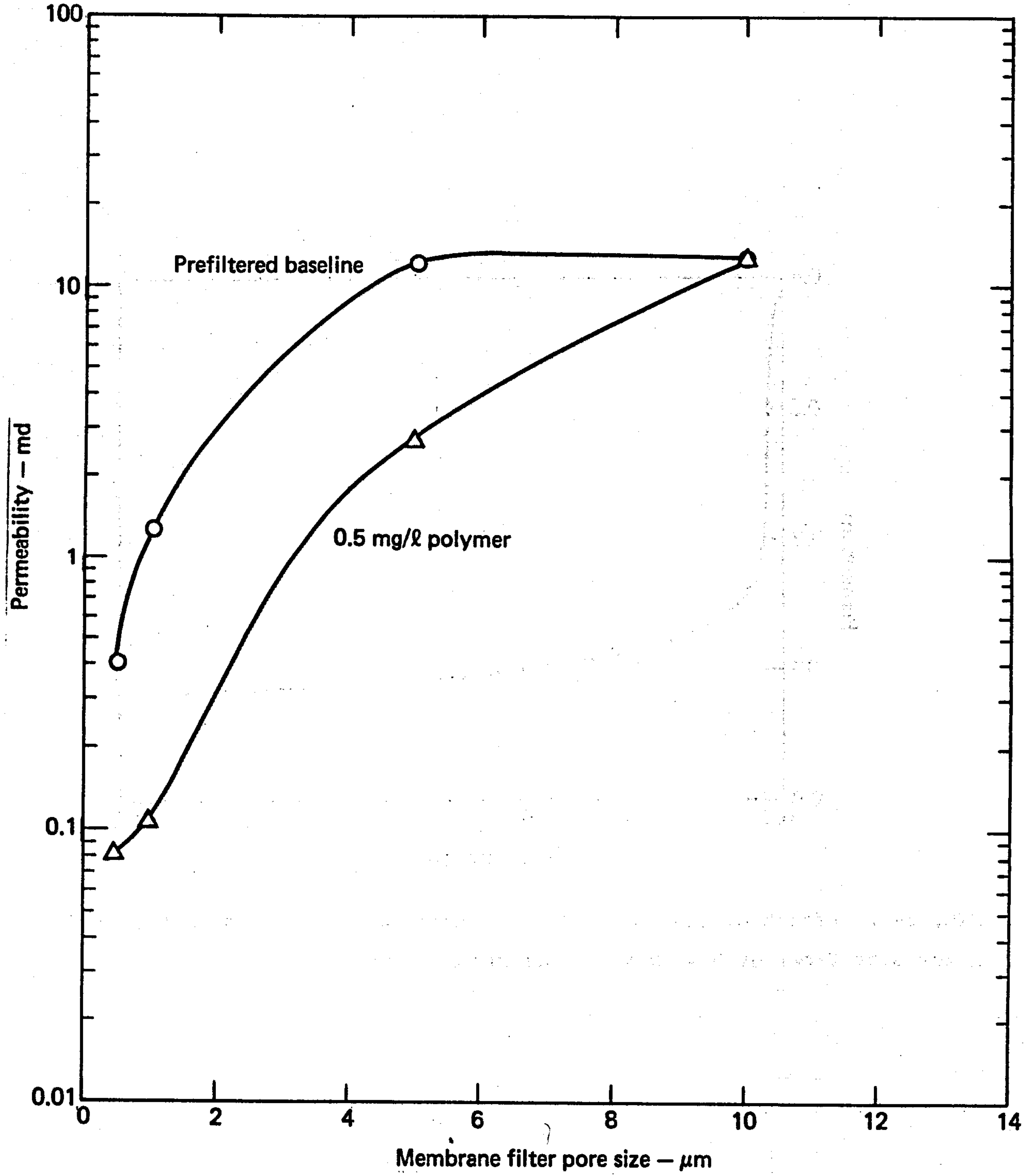


FIG. 5-6. Effect of 15 M amionic polymer (after 30 minutes of flow) on the permeability of various pore size membrane filters.

Settling: 60 ppm alum and 0.2 ppm 4500

Volume, ℓ	Time, min	Flow rate, ℓ/min
0.200	0.40	0.500
0.400	0.80	0.500
0.600	1.20	0.500
0.800	1.60	0.500
1.000	2.00	0.500
1.200	2.40	0.500
1.400	2.90	0.400
1.600	3.30	0.500
1.800	3.70	0.500
2.000	4.40	0.286
2.200	4.80	0.500
2.400	5.30	0.400
2.600	5.70	0.500
2.800	6.20	0.400
3.000	6.80	0.333
3.200	7.50	0.286
3.400	8.40	0.222
3.600	9.60	0.167
3.800	11.40	0.111
4.000	13.50	0.095

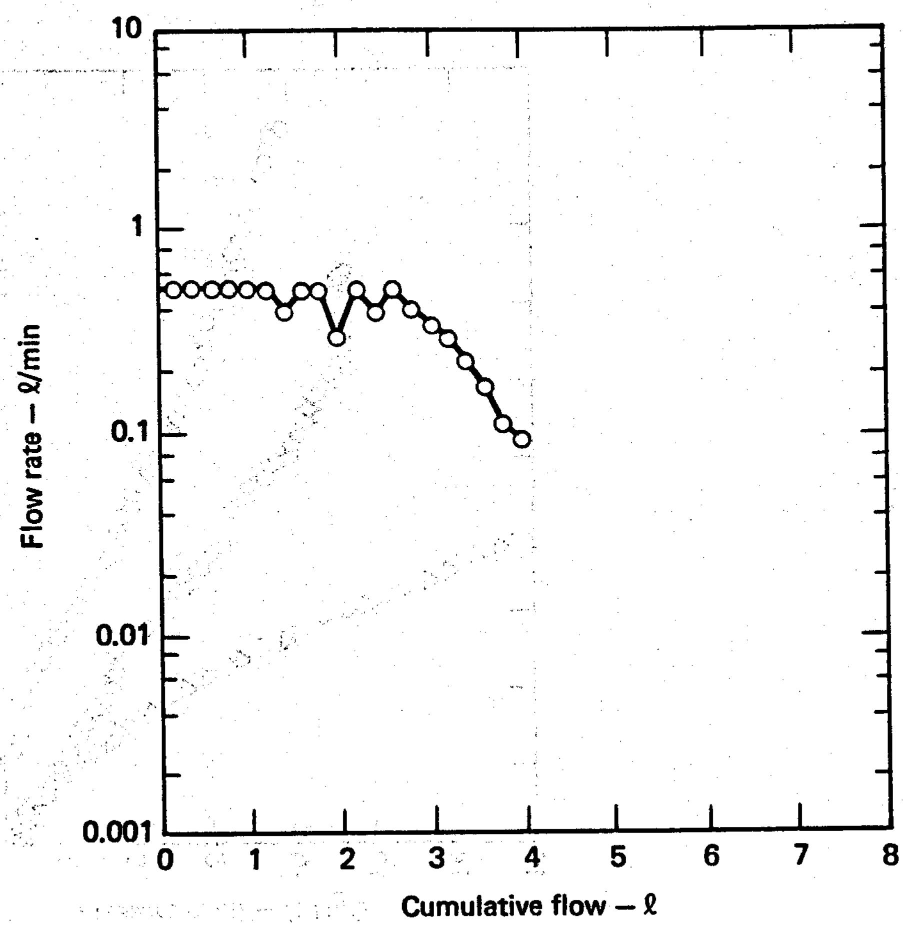


FIG. 5-7. SPR membrane filtration test data for Run L-30 on March 27, 1979 (ΔP = 8 psi; filter size = 10 μm).

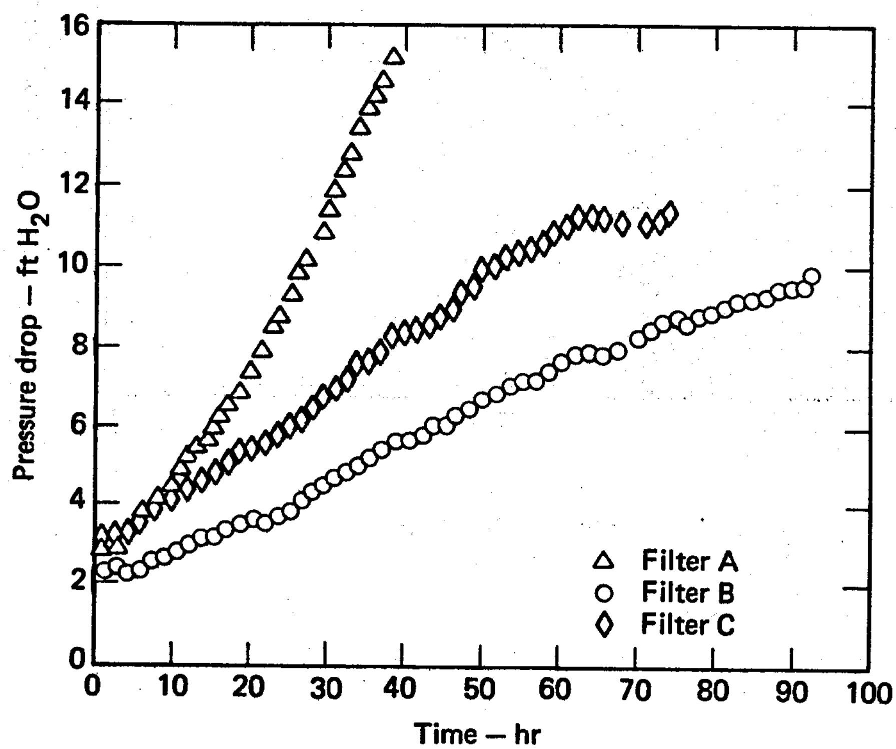


FIG. 5-8. Head loss versus time in downflow filters at the West Hackberry SPR site.

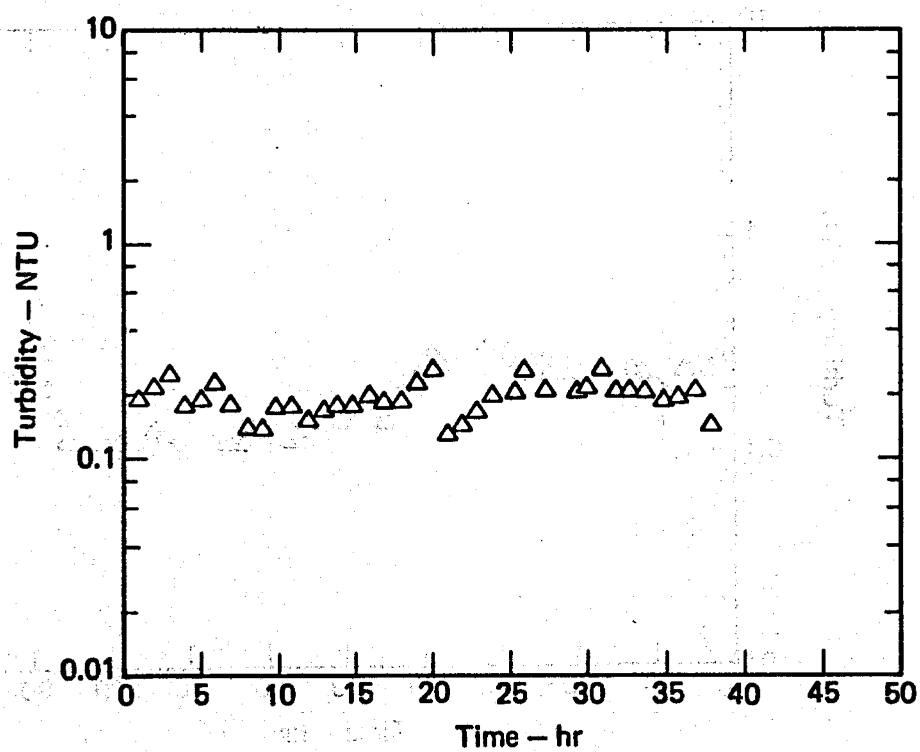


FIG. 5-9. Downflow filter effluent turbidity for Filter A at the West Hackberry SPR site.

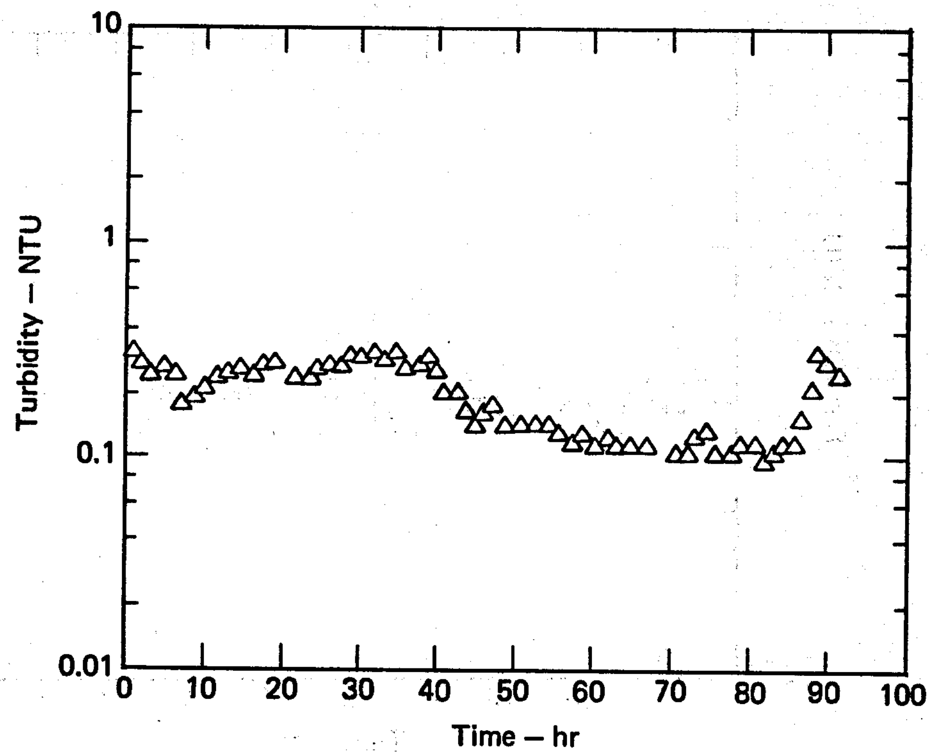


FIG. 5-10. Downflow filter effluent turbidity for Filter B at the West Hackberry SPR site.

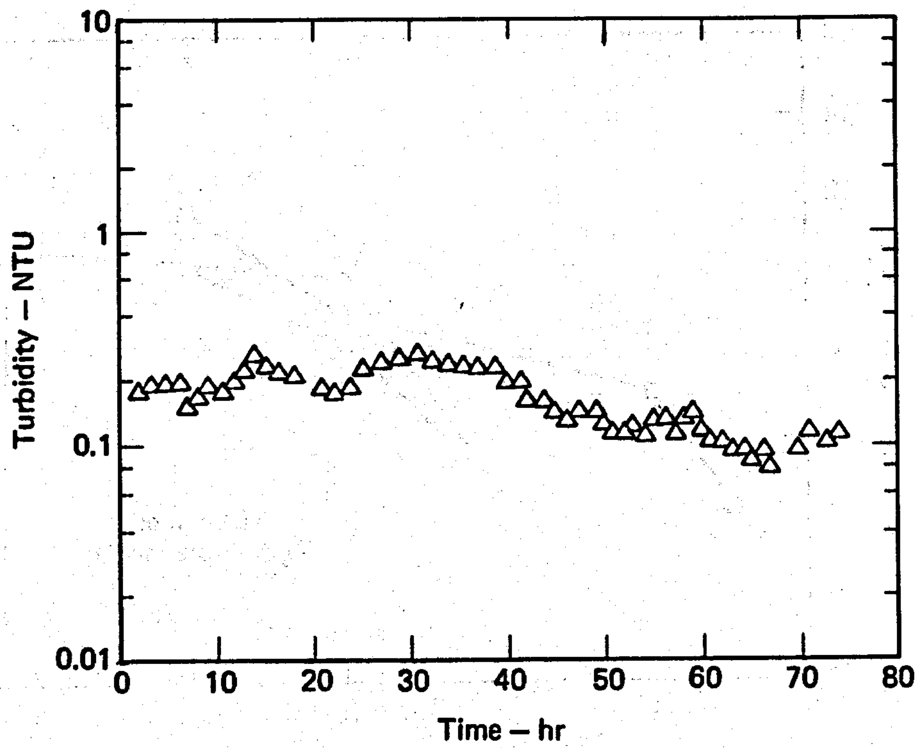


FIG. 5-11. Downflow filter effluent turbidity for Filter C at the West Hackberry SPR site.

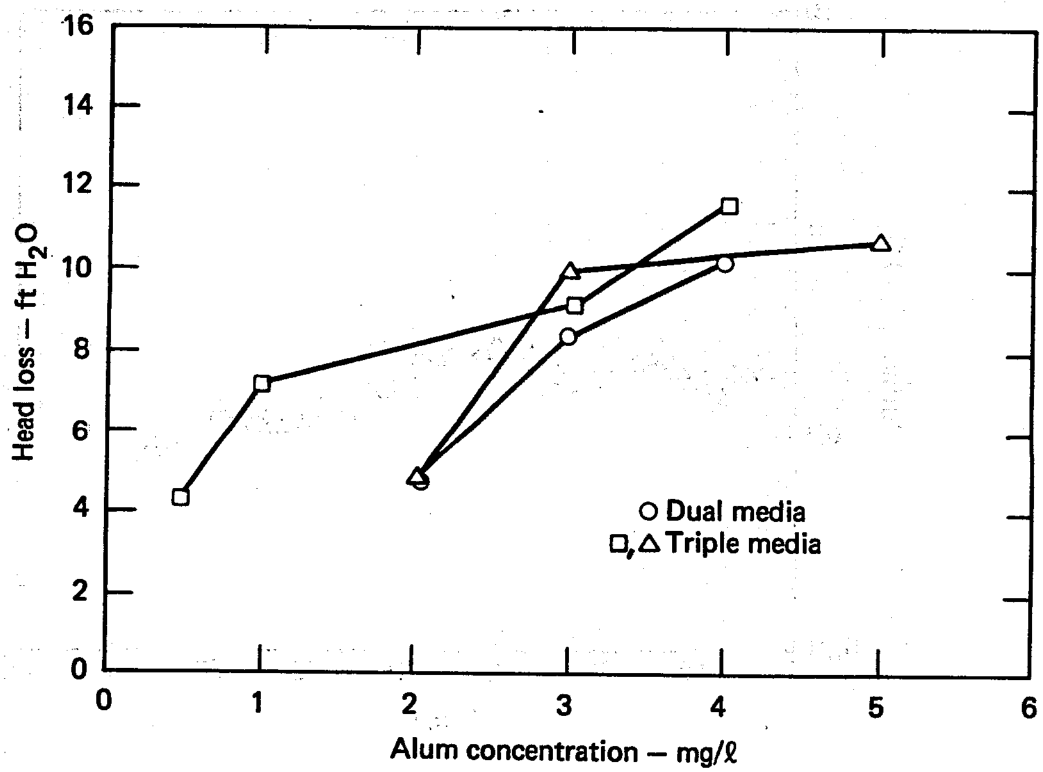


FIG. 5-12. Effect of alum concentration on head loss after 10 hours of granular media filtration.

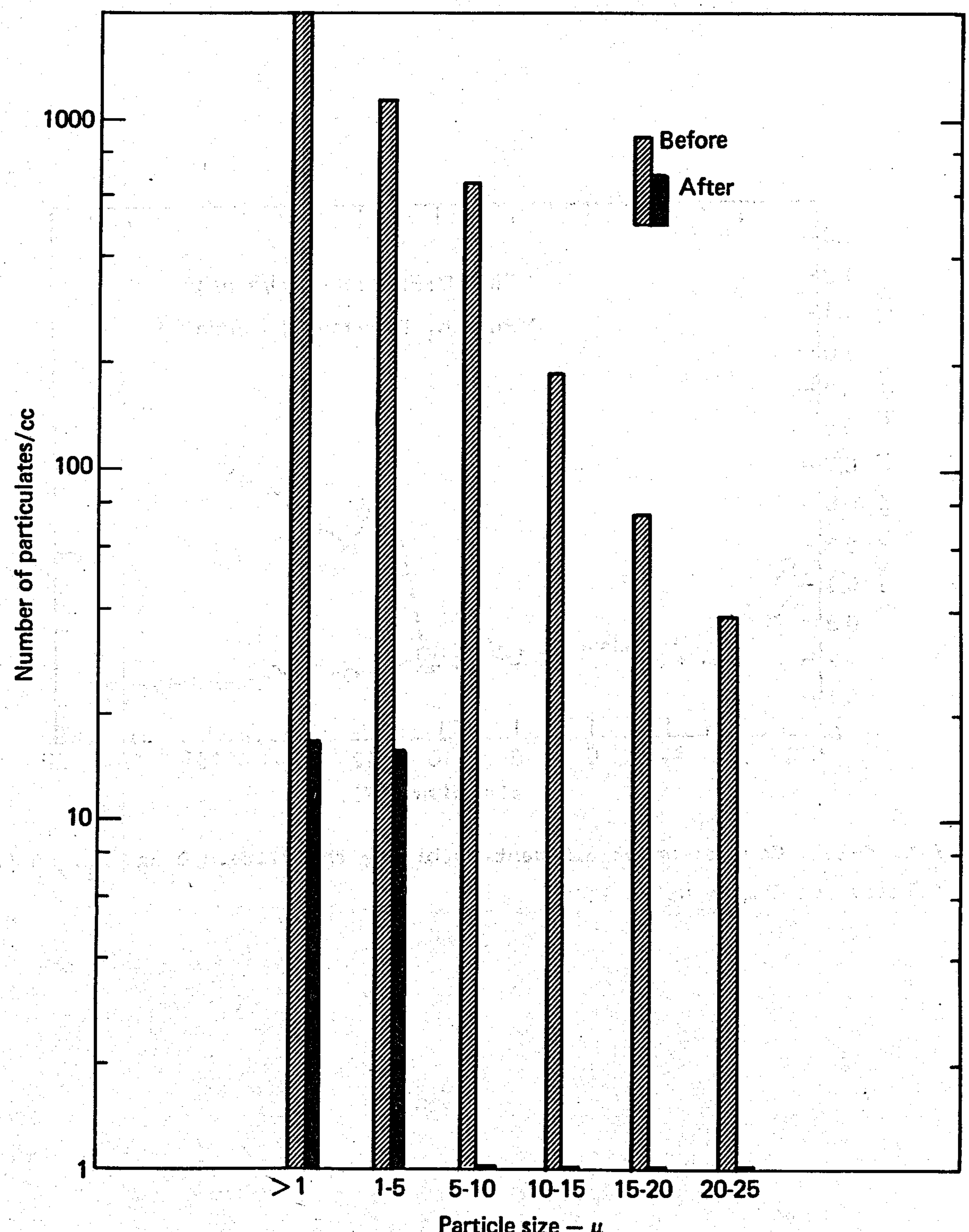


FIG. 5-13. Change in particle size distribution in leach brine at Bayou Choctaw by granular media filtration (Run D-3).

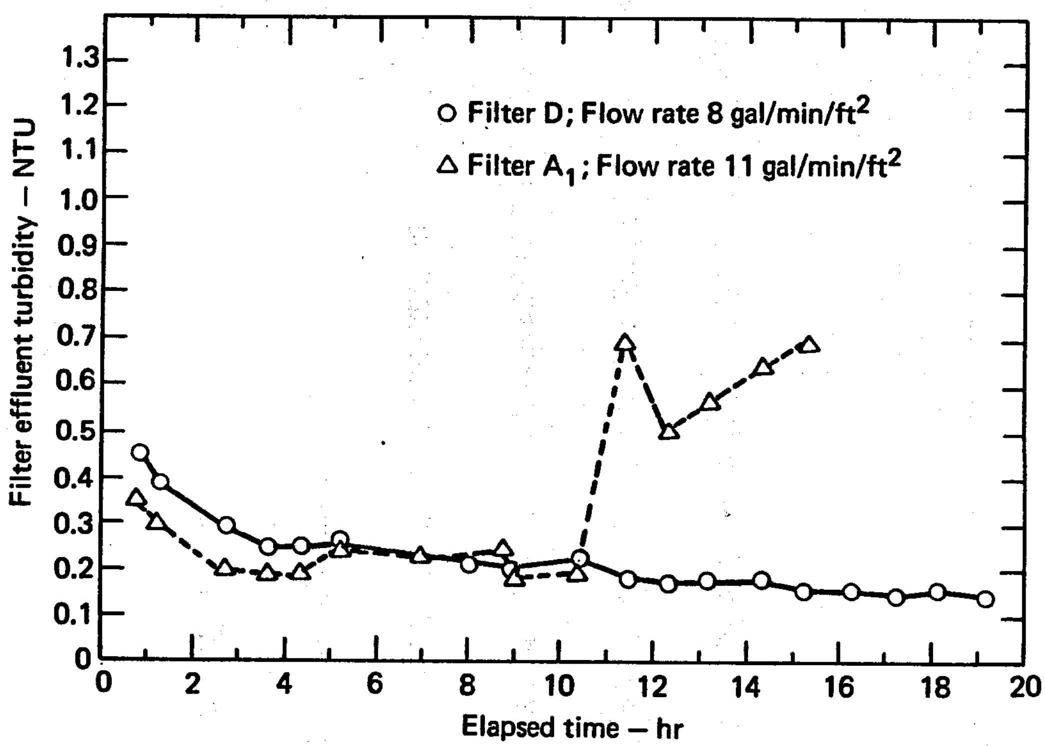


FIG. 5-14. Comparison of effluent turbidity for Filters D and A_1. Both filters use 2 mg/ℓ Nalco 3340.

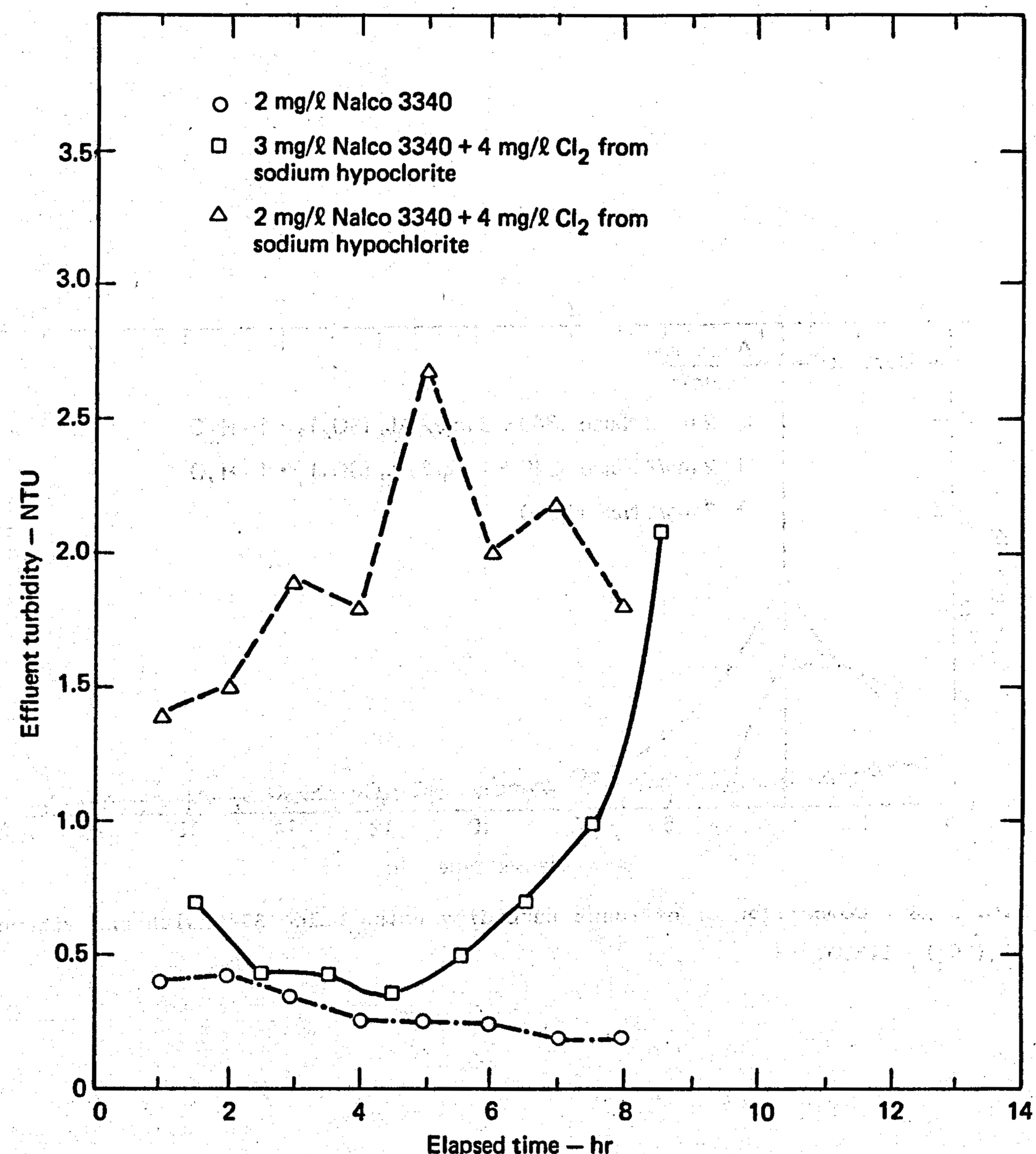


FIG. 5-15. Comparison of filter effluent turbidity using Nalco 3340 with and without Cl_2.

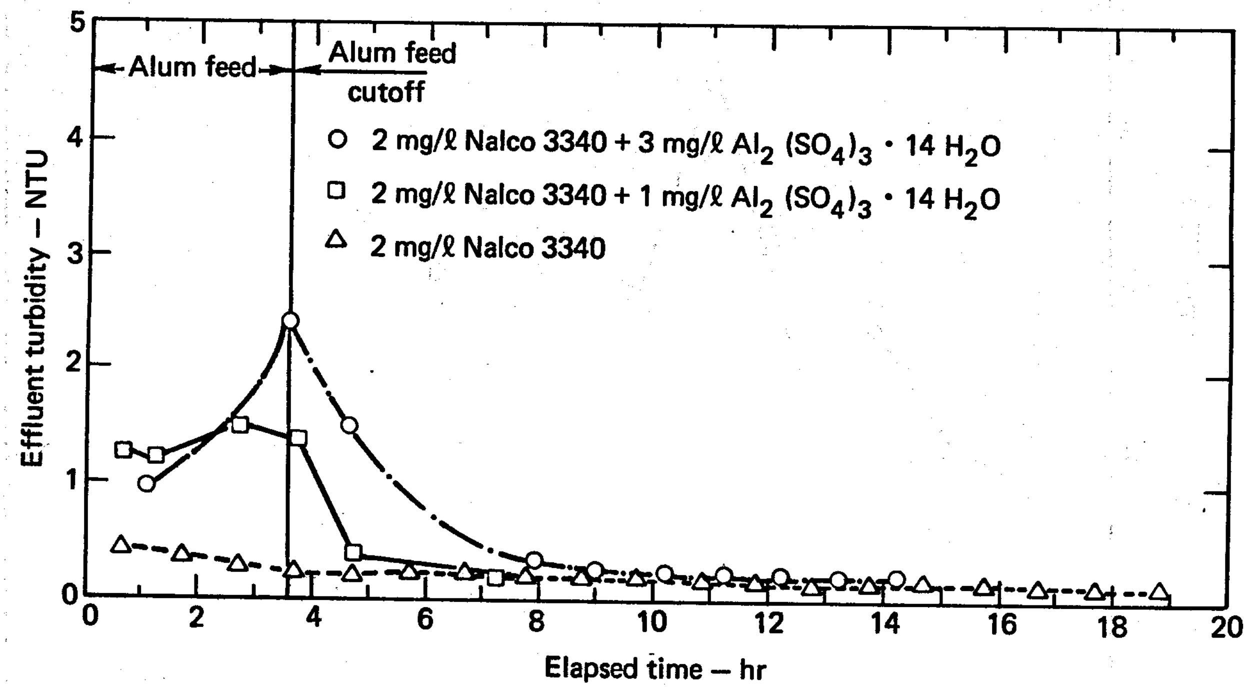


FIG. 5-16. Comparison of effluent turbidity using Nalco 3340 with and without $Al_2(SO_4)_3 \cdot 14H_2O$.

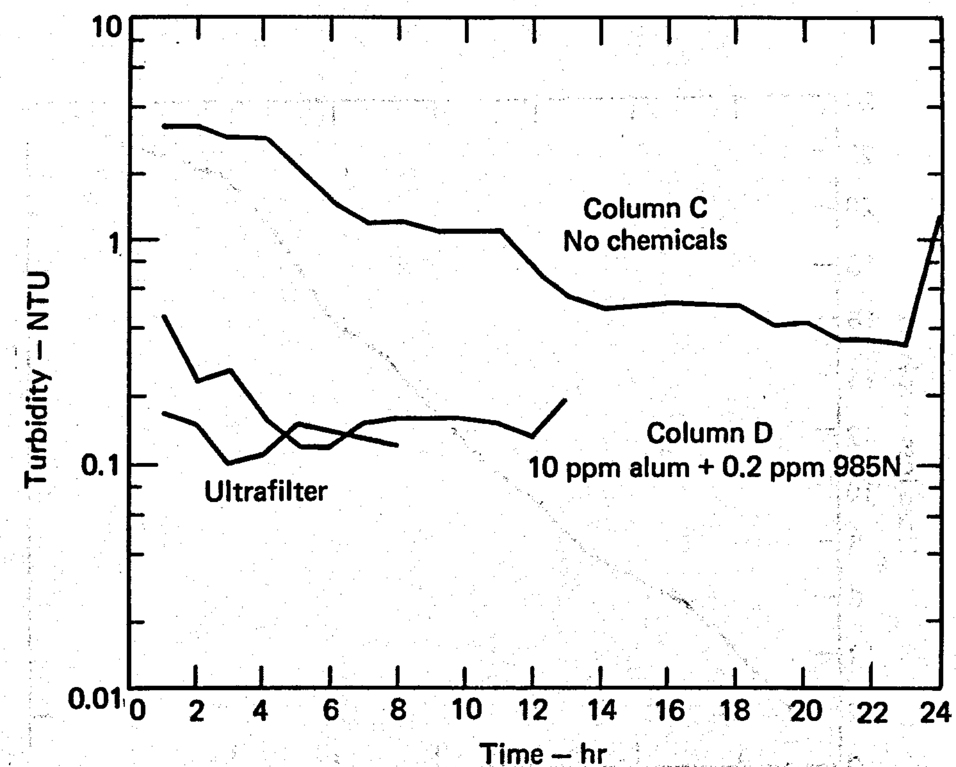


FIG. 5-17. Filtered brine turbidity at the Bryan Mound SPR site.

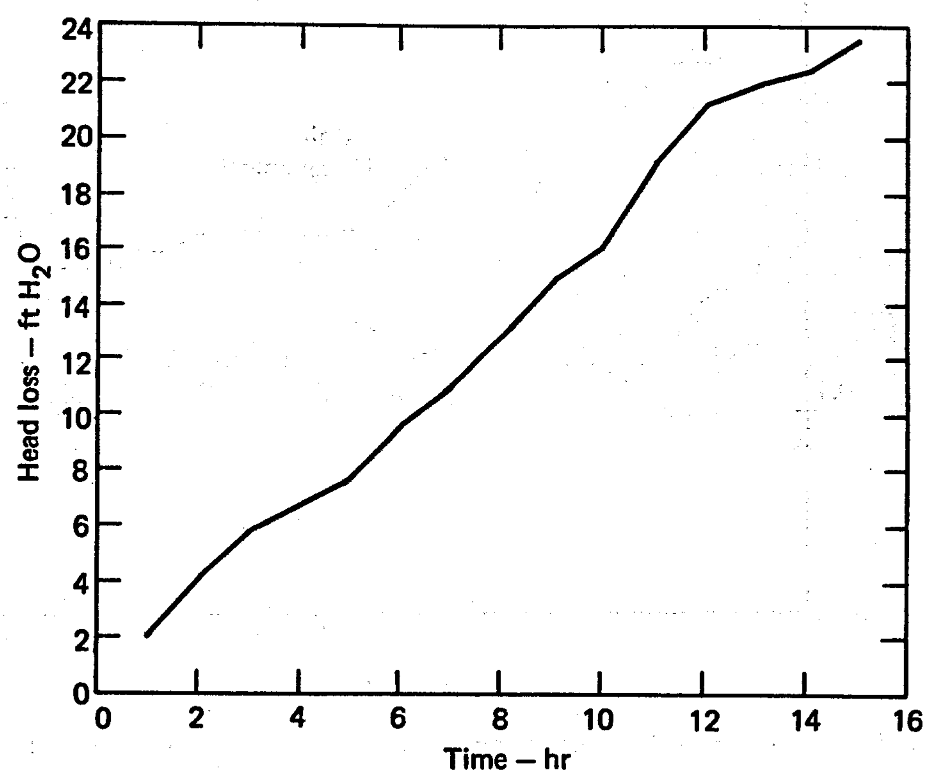


FIG. 5-18. Column D head loss (10 ppm alum and 0.2 ppm 985N) at the Bryan Mound SPR site.

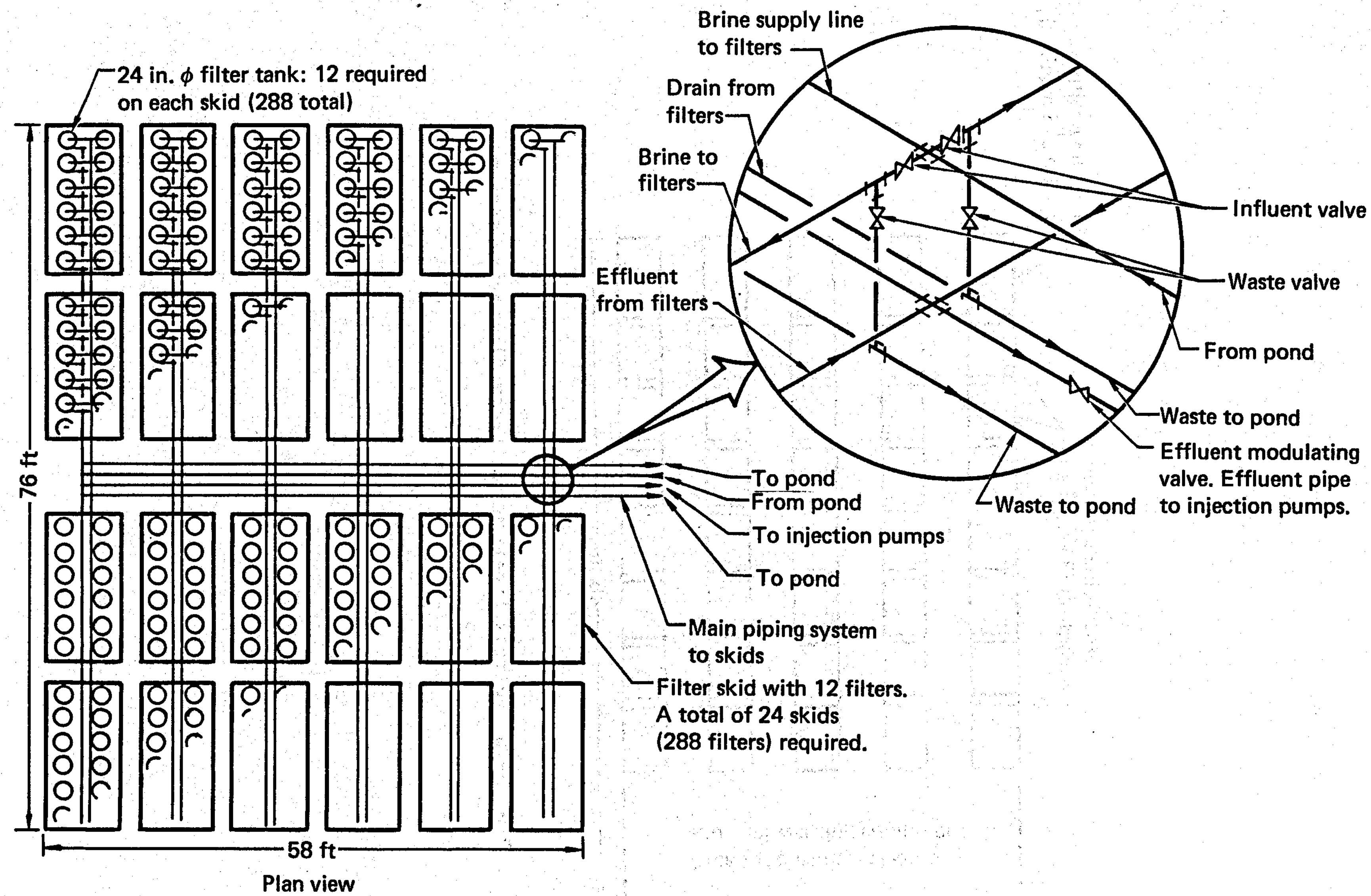


FIG. 5-19. Granular media cartridge filtration system.

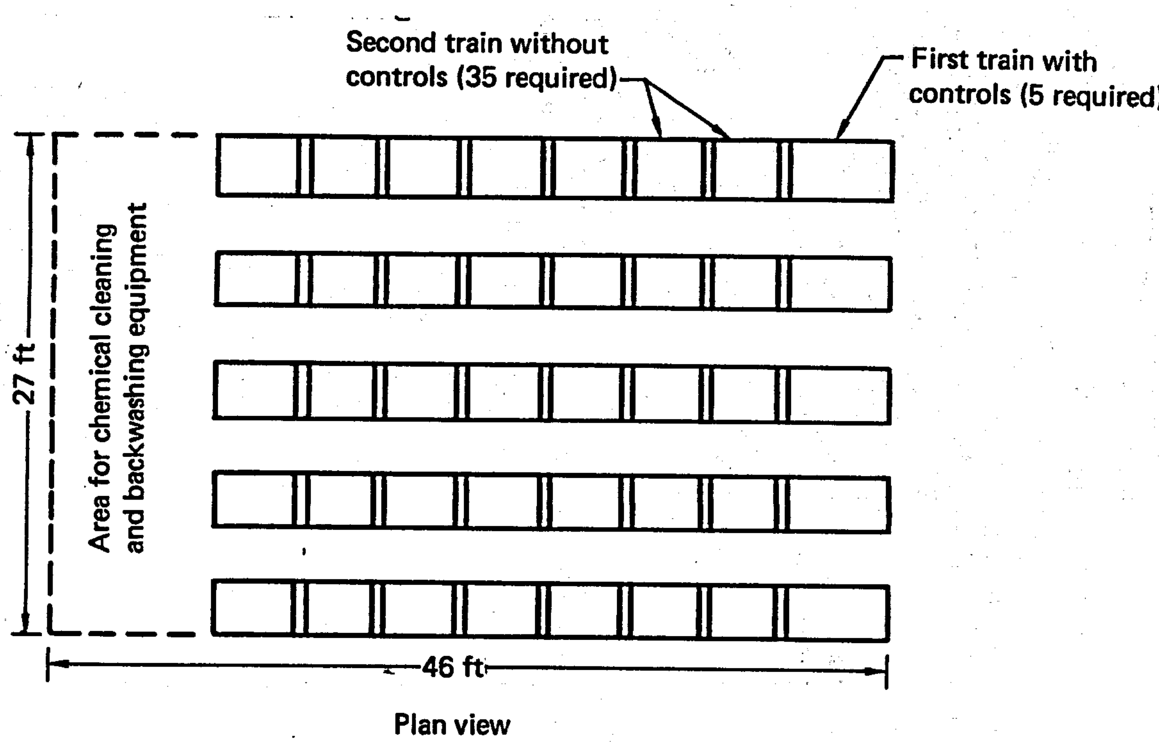


FIG. 5-20. Ultrafiltration cartridge filtration system.

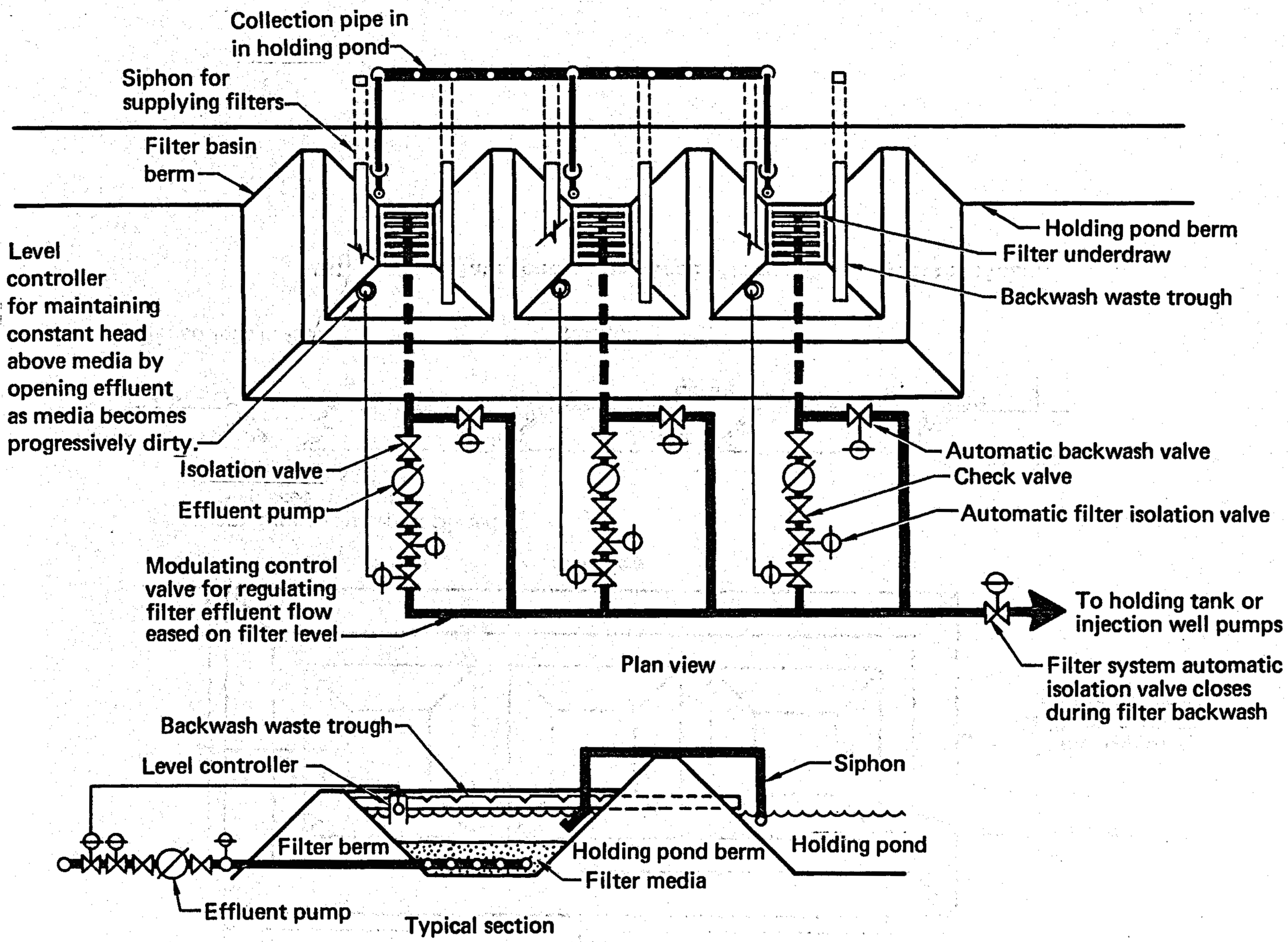


FIG. 5-21. Flow schema of fabricated in-place filters.

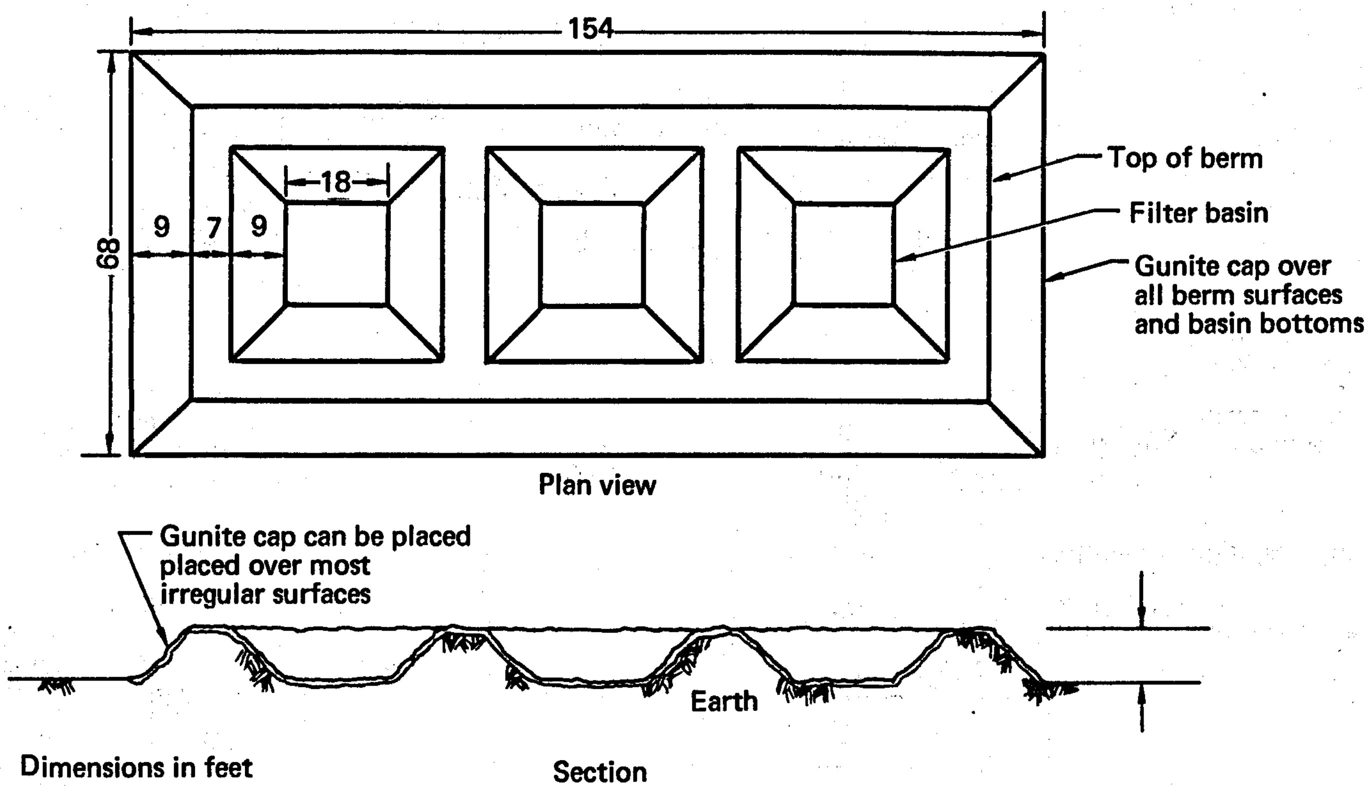


FIG. 5-22. Fabricated in-place filters with gunite liner.

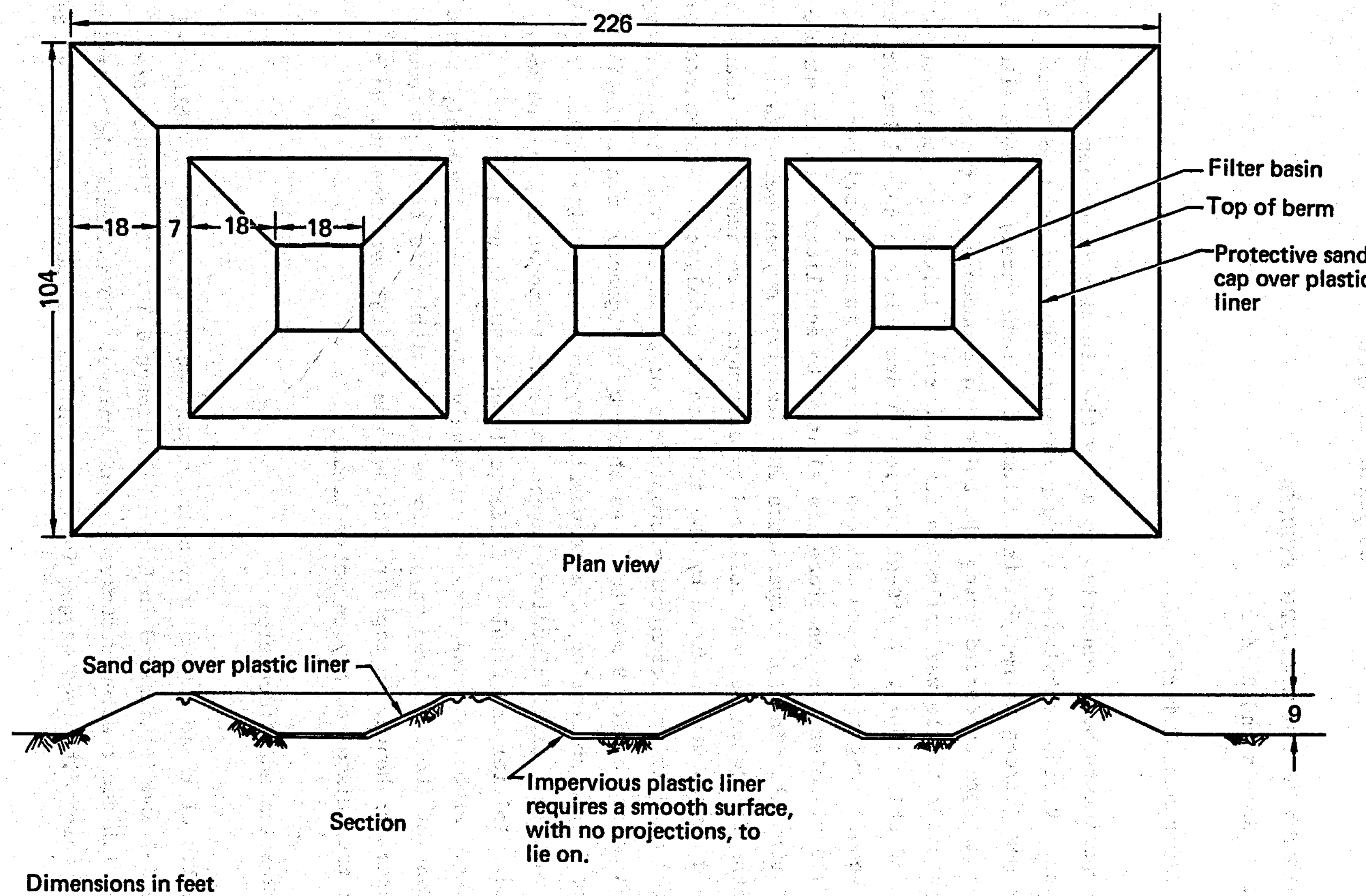


FIG. 5-23. Fabricated in-place filters with impervious plastic liner.

CHAPTER 6

CORROSION CONTROL

6.1 OXYGEN SCAVENGING KINETIC STUDIES

K. G. Knauss and R. Lim

6.1.1 Experimental Technique

Bench experiments were conducted to study the kinetics of oxygen scavenging reactions. Various catalyst-scavenger combinations were used to treat the water types (strong brine, diluted brine, and fresh water) at each site. All experiments were conducted using the following procedure. A fresh, representative sample was collected for each run. Initial pH was measured on a split of this sample. A 250-ml sample was drawn into a 400-ml beaker for the scavenging experiment and stirred slowly on a magnetic stirrer. A YSI Model 5739 dissolved oxygen probe was allowed to equilibrate in the sample for about 4 minutes. Initial temperature and dissolved oxygen were measured, and then catalysts (when needed) followed by scavenger were added. No change in dissolved oxygen was produced by the addition of catalysts. Scavengers were delivered quickly by mechanical micropipette or syringe. The dissolved oxygen was then monitored for 9 minutes. As shown by Montgomery et al. (1964),[33] there is little absorption of atmospheric oxygen on this time scale. At the end of each run, final dissolved oxygen content, temperature, and pH were recorded. Initial and final pH differ only when SO_2 is used as a scavenger. Probe response time is relatively slow. Typically, only about 90 percent of the dissolved oxygen is detected within the first 10 seconds of a measurement; hence, in rapid reactions, the initial measurements do not reflect true dissolved oxygen activities.

6.1.2 Results and Discussion

The results of these oxygen scavenging experiments are given in Tables 6-1 through 6-7 and illustrated in Figs. 6-1 through 6-15. The figures are plotted with uncorrected dissolved oxygen values. To estimate the relative speed at which dissolved oxygen is being consumed, a factor R is defined as the ratio of dissolved oxygen at 0 time to that present at time equal to 1 minute. These R values are included as the last column in each table. In assessing the relative merits of one catalyst-scavenger combination versus another, however, one must also consider the final dissolved oxygen content achieved at the end of each experiment. Figure 6-15 illustrates this point. In Section 6.1.3, the relative applied dosages is given in terms of stoichiometric amounts. In this sense, the stoichiometric dosage is the quantity of scavenger, determined by the coefficients of the balanced chemical equations, required to consume all the dissolved oxygen in the sample solution.

6.1.2.1 West Hackberry. The strong brine at the West Hackberry site produced the following results:

1. The applied dosages of about 1.7 times stoichiometric with SO_2 and 0.1 ppm of Cu or Co catalyst work quite well.
2. The applied dosgaes of about two to three times stoichiometric with Na_2SO_3 and 0.2 ppm of Cu or Co work well.
3. The uncatalyzed scavengers react much more slowly.
4. Increased dosage does not improve reaction rate nearly as well as using a lower dosage with catalyst.
5. Doubling the amount of catalyst with SO_2 scavenger does not significantly improve reaction rate.
6. Increasing the reaction temperature 10 deg C does not improve the reaction rate of uncatalyzed SO_2 reaction nearly as much as adding catalyst.
7. Commercial scavengers K477 and K490 do not work very well at recommended dosage rates. The Visco scavenger works well at several times the stoichiometric requirement.
8. Experiments were conducted using prefiltered brine to check for induced precipitation with Na_2SO_3 plus scavengers. Subsequent filtering with 0.4-micron membrane filters produced no detectable solids.
9. The applied SO_2 dosages do not lower pH prohibitively.

6.1.2.2 Bayou Choctaw. The strong brine at the Bayou Choctaw site produced the following results:

1. The applied dosages of 1.8 (SO_2 + catalyst), 2.0 (Na_2SO_3 + catalyst), and 3.0 (K494) times the stoichiometric amounts will all remove oxygen reasonably well.

2. The addition of catalyst improves reaction rate during the first minute, but uncatalyzed runs remove a comparable amount of dissolved oxygen by the end of the experiment.

The weak brine at the Bayou Choctaw site produced the following results:

1. The use of approximately 1.5 times the stoichiometric dose of SO_2 works satisfactorily with or without catalysts. Doubling the dose improves the rate considerably, but the pH is lowered to unacceptable values (about 5.2).
2. The results with Na_2SO_3 at comparable dosages produced similar results, i.e., no catalyst needed. However, increased dosages have no effect on pH.
3. A dosage rate of 1.9 times stoichiometric for K494 worked about as well as the other scavengers.

The fresh water at the Bayou Choctaw site (cavern lake) produced the following results:

1. The SO_2 will not remove dissolved oxygen even at twice the stoichiometric requirement with or without catalyst.
2. Na_2SO_3 scavenger at 1.8 times stoichiometric dosage plus Co catalyst is effective, whereas a 3.6 times dosage is required with Cu catalyst.
3. Dosages of K494 at one and two times stoichiometric do not work.

6.1.2.3 Bryan Mound. The strong brine at the Bryan Mound site produced the following results:

1. The applied dosages of 1.6 (SO_2), 1.8 (Na_2SO_3), and 1.8 (K494) times the stoichiometric amounts will remove dissolved oxygen reasonably well.
2. Unlike the other SPR sites under similar conditions, neither Co nor Cu catalyst significantly improves the reaction rate, nor is one catalyst to be preferred over the other. The applied SO_2 dosage does not lower pH prohibitively.

The strong brine with river water dilution produced the following results at Bryan Mound:

1. In terms of effectiveness in removing oxygen with scavenger-catalyst combinations, there is little difference between this brine and the results on the strong brine. It should be noted that this dilute brine (as defined by density) was observed to exist for only part of one day

(February 27, 1979) and amounted to a dilution of about 5 percent with fresh water. The experiments to study the kinetics of oxygen scavenging on this diluted brine were conducted on that day; yet the characteristics with respect to oxygen are identical to those obtained with strong brine.

The fresh water (river water) at Bryan Mound produced the following results:

1. Even at 2.7 times the stoichiometric dosage, SO_2 would not effectively scavenge dissolved oxygen utilizing Co catalyst. This inability of SO_2 to remove oxygen from the fresh water source was also observed at Bayou Choctaw.
2. With Na_2SO_3 scavenger at 1.2 times the stoichiometric dosage plus Co catalyst, the dissolved oxygen was effectively removed. At this Na_2SO_3 dosage, the Cu-catalyzed and uncatalyzed experiments showed little or no oxygen removal.
3. At 1.2 times the recommended dosage, K494 did not remove oxygen.

6.1.3 Conclusion

If it is determined that oxygen scavenging is required to prevent injection problems, then it should be possible to standardize this procedure at all three SPR sites. It appears that for treating strong or weak brines, SO_2 (with 0.1 ppm Co catalyst at West Hackberry and Bayou Choctaw) at a dosage rate of 1.5 or more times the stoichiometric requirement will work reasonably well. The use of SO_2 also has the advantage of being the most cost-effective solution to the problem.

6.2 IN-LINE TESTS OF OXYGEN SCAVENGERS

R. Quong, F. E. Locke, and W. P. Frey

6.2.1 Effect of Dissolved Oxygen

An important consideration in the assessment of brine injectability is the corrosiveness of the fluid. The type and rate of corrosion are important in determining equipment integrity over time and ultimate replacement expenses. Corrosion also results in the production of particulate products that find their way into the brine as suspended solids, thereby reducing brine injectability. In the presence of dissolved oxygen, the problem is greatly magnified because of increased corrosion rates--saline waters containing dissolved oxygen are highly corrosive, requiring the scavenging of dissolved oxygen. In the disposal pipelines and injection wells, an equilibrium corrosion rate is established, resulting in a continuous influx of corrosion products into the brine stream. This particulate matter adds significantly to the total mass of solid material deposited in the wellbore and reservoir. Assuming a disposal rate of 150,000 bbl/d of brine containing 1 ppm dissolved oxygen (Section 6.2.2.2) that reacts with iron to form magnetite, a solids production rate of 228 lb/d is possible. This is equivalent to 3.6 ppm suspended solids, which would sometimes be more than double the normal particulate concentration. The implication of uncontrolled corrosion is that an injection well would eventually become impaired due to the deposition of solids in the wellbore.

As described in Section 6.1, many measurements were made in the LLL mobile laboratory at the three sites to determine the effectiveness of various conventional scavenging compounds and catalysts in reducing dissolved oxygen concentration to an acceptable level in a reasonable amount of time.

6.2.2 Corrosion and Oxygen Scavenging Test Apparatus

Since pipeline corrosion rates are strongly dependent on fluid velocity, the best combination derived from the bench-scale tests was tested in a sidestream piping system where flow velocities equal to those in the disposal lines could be produced (i.e., 150,000 bbl/d in a 24-in.-dia pipeline equals a velocity of 3 ft/sec).

The sidestream measurements were made at West Hackberry and Bayou Choctaw. Although functionally analogous, the experimental hardware at the two sites was different. At Bayou Choctaw, a 28-ft^3 pipe section was included to allow time for the scavenging reaction to proceed to completion. We had no prior knowledge of scavenging rates in Bayou Choctaw strong brines and could not be sure that equipment modifications could be implemented within the 12-day test period; therefore, a conservative allowance of 7 minutes was provided for reaction time. For the West Hackberry work, which preceded that at Bayou Choctaw, time did not permit inclusion of a hold-up volume (which as it turns out was not necessary).

Basically the measurements were completed in a length of 2-in. pipe connected to a brine source provided by the low-pressure injection pumps. The brine passing through the apparatus was discharged back into the surge pond. Petrolite Instrument Corporation 3-electrode corrosion probes and automatic corrosion rate recorders were used to measure in-line corrosion rates. The electrodes were made of A106B steel to simulate pipe steel. At West Hackberry, the corrosion probes were installed upstream of the scavenger-catalyst injection point and at points 50 and 100 feet downstream, representing 17 and 33 seconds of reaction time, respectively, at a flow velocity of 3 ft/sec. Figure 6-16 is a schematic diagram of the corrosion and oxygen scavenging test setup at West Hackberry. At Bayou Choctaw, the two downstream probes were located side by side following the reaction vessel as shown in Fig. 6-17. A Signet Corporation sensor and recording system was used for flow measurements. The sensor, which utilized a fully submersed paddle wheel arrangement, performed well.

6.2.2.1 Dissolved Oxygen Scavenger. The bench-scale kinetic measurements (Section 6.2.1) showed that SO_2 (used as H_2SO_3) with a copper ($CuCl_2 \cdot H_2O$) catalyst performed as well if not better than the other combinations tested for scavenging oxygen. The combination of SO_2 and copper is probably the most cost-effective method in large applications. The only possible disadvantages are (1) pH reduction by the reaction

$$SO_2 + H_2O + \frac{1}{2} O_2 = SO_4^{=} + 2H^+,$$

which would increase brine corrosiveness, and (2) reduction of Cu^{++} and plating out on steel surfaces setting up galvanic corrosion sites.[14] If this should be a problem, Co^{++} (which was also effective in bench measurements) or possibly nickel could be substituted as catalysts.

The in-line scavenging measurements were conducted by injecting SO_2 and a 0.1 percent by weight Cu^{++} solution directly into the brine stream. The feed rates were regulated to provide sufficient SO_2 for oxygen removal and 0.1 mg Cu^{++} per liter of brine. At both sites, daily ambient temperatures fluctuated as much as 25 deg C requiring heating and insulation of the scavenging chemical feed system to keep SO_2 cylinder pressures above line pressure and at a reasonably constant value for control purposes. Weatherproofing also prevented SO_2 from condensating in the feed lines and $CuCl_2$ solution from freezing.

6.2.2.2 Test Results. Run times were at least 24 hours to allow corrosion rates to level off to a stable value as measured by the Petrolite probes. The results of the West Hackberry and Bayou Choctaw measurements are summarized in Table 6-8. Table 6-8 also includes baseline measurements without chemical scavenger additions and also data at somewhat higher brine velocities. These measurements clearly show that removal of dissolved oxygen is extremely important in reducing the corrosiveness of the brine. The use of SO_2 with a copper catalyst to reduce dissolved oxygen can reduce the corrosion rate of steel in these brines by at least an order of magnitude down to levels of 0.6 to 1.7 mils/yr. The in-situ corrosion rates of the disposal pipe lines have never been measured. But based on the above simulations, oxygen scavenging by fairly conventional techniques does work and should be considered mandatory prior to injection of ponded brines. This will directly reduce the amount of corrosion product particulate matter transported into the injection wells. It will be particularly beneficial when coupled with removal of noncorrosion-related particulates by granular-media or other brine-filtration processes.

As indicated in Table 6-8, the weight ratios of scavenger SO_2/dissolved oxygen were 3.7 at West Hackberry and 6.5 at Bayou Choctaw. In theory, a ratio of 4 is required. It was virtually impossible in the field to achieve the "correct" ratio for several reasons. First, the oxygen activity in the brine was variable over time. Secondly, we did not have a good estimate of the salinity correction factor for the dissolved oxygen readings. As discussed in Section 6.2.1, a value of 0.26 has now been established and was used to calculate the above ratios. Thirdly, it was difficult to regulate SO_2 flow rates by needle valve control because of fluctuating line pressures and cylinder pressures. We had no control over line pressures, and very coarse control over SO_2 cylinder pressures with heaters and insulation. Under these conditions, SO_2 injection requirements were adjusted, accordingly, to achieve (1) absolute corrosion rates in the scavenged brine of less than 1 mil/yr, (2) pH lowering of no more than 0.5 of a pH unit, and (3) residual dissolved oxygen activity in the scavenged brine of <100 ppb. In general, these conditions were met at both West Hackberry and Bayou Choctaw, although at Bayou Choctaw a large excess of scavenger was necessary and may be characteristic of these brines.

Although on-line corrosion rate data were not obtained for weak brines at Bayou Choctaw and ponded brine at Bryan Mound, enough bench-scale data were obtained to conclude that the SO_2-Cu catalyst would also be satisfactory for oxygen removal.

6.3 MICROBIOLOGICAL INVESTIGATIONS

R. Morita*

The major objective of the microbiological study was to determine whether sulfate-reducing bacteria were present in the injection water and brine ponds the West Hackberry, Bayou Choctaw, and Bryan Mound SPR sites. The sulfate-reducing bacteria have been implicated in the "souring" of oil fields. More specifically they have been involved in the anaerobic corrosion of ferrous metals in pipelines and oil-well casings and permeability loss in oil reservoirs by FeS formation, decomposition of drilling fluid additives, and bacterial growth in injection waters. The detrimental effects of the sulfate-reducing bacteria in petroliferous materials and corrosion are well documented by Davis (1967)[37] and Shreir (1976).[38]

6.3.1 Materials and Methods

6.3.1.1 Elucidation of Sulfate-Reducing Bacteria. Medium M10E (Morita and ZoBell, 1955)[39] was employed for detecting the presence of sulfate-reducing bacteria in samples taken from SPR sites. This medium, which has a pH of 7.5, contains the following:

---

*Professor of Microbiology, Oregon State University, Corvallis, Oregon.

Potassium phosphate dibasic	0.2 g
Magnesium sulfate	0.2 g
Sodium sulfite	0.1 g
Ferrous ammonium sulfate	0.1 g
Calcium lactate	3.5 g
Ascorbic acid	0.1 g
Bacto-peptone	1.0 g
Yeast extract	1.0 g
Bacto-agar	3.0 g
Water	1000.0 mℓ

The medium for the water was made up with brine samples from the three sites.

Twenty-milliliter portions of the medium were dispensed into screw-cap test tubes (20 by 150 mm) and autoclaved at 2 atm for 20 minutes. The pH was adjusted with NaOH.

An inoculum of 1 ml from each brine sample was used. This was done in triplicate.

6.3.1.2 Brine Samples. Brine samples for bacterial analysis were taken by aseptic techniques. Brine samples (10 ml) for epifluorescent counts were treated with 30 percent formaldehyde (0.6 ml) to preserve the cells until the counts could be made.

6.3.1.3 Epifluorescent Bacterial Counts. Bacterial cell numbers (bacterial biomass) were determined by epifluorescent counts (Zimmerman and Meyer-Reil, 1974)[40] employing Nuclepore filters (0.2 μm pore size) previously stained with Ingalan Black BGL (Watson et al., 1977).[41] A Zeiss microscope fitted with epifluorescent optics was employed to count the number of cells in various samples of brine.

6.3.1.4 Sediment Samples. At West Hackberry, sediment samples around the injection site were also collected to determine whether sulfate-reducing bacteria were present and, if so, to determine whether adaptation to brine medium was possible. Adaptation of sulfate-reducing bacteria in sediment around the injection site to higher and higher concentrations of brine in the medium was determined.

6.3.2 Results

6.3.2.1 West Hackberry. When inoculated tubes were incubated in a medium made with brine water obtained from the pond (Table 6-9), no sulfate-reducing bacteria could be detected by the enrichment culture technique in the pond water, injection water, or the water pumped (pond in) to the pond. Negative results obtained in the elucidation studies does not mean sulfate-reducing bacteria are absent. (This is one of the pitfalls we have in microbiological techniques.) The number of bacterial cells in the brine samples varied from a low of 3.5×10^3 to 1.7×10^6 bacteria/ml. If one assumes the average weight of carbon per bacterial cell as 207.5 fg (femtogram or 10^{-15} g; Watson et al., 1977),[41] then the amount of bacterial biomass is rather insignificant.

Sulfate-reducing bacteria were present in the sediment samples taken near the injection site when elucidated with medium made with seawater. Because sulfate-reducing bacteria are known to be able to grow in brine situations (Nissenbaun, 1975)[42] and the possible contamination of injection water with sulfate reducers, adaptation studies were initiated to determine whether they could adapt to media made with brine within the short period of time employed in this investigation. Within the time frame of this study the sulfate reducers did not adapt to the medium made up with brine solution obtained from the pond at West Hackberry.

The strong brine from West Hackberry does not exclude microbial life. Halophilic bacteria (those that grow in 12 percent NaCl or higher) were growing on the surface (aerobic surface) of the M10E medium as indicated by the presence of a reddish coloration. These halophilic bacteria could be cultured on the proper medium in the laboratory (Table 6-10).

6.3.2.2 Bayou Choctaw. Sulfate-reducing bacteria do occur in the water from Injection Pad 3 but is evidenced only by inoculating the water into medium prepared with lake water. The sulfate-reducing bacteria in water from

Injection Pad 3 do not express themselves in medium made up with brine from Bayou Choctaw (Table 6-11).

The bacterial counts ranged from 6.02×10^6 to 6.22 bacteria/ml, which is two orders of magnitude higher than that at the West Hackberry site (Table 6-12).

Microscopic examination of the brines from this site (some appeared slightly greenish) revealed no good organized groups of procaryotic cells so no scientific identifications could be made.

Again, halophilic bacteria were present in the brine samples from this area.

6.3.2.3 <u>Bryan Mound</u>. Sulfate-reducing bacteria could not be detected in any samples obtained from Bryan Mound. The epifluorescent bacterial count ranged from 1.46×10^4 to 2.14×10^5 bacteria/ml. Halophilic bacteria, however, were cultured from the various brine solutions obtained from microbiological analysis. The data for this area are presented in Tables 6-13 and 6-14.

6.3.3 Discussion

6.3.3.1 <u>West Hackberry</u>. Although no sulfate reducers were elucidated in the various brine samples, contamination with sediment can occur in and around the West Hackberry site. The sediment in and around West Hackberry contains sulfate-reducing bacteria. Although the sulfate-reducing bacteria did not grow in the brine water sulfate-reducing medium, there is always the possibility of adaptation with time to the conditions of high brine since it is known that sulfate reduction occurs in natural brine situations (Nissenbaun, 1975)[42] and in oil well reservoirs where brine is present and the system has become "sour."

The short-term adaptation studies performed within the limited time period of this investigation does not eliminate the possibility of this process happening over a period of time in terms of years. The pH of the brine solution appears to be optimal for the growth of sulfate reducers; the halophilic bacteria in the brine could supply the necessary nutrients for the growth of the sulfate-reducing bacteria. Enough sulfate is in the brine solution to provide it with the proper hydrogen and electron acceptor and the anaerobic conditions could be brought about in due time by the metabolic processes of the halophilic bacteria present (halophiles are aerobic and can use the dissolved oxygen present). If halophilic bacteria are capable of utilizing certain hydrocarbons in the petroleum, more energy would be available to bring about reducing conditions and the possible metabolic end products of halophilic bacterial metabolism could then be used by the sulfate-reducing bacteria as an energy source. The brine water appears to have enough iron for the metabolism of the sulfate-reducing bacteria.

At the present time, there does not appear to be any difficulty with the microbiology of the brine in terms of possible corrosion of metal systems in the Strategic Oil Reserve at West Hackberry. However, it does not eliminate the future involvement of sulfate-reducing bacteria in making the system "sour," which has been known to occur in oil wells after water flood operations for secondary recovery of oil have begun. Again, it is a time-dependent process.

6.3.2.2 Bayou Choctaw. Although sulfate-reducing bacteria were not elucidated in most of the samples obtained at the Bayou Choctaw site, their presence in the brine taken from Injection Pad 3 does present a possible future problem for the possible development of the sulfate reducers. Although the pH of the brine obtained from this site is not optimal for the growth of sulfate-reducing bacteria, they can grow at the pH values observed in the various brine solutions of this area. Although the organic carbon analysis is not now known for this area, it is probably higher than the system at West Hackberry—mainly because mixtures of Cavern Lake water and strong brine are injected. Lake water should contain more organic matter.

Again, halophilic bacteria could be isolated from the brines and the previous statements concerning the microbiology of the West Hackberry site also applies to this area. However, the potential danger in this area is greater because the use of weak brine solutions could permit sulfate-reducing bacteria to adapt more rapidly and there is probably a greater organic load injected into the system.

6.3.3.3 Bryan Mound. No sulfate reducers were demonstrated in the samples obtained from Bryan Mound. However, the halophilic bacteria grew readily in these samples. Again, all the statements made in relation to the West Hackberry site apply. In the brine solutions having pH values close to 7.0, the sulfate-reducing bacteria could develop whereas in certain cavern brines where the pH reaches 11.05, there probably will be no difficulty with the growth of bacteria that could be classified as a nuisance. However, the high values obtained for the organic matter in the brine, river, and injection waters at Bryan Mound are disturbing. These large values (up to 39 mg/l at Injection Site 3B) could help to accelerate adaptation of sulfate-reducing bacteria. Adaptation to environmental factors by microbes is time and energy related.

6.3.4 Conclusions

At this time, there appears to be no difficulty with the microbiology of the injection sites. However, the sites bear watching, especially the Bayou Choctaw site, for the possible development (adaptation) of sulfate-reducing bacteria in the systems. The complete absence of hydrogen sulfide in the weak and/or strong brines at all sites, even after years for adaptation, is very strong evidence that the likelihood of a problem in the future is very remote. However, it is recommended that a check for sulfate reducing bacteria be included in an annual survey at each site. Field analysis for H_2S should be included in a quarterly check. Detection of <u>any</u> H_2S should trigger a bacterial check until it can be proven that the H_2S comes from another source, i.e., the crude oil being stored.

TABLE 6-1. Removal of dissolved oxygen from strong brine (West Hackberry).[a]

Run No.	Scavenger	Catalyst	Uncorrected $D_0 \rightarrow D_f$, ppm	Corrected $D_0 \rightarrow D_f$, ppm	$T_0 \rightarrow T_f$	$pH_0 \rightarrow pH_f$	R
1	33 ppm Visco	-	5.8→0.60	1.51→0.16	-	-	2.9
2	50 ppm Visco	-	5.3→0.35	1.38→0.09	-	-	4.8
3	100 ppm Visco	-	5.2→0.30	1.35→0.08	-	-	3.0
4	35 ppm SO_2	-	5.1→0.34	1.33→0.09	-	7.70→6.69	2.3
5	40 ppm Na_2SO_3	-	4.8→0.42	1.25→0.11	-	7.66→7.68	1.3
6	40 ppm Na_2SO_3	0.01 ppm Co	3.95→0.18	1.03→0.047	21.5	-	7.2
7	35 ppm SO_2	0.0125 ppm Co	3.55→0.15	0.92→0.039	22.5	-	6.5
8	8 ppm Na_2SO_3	-	2.05→1.45	0.53→0.38	21.2	-	1.1
9	8 ppm Na_2SO_3	0.01 ppm Co	2.23→0.70	0.58→0.18	21.5	-	1.3
10	16 ppm Na_2SO_3	0.01 ppm Co	2.35→0.20	0.61→0.052	22.0	→7.66	2.8
11	16 ppm Na_2SO_3	0.1 ppm Cu	2.05→0.15	0.53→0.039	21.0	7.68→7.65	5.1
12	16 ppm Na_2SO_3	0.1 ppm Co	1.73→0.15	0.45→0.039	22.5	→7.67	4.3
13	7 ppm SO_2	-	2.93→2.75[b]	0.76→0.72	20.6	7.65→7.54	1.1
14	7 ppm SO_2	0.1 ppm Co	2.85→0.25	0.74→0.07	21.0	7.65→7.45	3.2
15	7 ppm SO_2	0.1 ppm Cu	2.95→0.20	0.77→0.052	21.5	7.66→7.43	5.9
16	20 ppm K477	-	3.85→2.15	1.0→0.56	21.3	7.61→7.61	1.4
17	10 ppm K490	-	3.85→3.65[b]	1.0→0.95	22.2	7.61→7.55	1.0
18	7 ppm SO_2	0.2 ppm Cu	3.95→0.29	1.03→0.08	21.0	7.65→7.38	4.9
19	7 ppm SO_2	0.1 ppm Cu	3.95→0.80	1.03→0.21	29.0	7.64→7.39	3.8
20	7 ppm SO_2	-	3.75→1.20	0.98→0.31	29.9	7.73→7.42	1.6

[a]D = Dissolved oxygen (ppm); T = Temperature (°C); 0 = Initial value (subscript); f = Final value (subscript); R = Defined in text.

[b]Ended at 2 min.

TABLE 6-2. Removal of dissolved oxygen from strong brine (Bayou Choctaw).[a]

Run No.	Scavenger	Catalyst	Uncorrected $D_0 \rightarrow D_f$, ppm	Corrected $D_0 \rightarrow D_f$, ppm	$T_0 \rightarrow T_f$	$pH_0 \rightarrow pH_f$	R
1	7 ppm SO_2	0.1 ppm Cu	3.6→0.23	0.94→0.06	24.0→24.6	6.62→6.19	6.6
2	7 ppm SO_2	0.1 ppm Co	4.3→0.15	1.12→0.039	18.9→21.1	6.78→6.29	3.2
3	7 ppm SO_2	-	4.7→0.20	1.27→0.052	19.5→21.5	6.7→6.23	1.9
4	16 ppm Na_2SO_3	0.1 ppm Cu	3.6→0.18	0.94→0.047	24.0	-	7.9
5	16 ppm Na_2SO_3	0.1 ppm Co	3.75→0.15	0.98→0.039	19.6→21.9	-	3.4
6	16 ppm Na_2SO_3	-	3.45→0.15	0.90→0.039	19.7→22.4	-	1.6
7	30 ppm K494	-	4.55→0.15	1.18→0.039	19.2→21.7	-	4.8

[a]D = Dissolved oxygen (ppm); T = temperature (°C); 0 = Initial value (subscript); f = Final value (subscript); R = Defined in text.

TABLE 6-3. Removal of dissolved oxygen from weak brine (Bayou Choctaw).[a]

Run No.	Scavenger	Catalyst	Uncorrected, $D_0 \rightarrow D_f$, ppm	Corrected, $D_0 \rightarrow D_f$, ppm	$T_0 \rightarrow T_f$	$pH_0 \rightarrow pH_f$	R
8	7 ppm SO_2	0.1 Cu	7.8→0.95	2.03→0.25	15.2	6.33	4.7
9	14 ppm SO_2	0.1 ppm Cu	8.0→0.18	2.08→0.047	12.9→17.0	6.42→5.71	7.6
10	28 ppm SO_2	0.1 ppm Cu	7.8→0.10	2.03→0.026	14.8→17.4	6.31→5.23	12.0
11	14 ppm SO_2	0.1 ppm Co	8.5→0.15	2.21→0.039	13.0→16.3	6.3→5.55	6.5
12	28 ppm SO_2	1.0 ppm Co	8.4→0.15	2.18→0.039	12.8	6.3→5.24	11.2
13	42 ppm SO_2	0.1 ppm Co	9.0→0.10	2.34→0.026	14.0→16.1	6.38→5.22	12.0
14	28 ppm SO_2	None	8.8→0.10	2.29→0.026	14.2→16.8	6.3→5.45	11.0
15	14 ppm SO_2	None	8.7→0.12	2.26→0.031	14.0	6.3→5.72	7.3
16	16 ppm Na_2CO_3	0.1 ppm Cu	6.95→1.20	1.81→0.31	12.2→16.0	6.42	3.4
17	24 ppm Na_2SO_3	0.1 ppm Cu	7.5→0.15	1.95→0.039	11.7→15.2	6.41→6.38	7.9
18	24 ppm Na_2SO_3	0.1 ppm Co	9.4→0.30	2.44→0.078	11.2→15.2	6.3→6.24	8.5
19	24 ppm Na_2SO_3	None	9.8→0.72	2.55→0.19	12.5	-	8.5
20	32 ppm Na_2SO_3	0.1 ppm Cu	7.7→0.20	2.00→0.052	11.2	6.42	6.4
21	32 ppm Na_2SO_3	0.1 ppm Co	8.4→0.20	2.18→0.052	11.4→15.0	-	6.7
22	48 ppm Na_2SO_3	0.1 ppm Co	7.7→0.15	2.00→0.039	12.7	-	9.6
23	48 ppm Na_2SO_3	0.1 ppm Cu	8.2→0.10	2.13→0.026	13.5	-	9.7
24	48 ppm Na_2SO_3	None	7.4→0.10	1.92→0.026	13.8→17.5	-	11.4
25	64 ppm Na_2SO_3	0.1 ppm Co	8.2→0.12	2.13→0.031	12.8→16.9	-	11.7
26	96 ppm Na_2SO_3	0.1 ppm Co	7.6→0.10	1.98→0.026	13.0→17.5	-	13.8
27	40 ppm K494	None	7.3→0.15	1.90→0.039	14.8→17.6	6.4→5.89	8.6

[a]D = Dissolved oxygen (ppm); T = temperature (°C); 0 = Initial value (subscript); f = final value (subscript); R = Defined in text.

TABLE 6-4. Removal of dissolved oxygen from Cavern Lake water (Bayou Choctaw).[a]

Run No.	Scavenger	Catalyst	Uncorrected $D_0 \rightarrow D_f$, ppm	$T_0 \rightarrow T_f$	$pH_0 \rightarrow pH_f$	R
28	14 ppm SO_2	0.1 ppm Cu	5.4→4.53	9.0→10.8	-	1.0
29	28 ppm SO_2	0.1 ppm Cu	5.5→3.90	9.0→11.0	7.06→6.34	1.3
30	28 ppm SO_2	0.1 ppm Co	6.3→3.84	13.4	7.13	1.4
31	56 ppm SO_2	0.1 ppm Co	6.2→1.40	15.0→19.8	7.1→5.80	1.6
32	48 ppm Na_2SO_3	0.1 ppm Cu	4.73→2.95[b]	11.0	7.08	1.6
33	64 ppm Na_2SO_3	0.1 ppm Cu	4.90→2.08[b]	10.0	-	2.4
34	80 ppm Na_2SO_3	0.1 ppm Cu	4.85→1.5[b]	9.0→10.5	-	3.1
35	80 ppm Na_2SO_3	0.1 ppm Co	6.20→0.30	8.0	-	13.8
36	80 ppm Na_2SO_3	-	6.3→2.06	8.0→12.0	-	2.7
37	112 ppm Na_2SO_3	0.1 ppm Cu	5.20→1.2	9.0→10.9	-	4.3
38	160 ppm Na_2SO_3	0.1 ppm Cu	5.0→0.73[b]	9.1	-	6.7
39	160 ppm Na_2SO_3	0.1 ppm Co	6.3→0.10	8.2→12.0	-	14.7
40	160 ppm Na_2SO_3	-	6.2→0.23	8.2	-	14.4
41	320 ppm Na_2SO_3	0.1 ppm Cu	5.05→0.42	10.0	-	10.7
42	320 ppm Na_2SO_3	0.2 ppm Cu	4.85→0.23	9.9	-	12.1
43	320 ppm Na_2SO_3	-	6.50→0.20	9.2→10.4	7.02	11.8
44	400 ppm Na_2SO_3	0.2 ppm Cu	6.50→0.20	7.6→10.2	-	10.8
45	50 ppm K494	-	5.10→3.75	14.7→16.5	7.46	1.3
46	100 ppm K484	-	5.25→2.75	14.3	-	1.6

[a]D = Dissolved oxygen (ppm); T = temperature (°C); 0 = Initial value (subscript); f = final value (subscript); R = Defined in text.

[b]Run stopped at 4 min.

TABLE 6-5. Removal of dissolved oxygen from strong brine (Bryan Mound).[a]

Run No.	Scavenger	Catalyst	Uncorrected $D_0 \rightarrow D_f$, ppm	Corrected $D_0 \rightarrow D_f$, ppm	$T_0 \rightarrow T_f$	$pH_0 \rightarrow pH_f$	R
1	7 ppm SO_2	0.1 ppm Co	4.35→0.15	1.13→0.039	23.5→25.0	6.89→6.29	6.2
2	7 ppm SO_2	0.1 ppm Cu	4.15→0.13	1.08→0.034	23.5→24.8	6.89→6.26	8.7
3	7 ppm SO_2	-	4.40→0.12	1.14→0.031	24.0→25.1	→6.19	8.0
4	16 ppm Na_2SO_3	0.1 ppm Co	4.55→0.27	1.18→0.07	23.0→23.6	→6.91	7.2
5	16 ppm Na_2SO_3	0.1 ppm Cu	4.10→0.18	1.07→0.047	23.5→24.2	-	5.9
6	16 ppm Na_2SO_3	-	4.30→0.13	1.12→0.034	23.7→24.0	-	7.8
7	20 ppm K494	-	4.25→0.08	1.11→0.021	23.6→24.1	-	12.1

[a]D = Dissolved oxygen (ppm); T = temperature (°C); 0 = Initial value (subscript); f = final value (subscript); R = Defined in text.

TABLE 6-6. Removal of dissolved oxygen from diluted brine (Bryan Mound).[a]

Run No.	Scavenger	Catalyst	Uncorrected $D_0 \rightarrow D_f$, ppm	Corrected $D_0 \rightarrow D_f$, ppm	$T_0 \rightarrow T_f$	$pH_0 \rightarrow pH_f$	R
8	7 ppm SO_2	0.1 ppm Co	3.75→0.13	0.98→0.034	25.1→25.7	6.73→6.23	6.0
9	7 ppm SO_2	0.1 ppm Cu	4.10→0.20	1.07→0.052	25.7→26.2	-	8.2
10	7 ppm SO_2	-	4.25→0.13	1.11→0.034	26.0→27.0	-	7.5
11	20 ppm Na_2SO_3	0.1 ppm Co	4.30→0.34	1.12→0.09	2.6→26.8	-	7.8
12	20 ppm Na_2SO_3	0.21 ppm Cu	4.70→0.60	1.22→0.16	25.8→26.5	-	9.4
13	20 ppm Na_2SO_3	-	4.30→0.40	1.12→0.10	26.1→26.9	-	9.2
14	20 ppm K494	-	4.65→0.07	1.21→0.018	25.3→26.2	-	11.6

[a]D = Dissolved oxygen (ppm); T = temperature (°C); 0 = Initial value (subscript); f = final value (subscript); R = Defined in text.

TABLE 6-7. Removal of dissolved oxygen from Brazos River water (Bryan Mound).[a]

Run No.	Scavenger	Catalyst	Uncorrected $D_0 \rightarrow D_f$, ppm	$T_0 \rightarrow T_f$	$pH_0 \rightarrow pH_f$	R
15	14 ppm SO_2	0.1 ppm Co	5.40→5.40[b]	18.8	8.07	1.0
16	28 ppm SO_2	0.1 ppm Co	5.30→4.83[c]	18.5→19.0	8.07→6.78	1.1
17	56 ppm SO_2	0.1 ppm Co	5.20→3.90[d]	18.5→19.6	→6.36	1.1
18	24 ppm Na_2SO_3	0.1 ppm Co	5.20→3.20[c]	18.9→19.2	-	1.6
19	32 ppm Na_2SO_3	0.1 ppm Co	5.40→2.58[b]	19.0	-	2.1
20	48 ppm Na_2SO_3	0.1 ppm Co	5.10→0.20	19.1→20.9	-	25.5
21	48 ppm Na_2SO_3	0.1 ppm Cu	4.70→4.57[b]	19.6→19.9	-	1.0
22	48 ppm Na_2SO_3	-	5.3→5.4[c]	18.4	-	1.6
23	60 ppm K494	-	4.85→4.85[c]	18.7	-	1.0

[a]D = Dissolved oxygen (ppm); T = temperature (°C); 0 = Initial value (subscript); f = final value (subscript); R = Defined in text.

[b]Stopped at 1 min.

[c]Stopped at 2 min.

[d]Stopped at 5 min.

TABLE 6-8. In-line oxygen scavenging and corrosion rate measurements.

Parameter	West Hackberry	West Hackberry	West Hackberry	Bayou Choctaw
Test duration, hr	46	30.5	37.5	28
Brine flow rate, gal/min	40	30	30	30
Brine velocity, ft/sec	4.1	3.1	3.1	3.1
Scavenger/catalyst	None	None	SO_2, Cu^{++}	SO_2, Cu^{++}
Scavenger/flow rate, g/min	-	-	0.94	0.92
Catalyst/flow rate, mg/ℓ brine	-	-	0.10	0.10
Corrected[a] oxygen conc. before/after scavenger addition, ppm				
Before	0.95	0.49	1.82	1.05
After	0.91	0.45	0.013	0.0325
Stoichiometric weight ratio,[a] SO_2/O_2	-	-	3.7	6.5
pH Before	7.6	7.6	7.6	6.8
After scavenger addition	-	-	7.2	6.2
Corrosion rate, mils/yr				
Without scavenger				
Probe 1	-	28	40	20
Probe 2	12	16.5	-	-
Probe 3	6.5	17.5	-	-
With scavenger				
Probe 2	-	-	0.57	1.7
Probe 3	-	-	1.4	1.5

[a]Assuming 0.26 dissolved oxygen correction factor for salinity.

TABLE 6-9. Occurrence of sulfate-reducing bacteria in water samples taken from the West Hackberry SPR Injection Site.[a,b]

Inoculum source	Date sample collected	Growth of sulfate reducers at indicated temperature in M 10 E medium (incubation period 40 days)	
		30 C	37 C
Pond water	1/4/79	-	-
Pond water	1/5/79	-	-
Injection water	1/4/79	-	-
Injection water	1/5/79	-	-
Pumped water to pond	1/5/79	-	-

[a]Run in triplicate

[b]All controls were negative.

TABLE 6-10. Epifluorescent microbial counts of water samples taken from the West Hackberry SPR Injection Site.

Water sample	Date sample collected	Bacterial cells/mℓ
Pond water	1/4/79	1.0×10^4
Pond water	1/5/79	1.7×10^4
Injection water	1/4/79	1.1×10^4
Injection water	1/5/79	5.3×10^3
Pumped water to pond	1/5/75	3.5×10^3

TABLE 6-11. Occurrence of sulfate-reducing bacteria in water samples taken from Bayou Choctaw SPR Injection Site.[a,b]

	Growth of sulfate reducers at indicated temperature in M 10 E medium made with							
	Lake water		Injection Pad 3		Pumped water to pond		Injection water	
Inoculum source	30 C	37 C	30 C	37 C	30 C	37 C	30 C	37 C
Lake water	-	-	-	-	-	-	-	-
Injection Pad 3	+	+	-	-	-	-	-	-
Pumped water to pond	-	-	-	-	-	-	-	-
Injection water	-	-	-	-	-	-	-	-
Injection water	-	-	-	-	-	-	-	-
Controls	-	-	-	-	-	-	-	-

[a] Incubation period was 40 days.

[b] Run in triplicate.

TABLE 6-12. Epiflourescent microbial counts of water samples taken from the Bayou Choctaw SPR Injection Site.

Water sample	Date collected	Bacterial cells/ml
Lake water (fresh)	1/25/79	6.02×10^6
Injection pad 3	1/25/79	1.49×10^6
Pumped water to pond	1/25/79	6.64×10^5
Injection water	1/25/79	6.22×10^5

TABLE 6-13. Occurrence of sulfate-reducing bacteria in water samples taken from the Bryan Mound SPR Injection Site.[a,b]

Inoculum source	Growth of sulfate reducers at indicated temperature from Bryan Mound in M 10 E medium made with: Pumped water into pond, 30 C	Pumped water into pond, 37 C	Injection Pad water, 30 C	Injection Pad water, 37 C
Pumped water into pond	-	-	-	-
Injection pad water	-	-	-	-
Controls	-	-	-	-

[a]All runs in triplicate.

[b]Incubation period was 40 days.

TABLE 6-14. Epifluorescent microbial counts of water samples taken from the Bryan Mound SPR Injection Site.[a]

Water sample	Bacterial cells/mℓ
Injection water	1.46×10^4
Pumped water to pond	2.14×10^5
Injection Pad	1.63×10^5

[a]Samples received April 3, 1979.

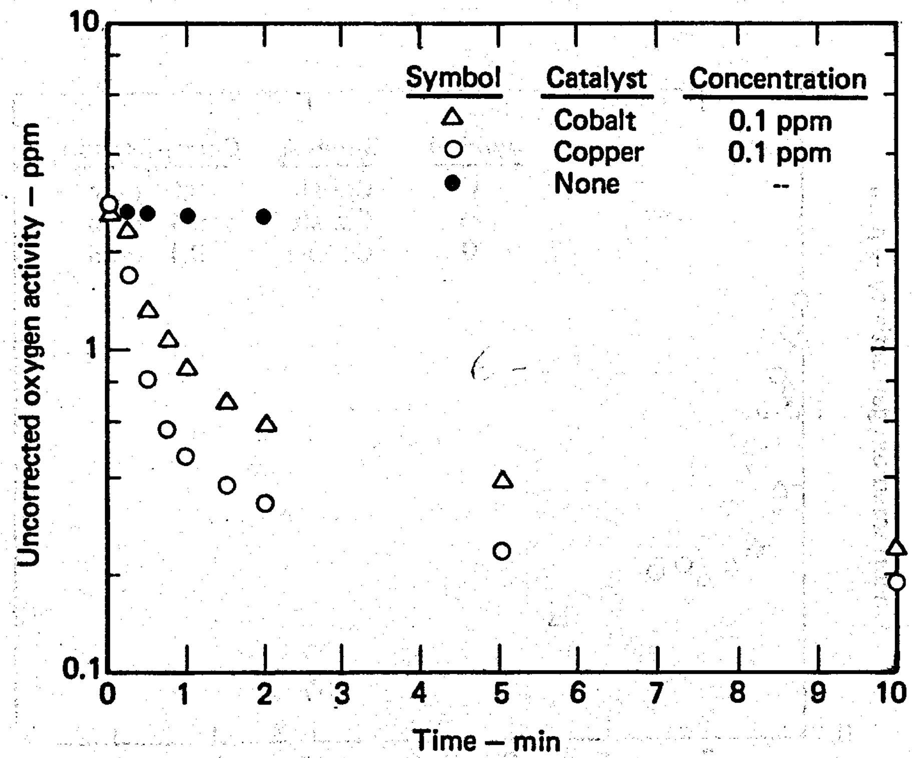


FIG. 6-1. Rate of removal of dissolved oxygen from brine with sulfur dioxide (7 ppm) at the West Hackberry SPR site.

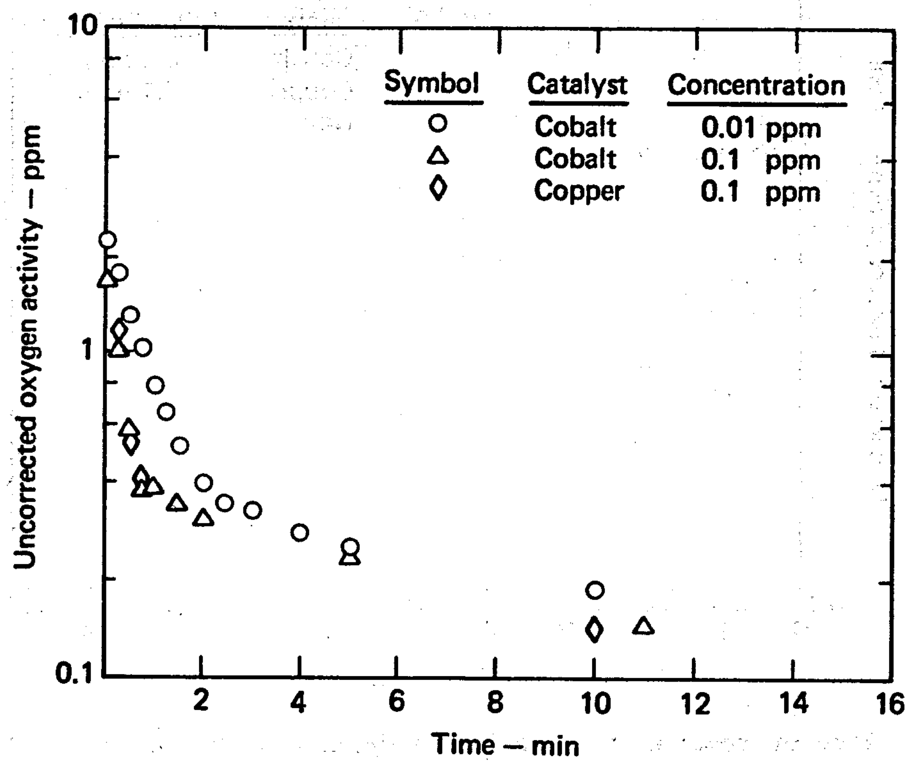


FIG. 6-2. Rate of removal of dissolved oxygen from brine with sodium sulfite (16 ppm) at the West Hackberry SPR site.

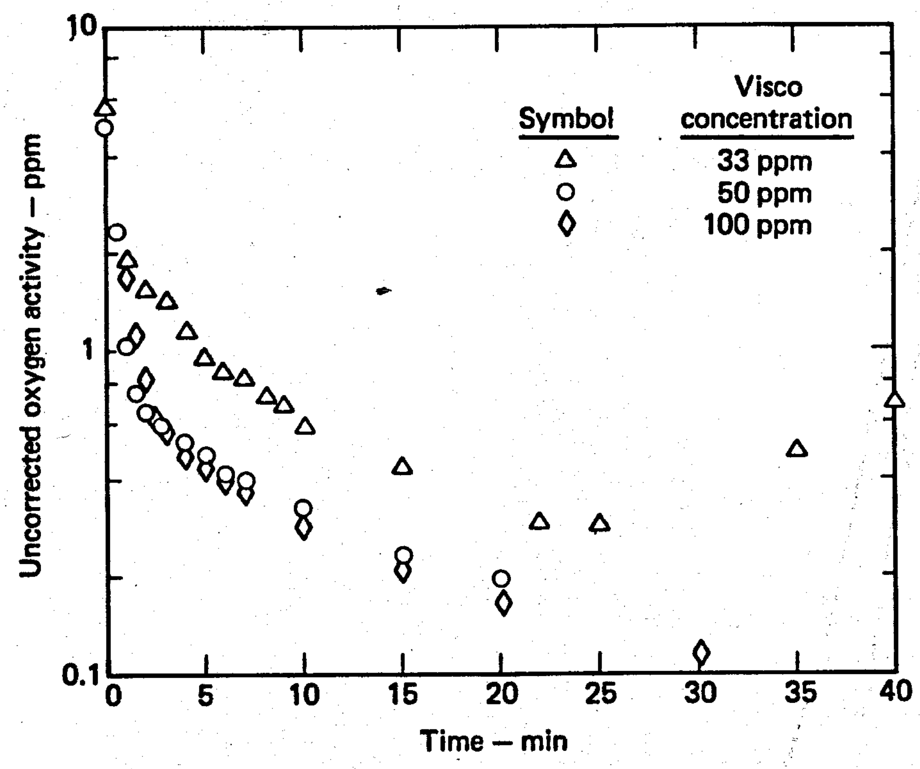


FIG. 6-3. Rate of removal of dissolved oxygen from brine with Visco 3656 (Nalco Chemical Company) at the West Hackberry SPR site.

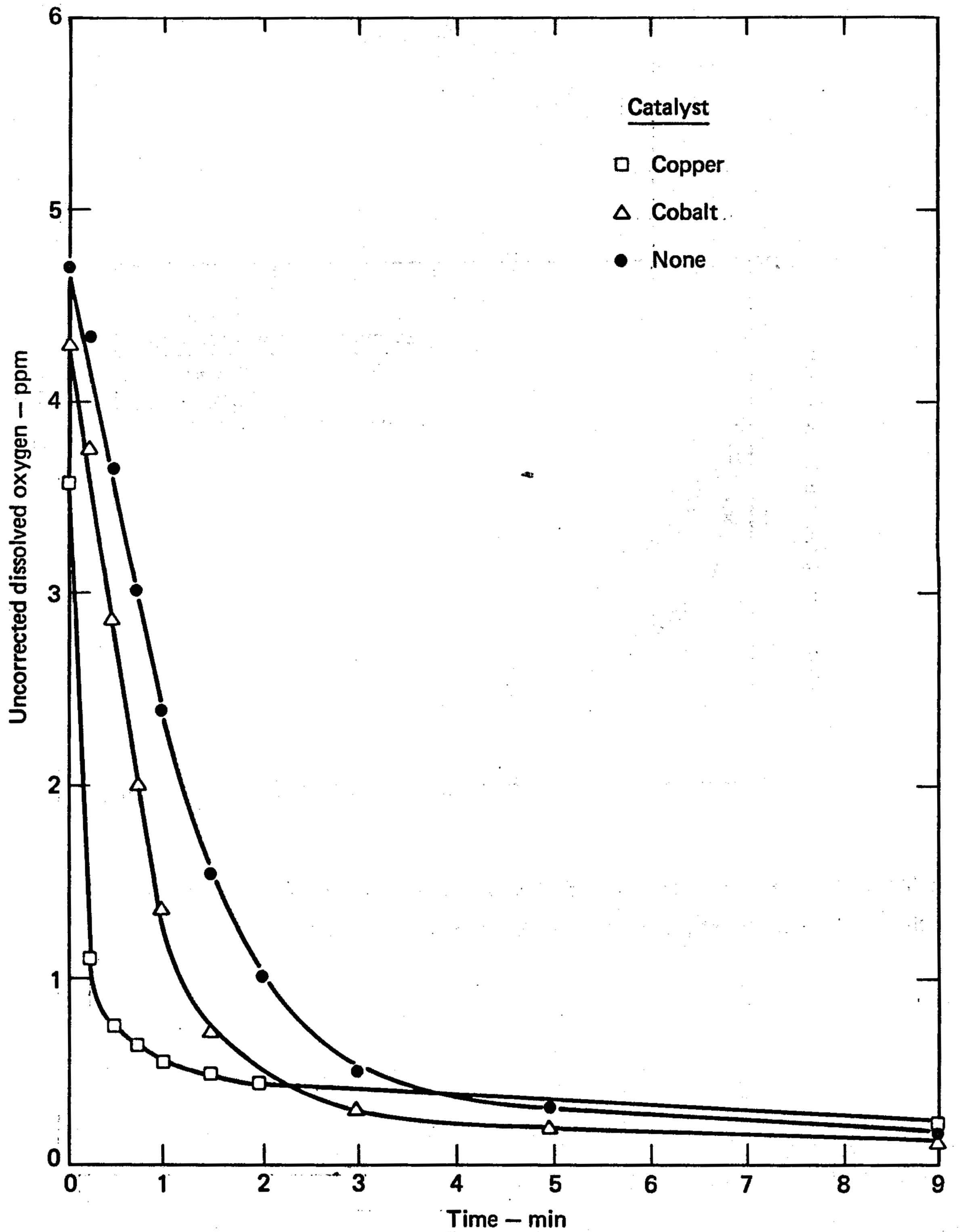


FIG. 6-4. Rate of removal of dissolved oxygen in Bayou Choctaw strong brine with 7 ppm sulfur dioxide.

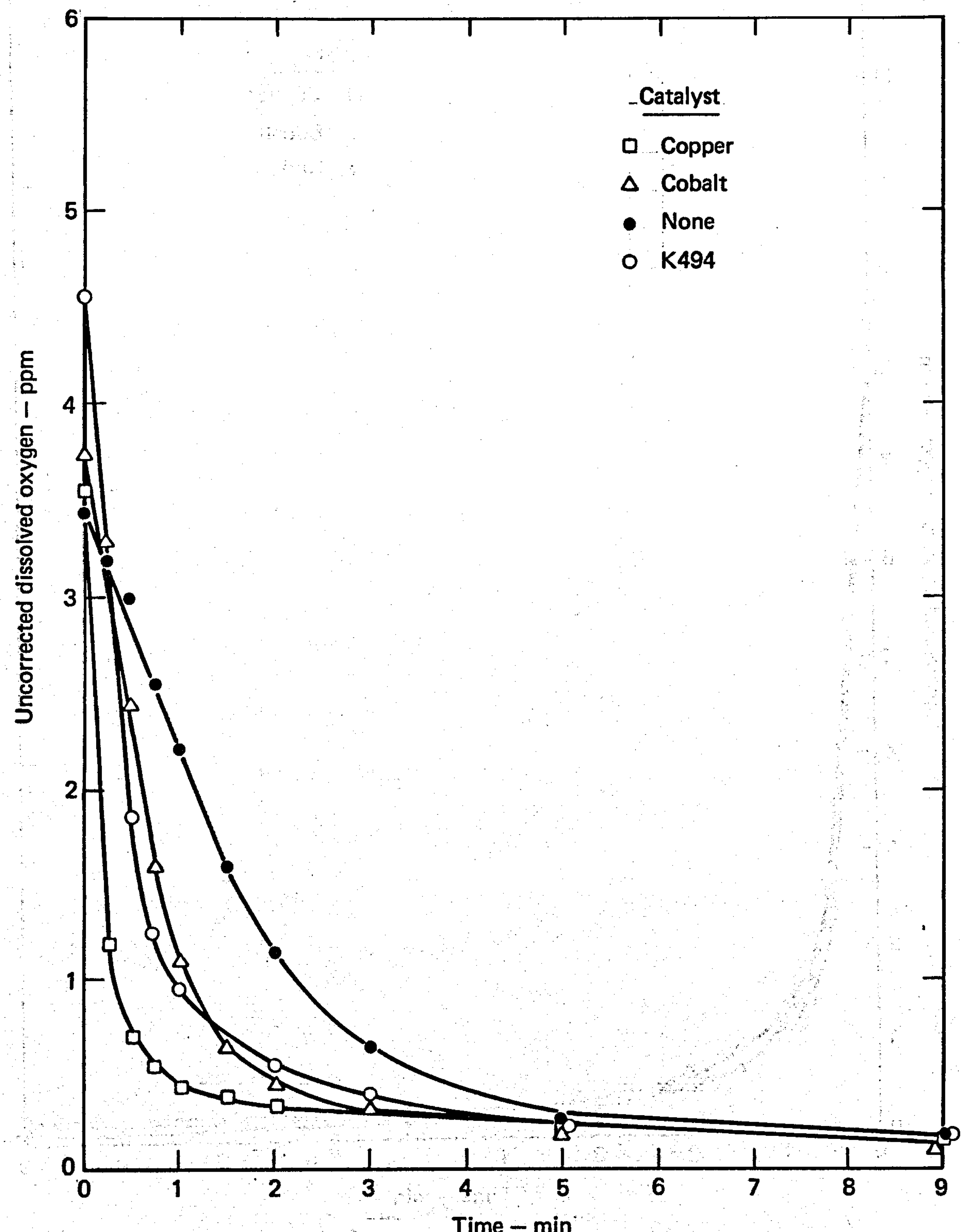


FIG. 6-5. Rate of removal of dissolved oxygen in Bayou Choctaw strong brine with 16 ppm Na_2SO_3.

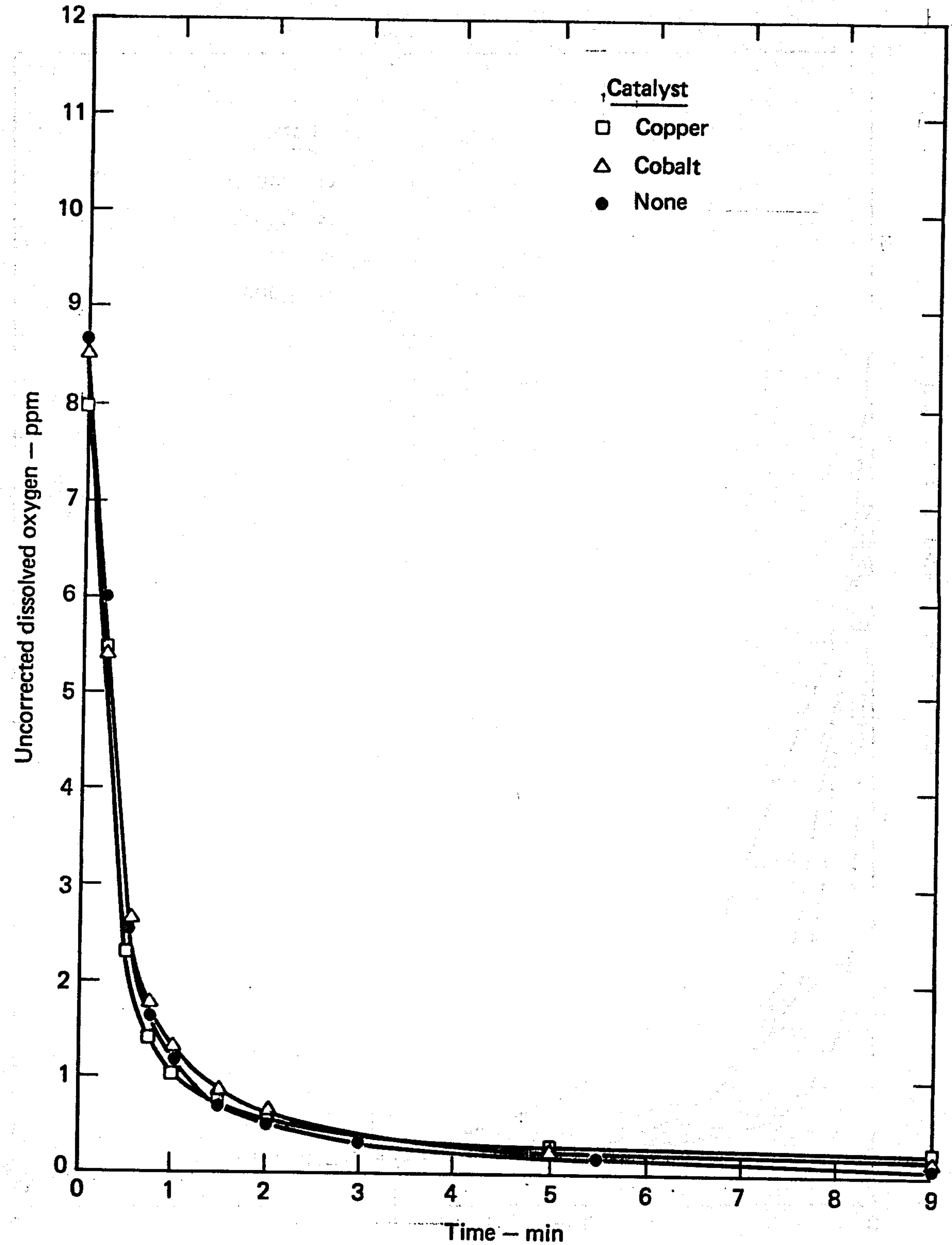


FIG. 6-6. Rate of removal of dissolved oxygen in Bayou Choctaw weak brine with 14 ppm sulfur dioxide.

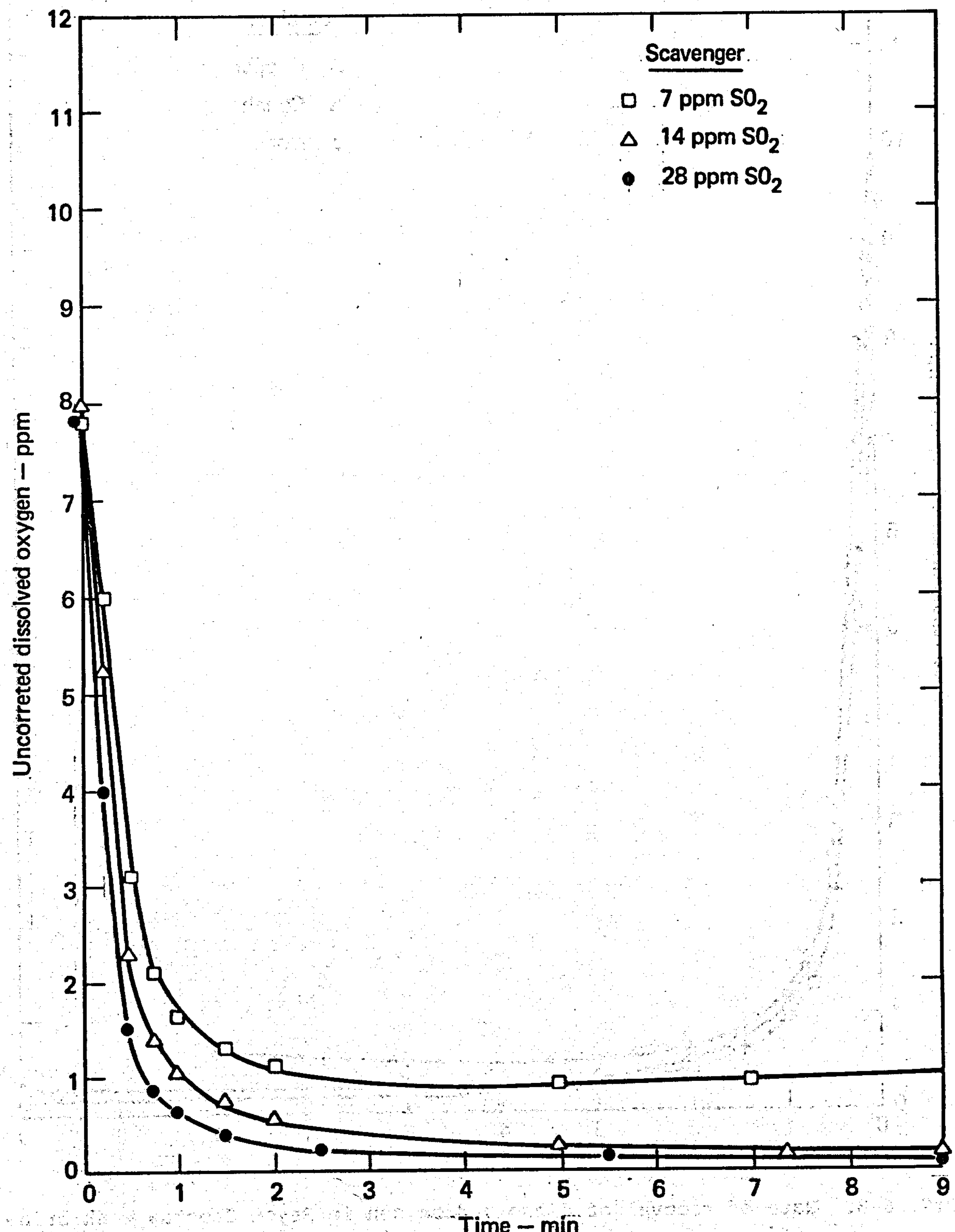


FIG. 6-7. Effect on rate of removal of dissolved oxygen in Bayou Choctaw weak brine with sulfur dioxide concentration and copper catalyst.

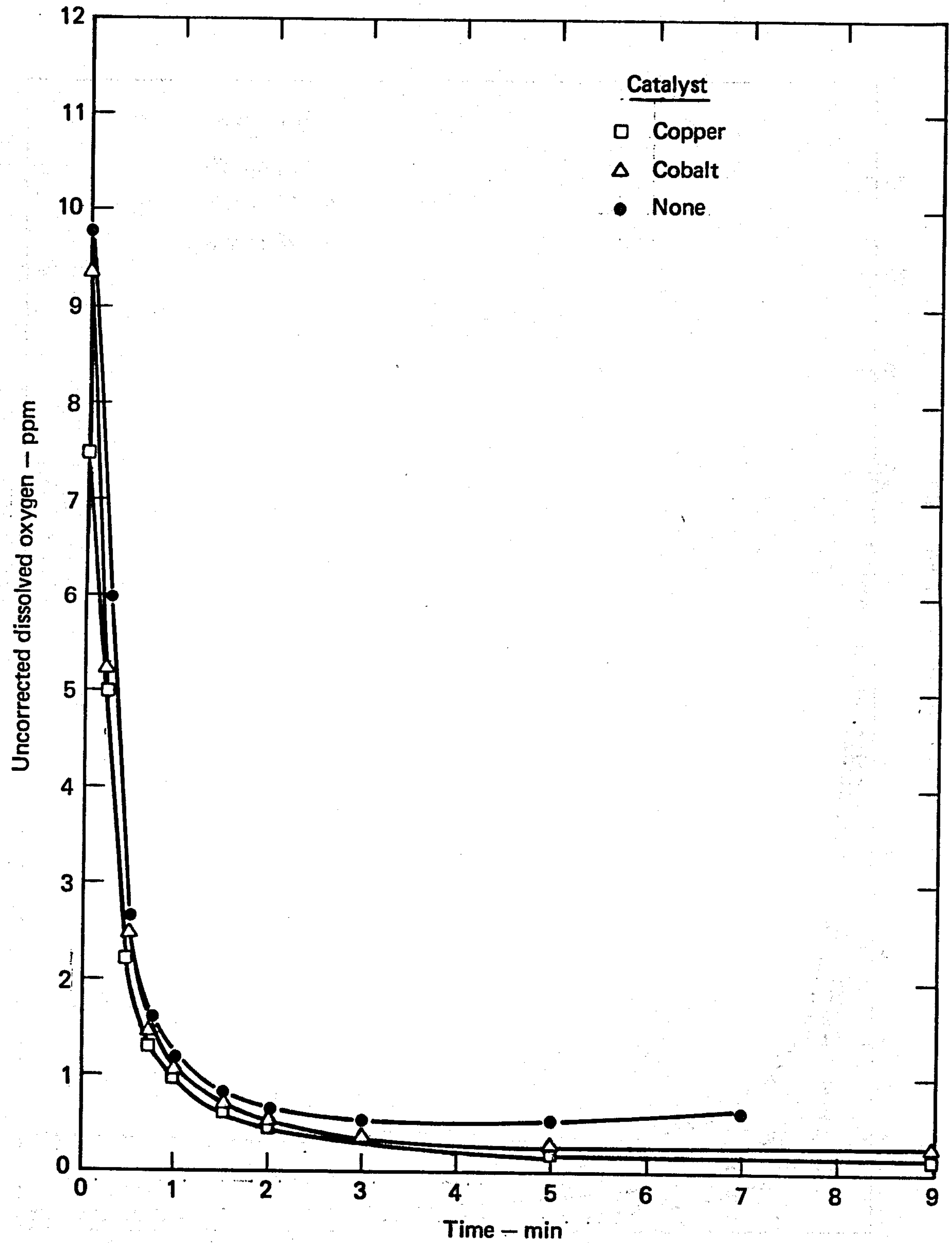


FIG. 6-8. Rate of removal of dissolved oxygen in Bayou Choctaw weak brine with 24 ppm Na_2SO_3.

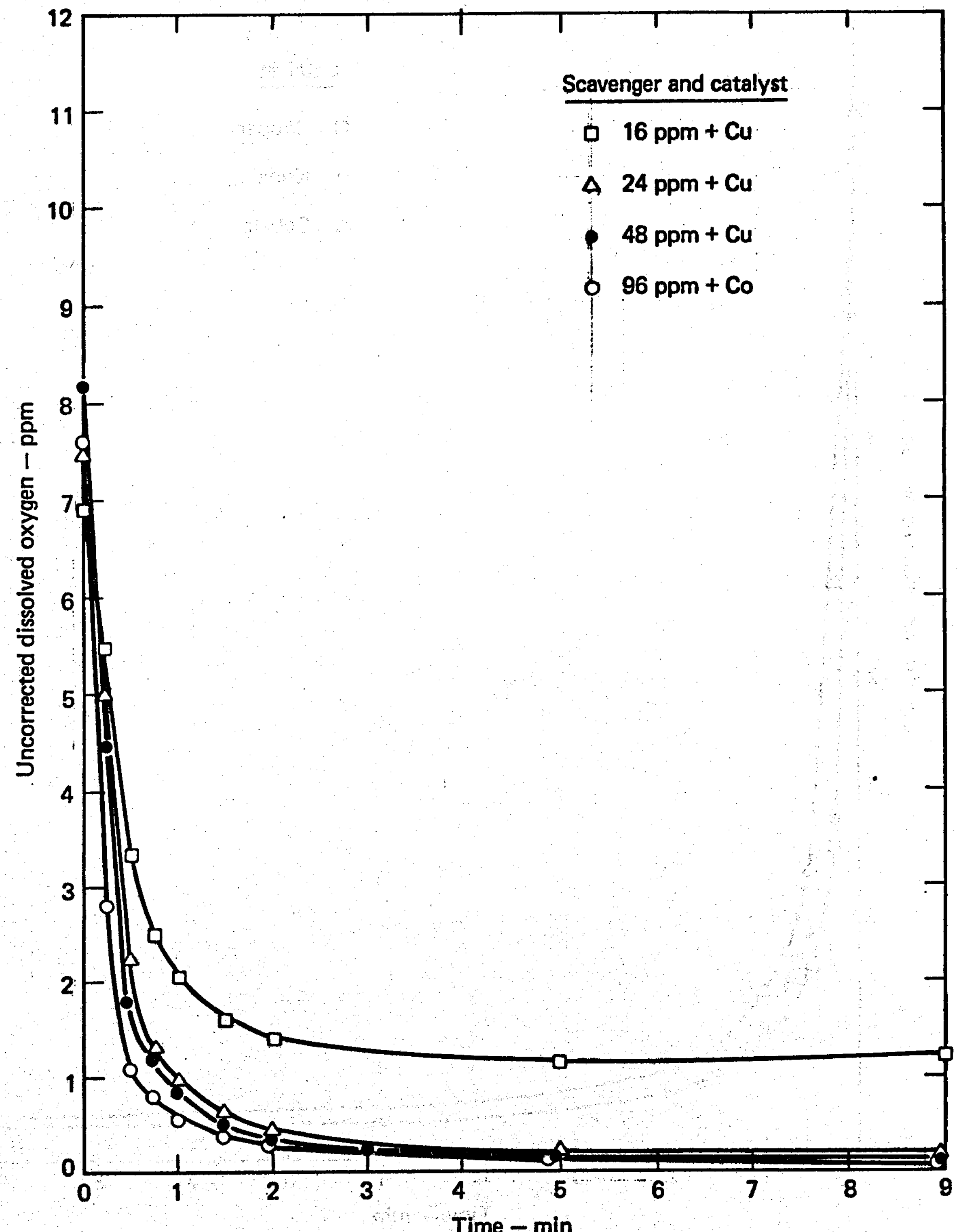


FIG. 6-9. Effect on rate of removal of dissolved oxygen in Bayou Choctaw weak brine with Na_2SO_3 concentration and catalysts.

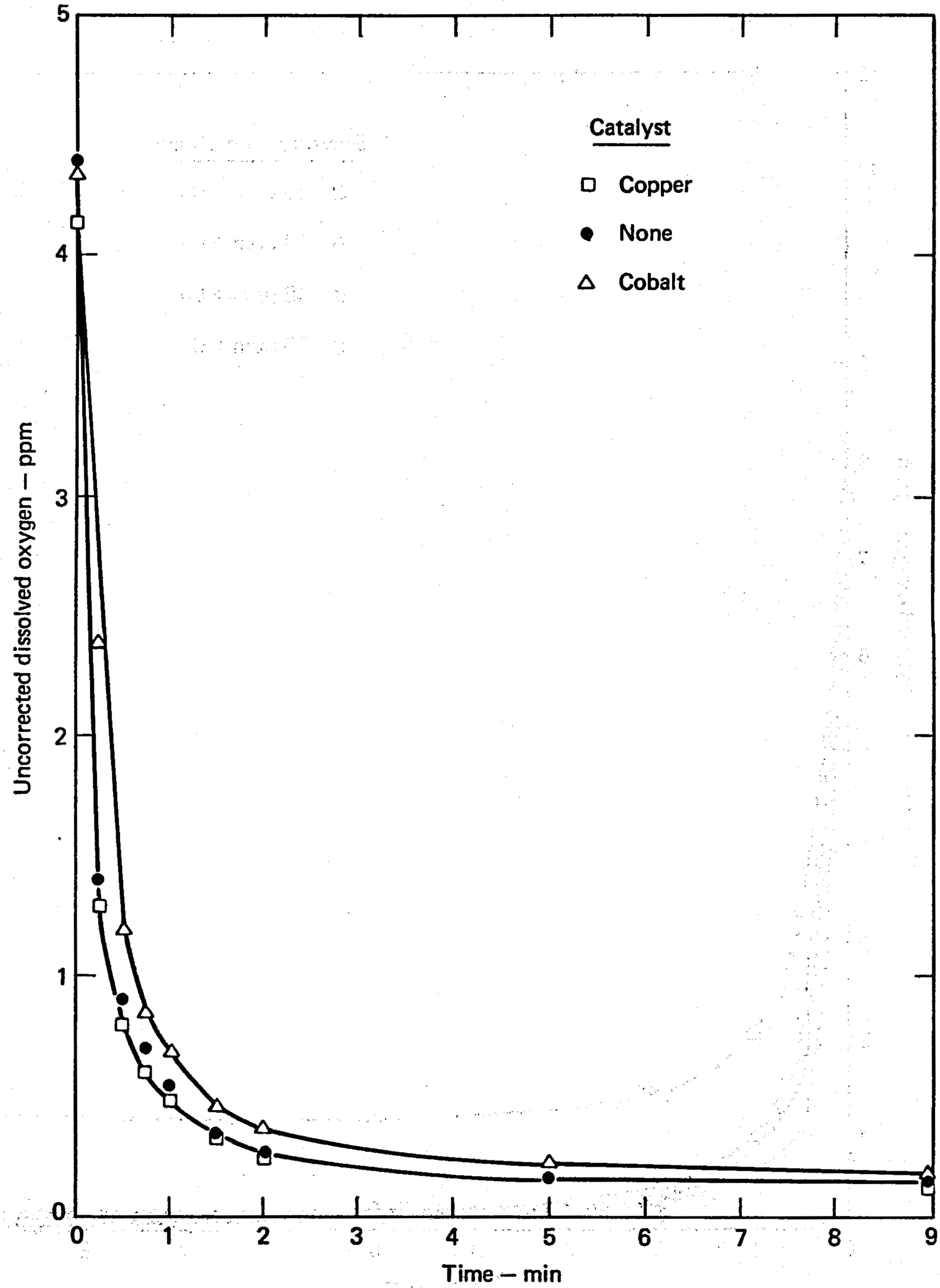


FIG. 6-10. Rate of removal of dissolved oxygen in Bryan Mound with 7 ppm sulfur dioxide.

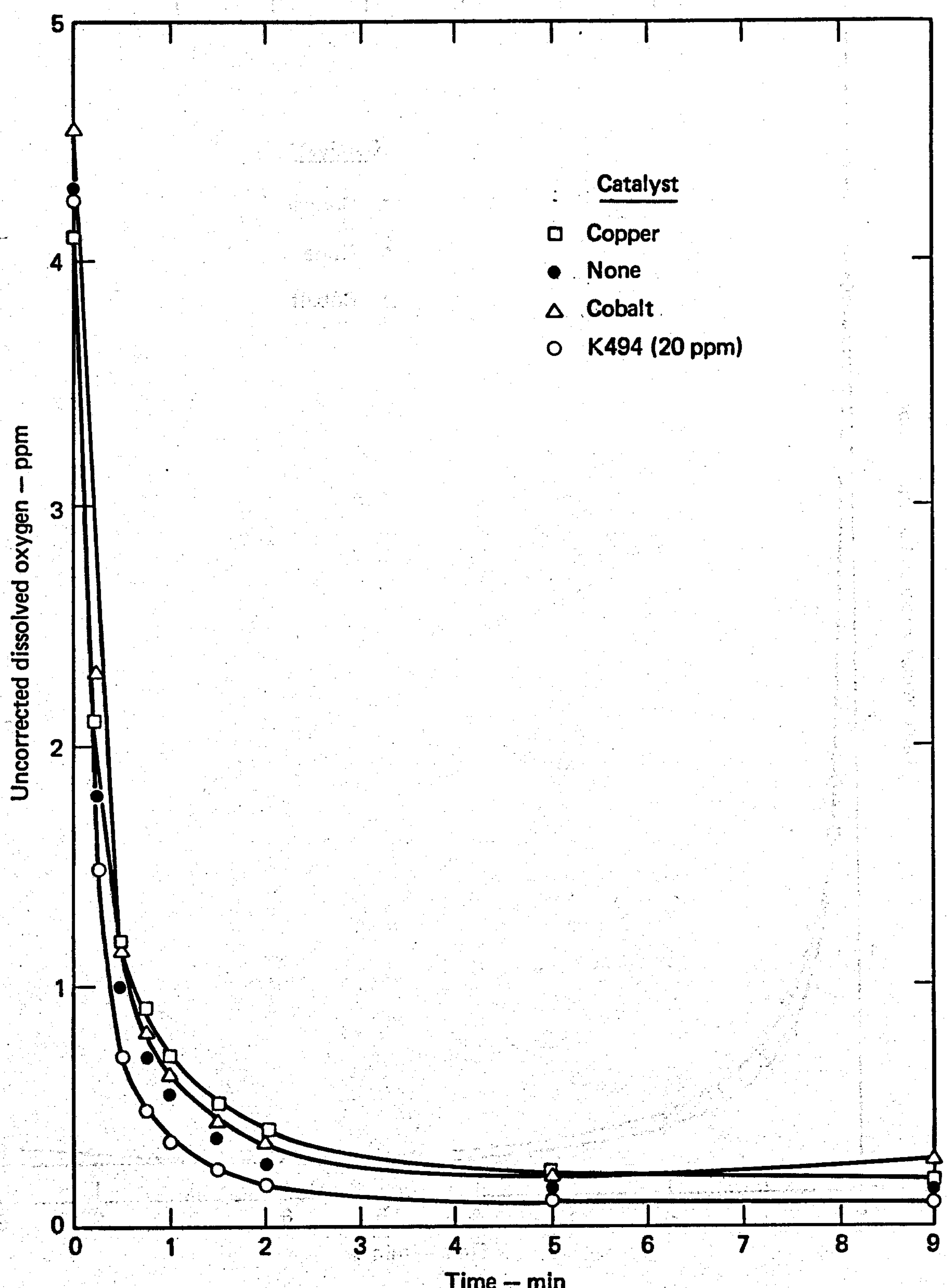


FIG. 6-11. Rate of removal of dissolved oxygen in Bryan Mound strong brine with 16 ppm Na_2SO_3.

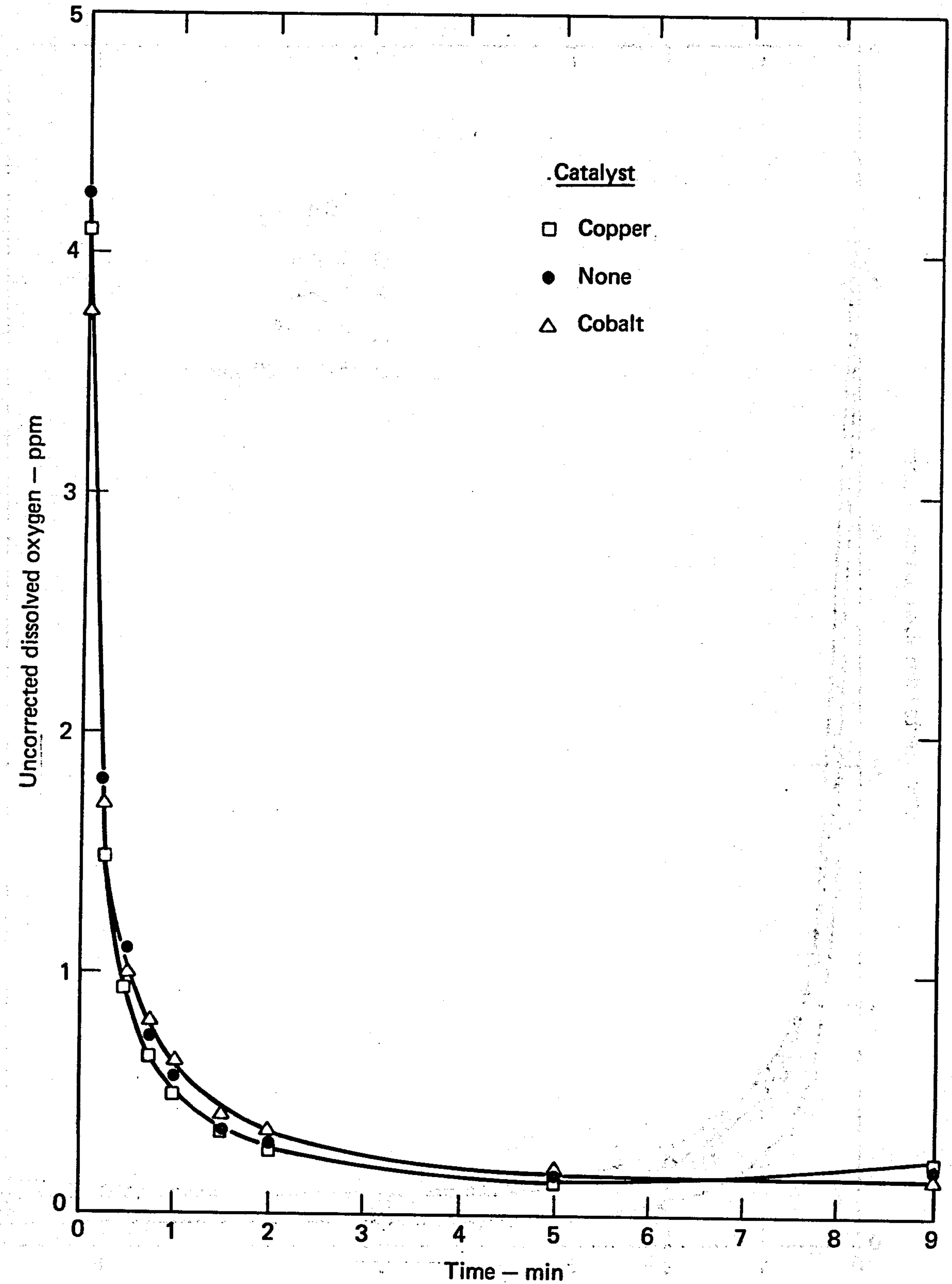


FIG. 6-12. Rate of removal of dissolved oxygen in Bryan Mound diluted brine with 7 ppm sulfur dioxide.

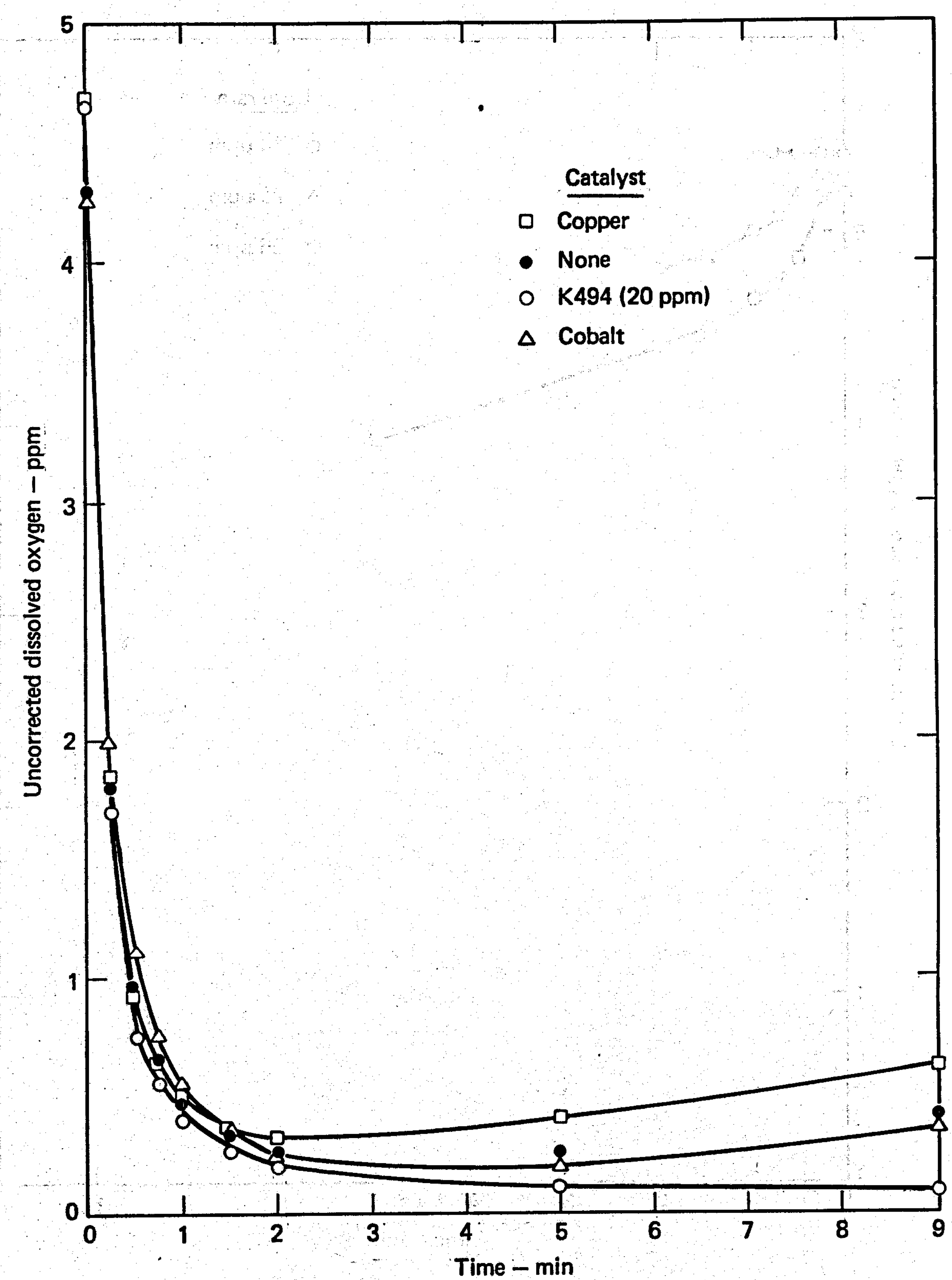


FIG. 6-13. Rate of removal of dissolved oxygen in Bryan Mound diluted brine with 20 ppm Na_2SO_3.

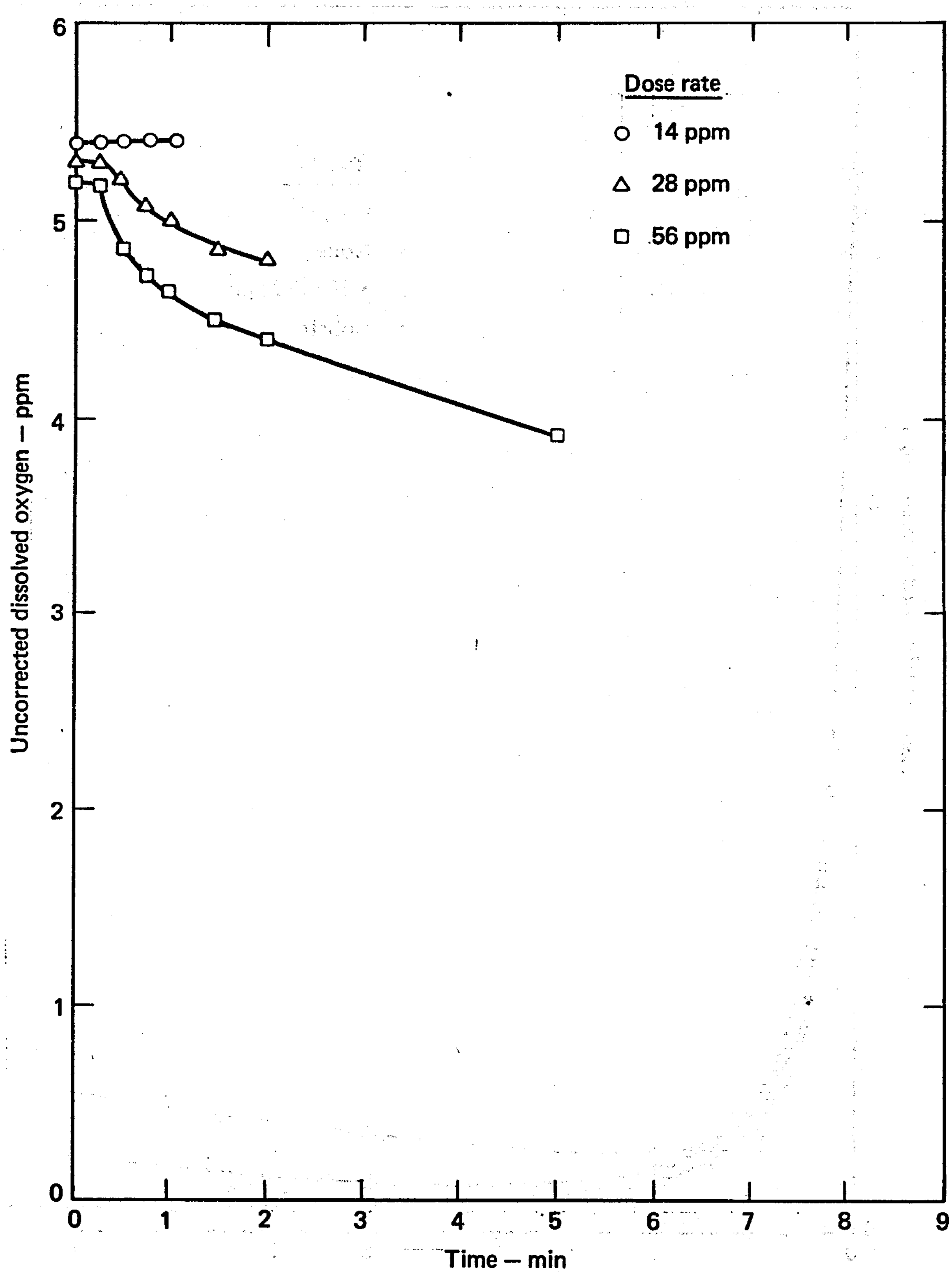


FIG. 6-14. Effect on rate of removal of dissolved oxygen in Bryan Mound river water with sulfur dioxide concentration and cobalt.

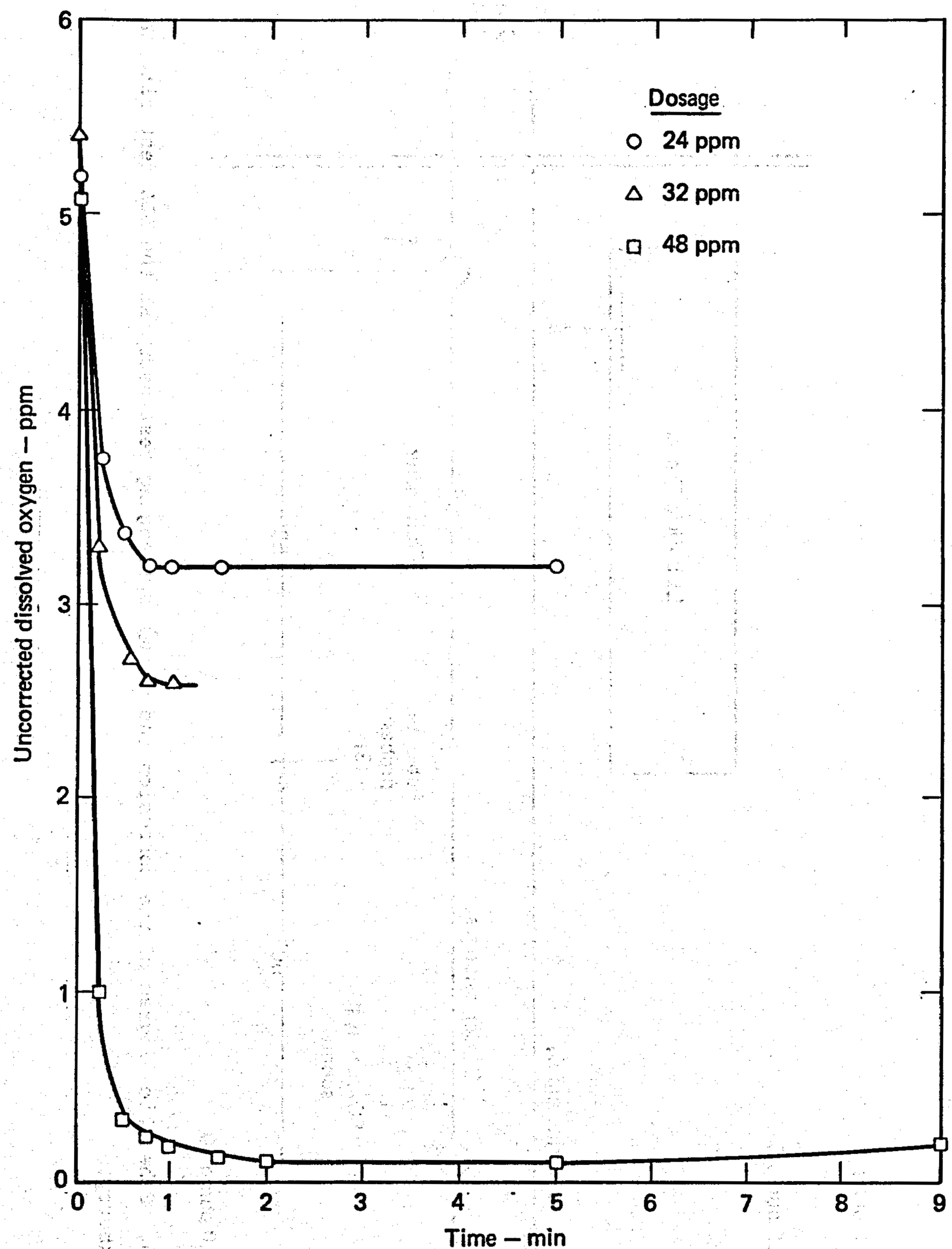


FIG. 6-15. Effect on rate of removal of dissolved oxygen in Bryan Mound river water with Na_2SO_3 concentration and cobalt.

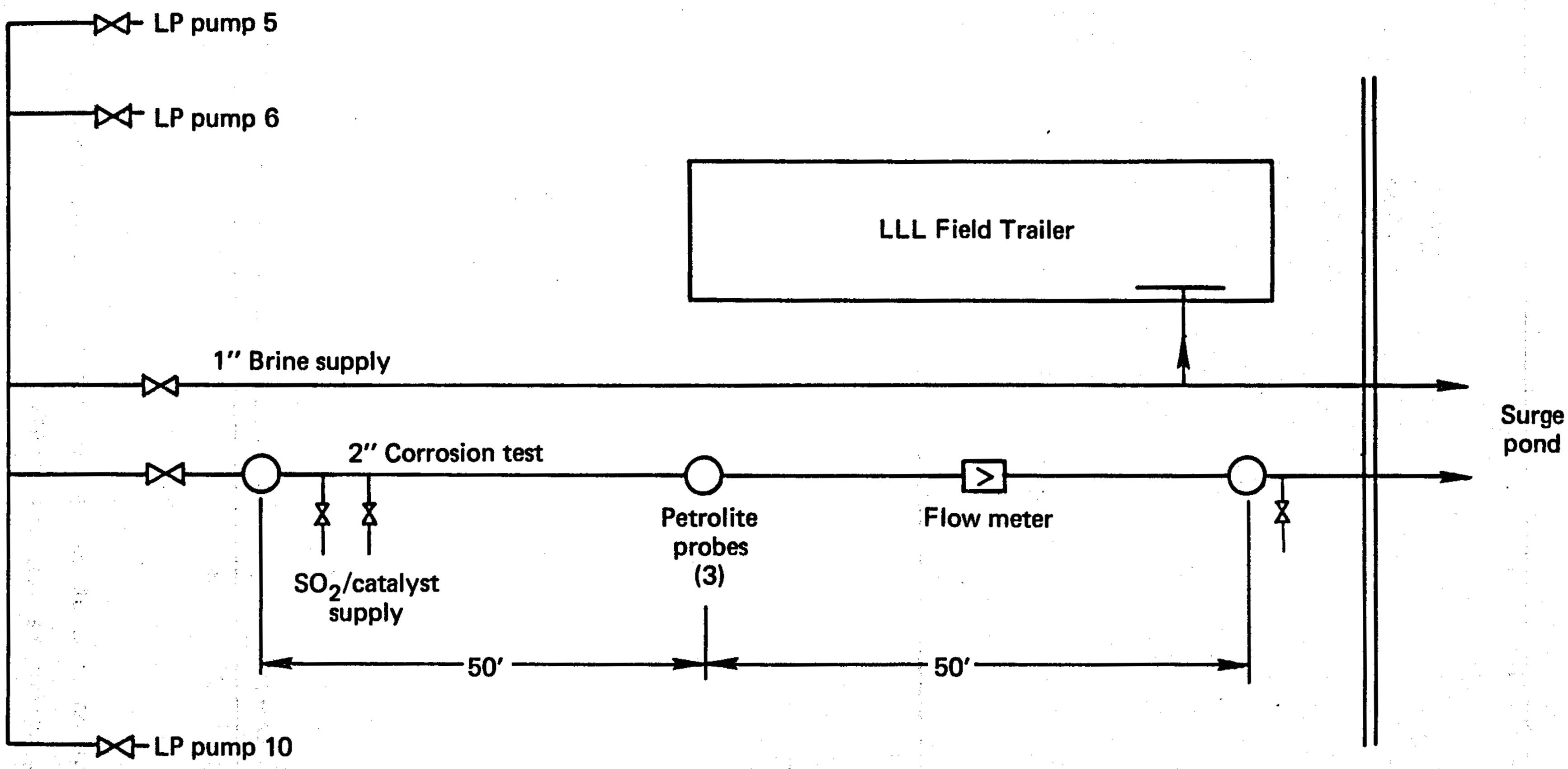


FIG. 6-16. Schematic diagram of the corrosion and oxygen scavenging test setup at the LLL test site in West Hackberry.

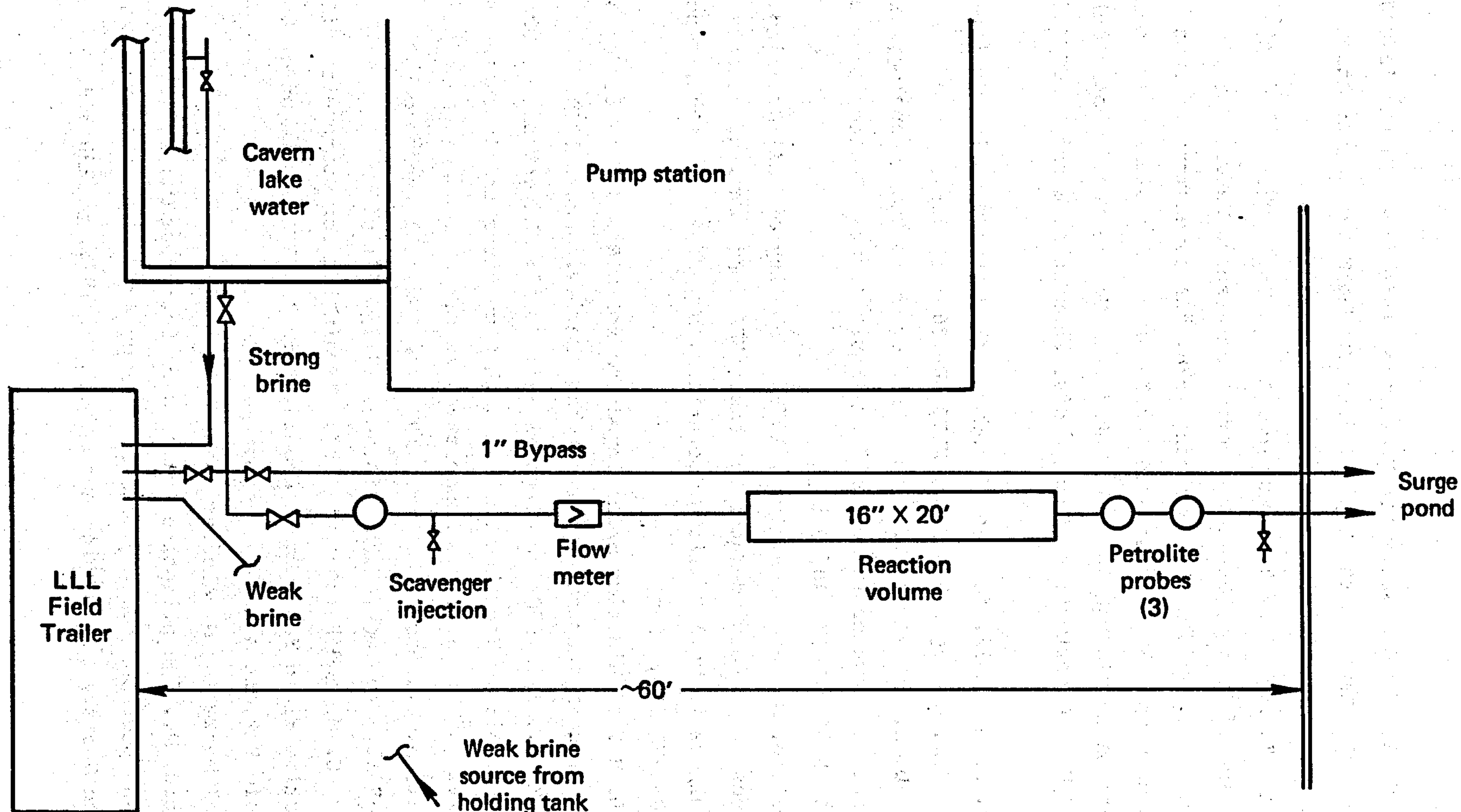


FIG. 6-17. Schematic diagram of the corrosion and oxygen scavenging test setup at the LLL test site in Bayou Choctaw.

REFERENCES

1. Smith, C. G., 1976, "Saltwater-Freshwater Interfaces in the '2,000' and '2,800-Foot' Sands in the Capital Area Ground Water Conservation Commission, Bulletin No. 1, 23 p.
2. Magorian, T. R., 1978, "Geotechnical Study, Bayou Choctaw," U.S. Department of Energy, Strategic Petroleum Reserve Report, 23 p.
3. Knutson, C. F., and C. R. Boardman, 1978, "An Assessment of Subsurface Saltwater Disposal Experience on the Texas and Louisiana Gulf Coast For Application to Disposal of Salt Water from Geopressured Geothermal Wells," U.S. Department of Energy, Div. Geothermal Energy, NVO/1531-2, August 4.
4. Warner, D. L., 1972, "Survey of Industrial Waste Injection Wells, Vols. I and II, U.S. Geological Survey, NTIS AD-756-641, June.
5. Warner, D. L., et al., 1977, "An Introduction to the Technology of Subsurface Wastewater Injection," EPA Environmental Protection Technology Series, EPA-600/2-77 240, 345 p.
6. Campbell, M. D., and G. R. Gray, 1975, "Mobility of Well-Drilling Additives in the Ground-Water Systems," EPA Conf. Envirn. Aspects of Chemical Use in Well-Drilling Operations, May 21-23, Houston, Report EPA-560-1-75-004, 45 p.
7. Owen, L. B., "Evaluating Brine Injection for DOE's Strategic Petroleum Reserve Program," Energy and Technology Review, August 1979.
8. Davis, K. E., 1979, "Brine Disposal Well No. 2: Report on the Use of Compressed Air to Backflow Well at High Flow Rates and Increase Injectivity," Ken E. Davis Associates, 16 p.
9. Campbell, M. D., and J. H. Lehr, 1973, "Water Well Technology," McGraw-Hill, New York, (4th Printing, 1977), 601 p.
10. Hudgins, C. M. and Patton, C., 1979, "Evaluation of Commercial Filters, Comparative Field Test, Bayou Choctaw Site," U.S. Department of Energy, Strategic Petroleum Reserve Report, 40 p.
11. Chemical Marketing Newsletter, April 30, 1979.
12. Gruenfeld, M., "Quantitative Analysis of Petroleum Oil Pollutants by Infrared Spectrophotometry, *Water Quality Parameters, ASTM STP 573*, American Society for Testing and Materials, 1975, p. 290-308.

13. MacArthur, C. G. (1916) in Linke, W. F., *Solubilities, Inorganic and Metal-Organic Compounds*, Vol. II, fourth edition, 1965.

14. Hudgins, C. M., Petro Tech Consultants, Inc., personal communications 1979, 1980.

15. Wolery, T. J., *Calculation of Chemical Equilibrium between Aqueous Solution and Minerals*, Lawrence Livermore Laboratory, UCRL-52658 (1979).

16. J. R. Wood, "Thermodynamics of Brine-Salt Equilibria--I. The Systems Nale-KCl-$MgCl_2$-$CaCl_2$-H_2O and NaCl-$MgSO_6$-H_2O at 25 Degrees C," *Geochim. Cosmochim. Acta*, V.39, pp. 1147-1163 (1975).

17. Doscher, T. M., and L. Weber, 1957, The Use of the Membrane Filter in Determining Quality of Water for Subsurface Injection: Drilling and Production Practice, (API), pp. 169-179.

18. Johnston, K. H., and J. L. Castagno, 1964, Evaluation by Filter Methods of the Quality of Waters Injected in Water-Floods: U.S. Bureau of Mines Rept. 6426, 14 p.

19. Patton, C. C., 1977, Oilfield Water Systems: Published by Campbell Petroleum Series, 252 p.

20. Barkman, J. H. and D. H. Davidson, (1972), Measuring Water Quality and Predicting Well Impairment: *Jour. Petroleum Technology*, pp. 865-873.

21. Owen, L. B., P. Kasameyer, L. Thorsen, and R. Netherton, 1977, Predicting the Rate at Which Suspended Solids Plug Injection Wells: Proceedings, 3rd Workshop--Geothermal Reservoir Engineering, Stanford University.

22. Tewhey, J. D., M. A. Chan, P. W. Kasameyer, and L. B. Owen, 1978, Development of Injection Criteria for Geothermal Resources: Geothermal Resources Council, *Transactions*, Vol. 2, pp. 649-652.

23. Champlin et al., 1967, "Laboratory Testing and Evaluation of Porous and Permeable Rock for Nuclear Waste Disposal," U.S. Bureau of Mines RI 6926.

24. Analysis Laboratories, New Orleans, Louisiana.

25. Mungon, N., "Permeability Reduction Through Changes in pH and Salinity," *Jour. Pet. Tech.* (Dec. 1965), 1449.

26. Jordon, C. A., T. A. Edmondson, and M. J. Jeffries-Harris, "The Bay Marchand Pressure Maintenance Project--Unique Challenges of an Offshore Sea-Water Injection System," *Jour. Pet. Tech.* (April 1969), 389.

27. Farley J. T., and D. G. Redline, "Evaluation of Flood Water Quality in the West Montalvo Field," *Jour. Pet. Tech.* (July 1968), 683.

28. Quong, R., F. Schiepflin, N. D. Stout, G. E. Tardiff, and F. R. McLain, "Processing of Geothermal Brine Effluents for Injection," Geothermal Resources Council, Transactions, Vol. 2, pp. 551-554, 1978.

29. Stumm, W., and J. Morgan, "Aquatic Chemistry and Introduction Emphasizing Chemical Equilibria in Natural Water," N. Y. Wiley-Interscience, 1970.

30. Cleasby, J. L., Dept. of Civil Engineering, Iowa State University, Ames, Iowa, personal communication.

31. Roebeck, Gordon, Chief of Water Research, EPA, Cincinatti, Ohio, personal communication.

32. Conley, Walter, Director of Research, Neptune Microfloc, Inc., Corvallis, Oregon, personal communication.

33. Bishop, Steve, Metcalf and Eddy Engineers, 50 Stanford Street, Boston, Massachusetts, personal communication.

34. Trussal, Rhodes, James & Montgomery Eng., 535 Walnut Street, Pasadena, California, personal communication.

35. O'Melia, C. R., "The Role of Polyelectrolytes in Filtration Processes," Nat. Tech. Information Service, EPA Report--670/2-74-032 (April 1974).

36. Montgomery, H. A. C., H. S. Thom, and A. Cockburn, "Determination of Dissolved Oxygen by the Winkler Method and the Solubility of Oxygen in Pure Water and Seawater," *J. Appl. Chem.*, V. 14 (1964), p. 280-296.

37. Davis, J. B., 1967, *Petroleum Microbiology*, Elsevier Publ. Co., Amsterdam, London, and New York.

38. Shreir, L. L., 1976, *Corrosion*, Vol. 1, 2nd Ed., Newnes-Butterworths, London and Boston.

39. Morita, R. Y., and C. E. ZoBell, 1955, Occurrence of Bacteria in Pelagic Sediments Collected during the Mid-Pacific Expedition, Deep-Sea Res., 3:66-73.

40. Zimmerman, R., and Meyer-Reil, L.-A., 1974, A New Method for Fluorescent Staining of Bacterial Populations on Membrane Filters: Kiel, Meeresforsch., V. 30, p. 24-27.

41. Watson, S. W., T. J. Novitsky, H. L. Quinby, and F. W. Valois, 1977, Determination of Bacterial Numbers and Biomass in the Marine Environment, *Appl. Environ. Microbiol.*, 33:940-946.

42. Nissenbaun, A., 1975, Microbiology and Biogeochemistry of the Dead Sea, *Mar. Ecol.*, 2:139-161.

APPENDIX I

CORE INFORMATION

THE CORE ANALYSIS DATA WHICH FOLLOW WERE TAKEN FROM BAYOU CHOCTAW WELL REPORTS PREPARED FOR DOE. THE BRINE INJECTION WELL NO. 1 REPORT WAS PREPARED BY GULF INTERSTATE ENGINEERING COMPANY, AND REPORTS FOR WELL NOS. 2 - 11 BY LOUIS RECORDS AND ASSOCIATES.

CORE INFORMATION

Well No.		Depths (ft.)	Ft. Cut	No. of Core Samples	Ft. Recovered	Performed Analyses
Well No. 1	Sidewalls Only	3694-6910		24		The Analysts
Well No. 2						
Core # 1		4042-4062	20		5	All Others By Core Laboratories
Core # 2		4062-4082	20		15	
Core # 3		4082-4102	20		0	
Core # 4		4102-4122	20		5	
Core # 5		No depths given.				
Core # 6		" " "				
Core # 7		" " "				
Core # 8		" " "				
Core # 9		" " "				
Core # 10		" " "				
Core # 11		4463-4483	20		20	
Core # 12		4924-4944	20		20	
Core # 13		4944-4964	20		17	
Core # 14		4964-4984	20		18	
Core # 15		4984-5004	20		20	
Core # 16		5004-5024	20		18	
Core # 17		5024-5044	20		18	
Core # 18		5044-5064	20		18	
Core # 19		5191-5211	20		20	
Core # 20		5211-5231	20		20	
Core # 21		5392-5412	20		18	
Core # 22		5412-5432	20		19	
Core # 23		6916-6930	14		12	
Sidewalls		3970-7045		120		
Well No. 3	Sidewalls Only	3765-7406		127		
Well No. 4	Sidewalls Only	6400-6575		36		
Well No. 5	Sidewalls Only	5110-5390		48		
Well No. 6						
Core # 1		4469-4489	20		19	
Core # 2		4489-4509	20		20	
Core # 3		4509-4529	20		5	
Sidewalls		4015-4680		99		
Well No. 7	Sidewalls Only	6640-6950		53		
Well No. 8	No Sidewalls					
Well No. 9	Sidewalls Only	4384-4699		82		
Well No. 10	Sidewalls Only	3520-7380		84		
Well No. 11	No Sidewalls, No Cores					
Well No. 12	No Data					

SIDEWALL CORE ANALYSIS

COMPANY Gulf Interstate Engineering DATE 7-26-77 FILE NO. B-7-77-368

WELL F. E. A. Disposal Well No. 1 LOCATION ______ ANALYST Smelker

FIELD Bayou Choctaw CORES Dresser/SW REMARKS ______

COUNTY-PARISH Iberville ST. La.

#	DEPTH	PERMEABILITY MILLIDARCYS KL	POROSITY %	SATURATION GAS BY VOLUME	OIL % PORE SPACE	WATER % PORE SPACE		COMB. GAS	INTERPRETATION	IN. REC.	DESCRIPTION
1	3694	4500	32.2	18.1	0.0	43.6		0	Gas	0.8	Sd: M-Crs G No Cut No Fluor
2	3765	2150	30.7	2.3	0.0	92.9		0	Water	0.5	Sd: MG No Cut No Fluo
3	4010	5050	35.0	23.5	0.0	36.1		0	Gas	0.5	Sd: M-Crs G No Cut Nc Fluor
4	4065	5275	33.5	5.0	0.0	82.1		0	Water	0.5	Sd: M-Crs. G No Cut N Fluor
5	4405	2150	34.0	5.6	0.0	83.8		0	Water	0.5	Sd: F-MG No Cut No Fluor
6	4430	4400	32.8	4.4	0.0	86.1		1	Water	0.5	Sd: M-Crs G No Cut Nc Fluor
7	5119	2650	33.2	4.1	0.0	87.8		0	Water	0.8	Sd: FG No Cut No Fluo
8	5173	1225	32.5	3.4	0.0	89.6		0	Water	0.5	Sd: FG No Cut No Fluo
9	5315	2350	33.9	4.9	0.0	88.8		0	Water	0.5	Sd: FG No Cut No Fluo
1	5435	3800	34.9	3.9	0.0	89.0		0	Water	0.8	Sd: F-MG No Cut No Fluor
1	5590	3225	33.5	4.1	0.0	87.8		0	Water	0.8	Sd: F-MG No Cut No Fluor
12	6130	1250	33.2	3.2	0.0	90.7		0	Water	0.8	Sd: FG Sli Calc No Cut Min Fluor
1	6232	1325	32.6	2.6	0.0	92.1		0	Water	0.5	Sd: FG No Cut No Fluo
1	6465	1150	32.4	4.4	0.0	86.4		0	Water	0.8	Sd: FG No Cut No Fluo
15	6500	950	30.1	3.7	0.0	88.0		0	Water	1.0	Sd: VFG W/Strks Ligni No Cut No Fluor
1	6710	1600	34.0	4.0	0.0	88.1		0	Water	0.5	Sd: VF-FG No Cut No Fluor
1	6732	1425	33.7	5.7	0.0	83.3		0	Water	0.5	Sd: FG No Cut No Fluo
18	6756	---- NO ANALYSIS----						0	Alterd Core	0.5	Sd: MG No Cut No Fluo

WELL F. E. A. Disposal Well #1

SAM NO	DEPTH	PERMEABILITY MILLIDARCYS K L	POROSITY %	SATURATION GAS BY VOLUME	SATURATION OIL % PORE SPACE	SATURATION WATER % PORE SPACE		COMB GAS	INTERPRETATION	In Rec	DESCRIPTION
19	6778	3800	35.0	4.3	0.0	88.1		0	Water	0.5	Sd: MG No Cut No Fluo
20	6798	975	33.4	3.4	0.0	90.4		0	Water	0.8	Sd: FG Sli Silty No Cut No Fluor
21	6815	---- NO ANALYSIS ----						0	Alterd Core	0.3	Sd: MG No Cut No Fluo
22	6838	2250	34.3	4.3	0.0	87.7		0	Water	0.5	Sd: FG No Cut No Fluor
23	6855	2600	33.7	4.2	0.0	87.5		0	Water	0.5	Sd: F-MG No Cut No Fluor
24	6910	2325	33.8	14.8	0.0	59.2		0	Gas	0.5	Sd: F-MG No Cut No Fluor

Company: GULF INTERSTATE ENGINEERING

Well: F.E.A. Disposal Well No. 1

Field: Bayou Choctaw Parish: Iberville

State: La. Type: Sch. SW Date: 7-26-77

SAND GRAIN SIEVE ANALYSIS

SCREEN SIZES

Number	Tyler Mesh	Opening mm	Opening Inches	3694 % RET.	3694 % CUM.	% RET.	% CUM.	% RET.	% CUM.	% RET.	% CUM.	% RET.	% CUM.	% RET.	% CUM.
	28	.594	.0234	30.0	30.0										
Coarse Grain	35	.419	.0165	32.4	62.4										
	48	.297	.0117	14.8	77.2										
Medium Grain	60	.249	.0098	4.6	81.8										
	80	.178	.0070	6.4	88.2										
100	100	.150	.0059	2.3	90.5										
120 Fine Grain	115	.124	.0049	0.9	91.4										
140	150	.104	.0041	0.4	91.8										
170	170	.089	.0035	0.9	92.7										
2.	200	.074	.0029	0.9	93.6										
: Very Fine Grain	250	.064	.0025	1.3	94.9										
?	270	.053	.0021	1.3	96.2										
:	325	.043	.0017	1.9	98.1										
Silt	BOTTOM			1.9	100.0										
	TOTAL			100	100										

PART 1
CONVENTIONAL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No. 2
BAYOU CHOCTAW

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
4042.0-43.0	3420	35.6	96.8	1.2	SD F-MG CLEAN
4043.0-44.0	2310	37.3	96.2	1.4	SD F-MG CLEAN
4044.0-45.0	6140	35.7	90.8	3.3	SD F-MG CLEAN
4046.0-47.0	5790	34.5	94.8	1.8	SD F-MG CLEAN
4048.0-49.0	2880	34.4	92.3	2.7	SD MG CLEAN
4049.0-62.0					LOST CORE
4062.0-67.9					LOST CORE
4067.9-69.0					SHALE GY CALC
4069.0-70.0					SHALE GY (90% MUD)
4070.0-74.0					MUDCAKE
4074.0-77.0					SHALE GY CALC
4077.0-82.0					LOST CORE
4082.0-02.0					LOST CORE
4102.0-17.0					LOST CORE
4117.0-19.2					SHALE GY SSLTY
4119.2-22.0					MUD

DOE - LOUIS RECORDS
BRINE INJ. WELL No. 2
BAYOU CHOCTAW

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
4463.0-63.5					SHALE
4463.5-63.7	150	37.5	79.9	7.6	SD FG CLEAN
4463.7-67.0					SHALE
4467.0-68.0	155	34.8	77.9	7.7	SD VFG SSHY(LAM)
4468.0-73.0					SHALE SSLTY
4473.0-74.0	820	32.4	85.3	4.8	SD VFG SSHY(LAM)
4474.0-75.0	860	36.4	90.7	3.4	SD FG CLEAN
4475.0-76.0	720	36.7	97.2	1.0	SD FG CLEAN
4476.0-77.0	1530	36.5	84.2	5.8	SD FG SSHY
4477.0-78.0	1740	34.9	85.9	4.9	SD FG CLEAN
4478.0-81.0					SD FG CLEAN (80% MUD)

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
4481.0-82.0	2720	37.3	87.1	4.8	SD FG CLEAN
4482.0-83.0					LOST CORE
4924.0-25.0	1960	37.7	86.5	5.1	SD MG CLEAN
4925.0-26.0	2700	38.8	90.1	3.9	SD MG CLEAN
4926.0-27.0	1500	37.6	91.7	3.1	SD MG CLEAN
4927.0-28.0	1770	37.4	92.2	2.9	SD F-MG CLEAN
4928.0-29.0	1600	37.0	97.8	0.8	SD MG CLEAN
4929.0-30.0	2430	38.2	90.6	3.6	SD F-MG CLEAN
4930.0-31.0	1690	38.3	84.2	6.0	SD MG CLEAN
4931.0-32.0	1960	39.6	88.0	4.8	SD MG CLEAN
4932.0-33.0	1500	34.4	89.9	3.5	SD MG CLEAN
4933.0-34.0	3770	34.7	94.0	2.1	SD FG CLEAN
4934.0-35	305	37.3	87.7	4.6	SD FG CLEAN
4935.0-36.0					SD FG SSHY (80% MUD)
4936.0-37.0	76	36.5	90.9	3.3	SD FG SSHY-SHY(LAM)
4937.0-38.0	97	31.0	98.0	0.6	SD FG SSHY
4938.0-39.0	10	29.0	98.6	0.4	SD FG SSHY(LAM)
4939.0-40.0	10	30.9	91.7	2.6	SD FG VSSHY(LAM)
4940.0-41.0	450	31.3	93.6	2.0	SD FG VSSHY
4941.0-42.0					SD FG CLEAN (80% MUD)
4942.0-43.0					SD FG SHY(60% MUD)
4943.0-44.0	645	33.5	88.6	3.8	SD FG CLEAN
4944.0-45.0	1470	37.3	88.2	4.4	SD FG CLEAN
4945.0-46.0	1310	37.9	90.7	3.5	SD FG CLEAN
4946.0-47.0					SD FG SSHY (50% MUD)
4947.0-50.0					SD FG SSHY-SHY (60% MUD)

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
4991.0-02.0					SD FG CLEAN (90% MUD)
5002.0-03.0		33.6	92,3	2,6	SD VFG SSHY
5003.0-04.0		33.8	94,4	1,9	SD VFG SSHY
5004.0-05.0					SD VFG SHY (60% MUD)
5005.0-08.0		33.3	89.8	3,4	SD VFG SHY
5008.0-09.0		28.6	89.1	3,1	SD VFG SHY FOSS
5009.0-10.0		27,1	87,6	3,4	SD VFG VSHY SFOSS
5010.0-11.0					SD VFG SHY FOSS (50% MUD)
5011.0-12.0		34.6	95,6	1,5	SD VF-FG SHY
5012.0-03.0		37.4	96,8	1,2	SD FG SSHY
5013.0-14.0		33,2	93.8	2,1	SD FG SHY FOSS
5014.0-16.0					SD FG SHY SFOSS (80% MUD)
5016.0-17.0		26,2	88,4	3,0	SD FG SHY SFOSS
5017.0-18.0		35,5	87,2	4,6	SD FG SHY
5018.0-19.0		34,3	92,0	2,8	SD VF-FG SSHY
5019.0-20.0		38,4	94,6	2,1	SD VF-FG CLEAN
5021.0-22.0		28,4	86,0	4,0	SD VF-FG SHY VFOSS
5022.0-24.0					LOST CORE
5024.0-25.0	895	27,9	83.0	4,7	SD VFG SHY(LAM) FOSS
5025.0-26.0	430	23,7	77,8	5,3	SD VFG SHY(LAM) FOSS
5026.0-27.0					SHALE GY W/FG SD INCL
5027.0-28.0					SHALE DK GY LIG SDY
5028.0-29.0					SHALE DK GY W/FG SD INCL
5029.0-30.0					SHALE GY SSDY
5030.0-30.5					SHALE GY-GRN GLAU SSDY
5030.5-31.0	485	35,4	84,4	5,5	SD FG SLTY

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
4950.0-52.0					SD VFG VSHY (60% MUD)
4952.0-53.0					SD FG SHY FOSS (50% MUD)
4953.0-55.0					SD FG SSHY (70% MUD)
4955.0-56.0					SHALE SLTY
4956.0-58.0					SD FG SSHY (80% MUD)
4958.0-60.0					SD VFG SSHY (50% MUD)
4960.0-61.0					SHALE SLTY
4961.0-64.0					LOST CORE
4964.0-65.0					SHALE GY
4965.0-65.9					MUD
4965.9-66.6		39.0	92.6	2.9	SD VFG SSHY (25% MUD)
4966.6-67.0					MUD
4967.0-73.0					SHALE GY
4973.0-77.8					SHALE GY SSLTY
4977.9-79.0		35.7	92.4	2.7	SD VFG SSHY FOSS
4979.0-80.0		38.1	91.7	3.2	SD VFG SHY FOSS
4980.0-81.0		30.6	90.2	3.0	SD FG SHY FOSS
4981.0-82.0					SD FG SHY (50% MUD)
4982.0-84.0					MUD
4984.0-85.0		40.5	94.9	2.5	SD FG CLEAN SFOSS
4985.0-86.0		37.5	94.5	2.1	SD FG SSHY SFOSS (10% MUD)
4986.0-87.0					SD FG SHY SFOSS (90% MUD)
4987.0-88.0		33.3	83.3	5.6	SD FG CLEAN
4988.0-89.0		41.9	91.1	3.7	SD FG CLEAN
4989.0-90.0		38.8	83.9	6.3	SD FG CLEAN
4990.0-91.0		35.6	89.2	3.8	SD FG CLEAN

DOE - LOUIS RECORDS
BRINE INJ. WELL No. 2
BAYOU CHOCTAW

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
5031.0-32.0	1030	34.9	82.5	6.1	SD FG CLEAN
5032.0-33.0	720	28.7	90.4	2.8	SD FG CLEAN
5033.0-34.0	57	34.7	80.8	6.7	SD VF-FG VSLTY
5034.0-35.0	625	36.9	88.0	4.4	SD VF-FG VSLTY
5035.0-36.0					SHALE GY SLTY
5036.0-37.0	<0.1	32.0	81.0	6.1	SILT VSHY
5037.0-38.0	4.0	22.2	88.9	2.5	SILT VSHY(LAM)
5038.0-39.0	1.6	25.0	87.3	3.2	SD VFG VSHY
5039.0-40.0	15	19.6	84.4	3.1	SD VFG VSHY LIG
5040.0-41.0	0.8	20.0	77.3	4.6	SD VFG VSHY LIG
5041.0-41.5	200	34.5	90.2	3.4	SD VFG SSHY SLTY
5041.5-42.0	5.8	27.8	85.1	4.1	SD VFG SSHY-SHY SLTY
5042.0-44.0					LOST CORE
5044.0-45.0					SHALE GY SCALC
5045.0-45.5					SHALE GY SCALC
5045.5-46.0					MUD
5046.0-48.0					SHALE SLTY SDY
5048.0-52.0					SD VFG SSHY (80% MUD)
5052.0-55.0					SHALE GY
5055.0-56.0					SHALE GY SSLTY
5656.0-59.0					SHALE GY
5059.0-60.0					SHALE GY SFOSS
5060.0-61.0					SHALE GY
5061.0-62.0					SHALE GY FOSS
5062.0-64.0					LOST CORE
5191.0-02.0					SHALE GY SLTY SCALC

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
5202.0-03.0	415	37.1	94.3	2.1	SD FG VSSHY
5203.0-04.0	745	37.2	88.8	4.2	SD FG CLEAN
5204.0-05.0	250	38.8	91.3	3.4	SD FG CLEAN
5205.0-06.0	975	38.4	88.2	4.6	SD FG CLEAN
5206.0-07.0	375	38.6	90.5	3.7	SD FG CLEAN
5207.0-08.0					SHALE GY SLTY SDY
5208.0-09.0	965	38.7	94.1	2.3	SD FG CLEAN
5209.0-10.0					SHALE GY
5210.0-11.0					SHALE W/TR FG SD
5211.0-12.0	920	31.1	80.0	6.2	SD FG SSLTY
5212.0-13.0	1340	29.5	90.0	3.0	SD FG CLEAN
5213.0-14.0	110	35.3	96.6	1.2	SD FG CLEAN
5214.0-15.0	810	35.1	96.4	1.3	SD VF-FG SSLTY
5215.0-16.0	335	35.1	94.5	1.9	SD VF-FG CLEAN
5216.0-17.0	345	34.4	95.4	1.6	SD VFG SSLTY
5217.0-18.0	825	38.1	87.5	4.8	SD VFG CLEAN
5218.0-19.0	485	38.3	87.7	4.7	SD VF-FG CLEAN
5219.0-20.0	170	36.7	87.7	4.5	SD FG CLEAN
5220.0-21.0	1240	28.7	94.9	1.5	SD VFG CLEAN
5221.0-22.0	325	36.0	95.5	1.6	SD FG CLEAN
5222.0-23.0	295	37.1	93.4	2.5	SD FG CLEAN
5223.0-24.0	380	32.7	91.7	2.7	SD FG CLEAN
5224.0-25.0	215	33.7	93.1	2.3	SD FG CLEAN
5225.0-26.0	1580	33.0	85.9	4.7	SD FG CLEAN
5226.0-27.0	1360	33.2	87.8	4.1	SD FG CLEAN
5227.0-28.0	2420	33.3	88.0	4.0	SD FG CLEAN
5228.0-29.0	1090	32.8	92.3	2.5	SD FG CLEAN
5229.0-30.0	925	24.2	91.3	2.1	SD VF-FG VSHY(LAM) SSLTY
5230.0-31.0	545	25.0	84.4	3.9	SD FG SHY-VSHY SSLTY

DOE - LOUIS RECORDS
BRINE INJ. WELL No. 2
BAYOU CHOCTAW

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
5392.0-93.0	115	36.1	95.7	1.6	SD FG CLEAN
5393.0-94.0	2000	39.0	90.3	3.8	SD FG CLEAN
5394.0-95.0	1270	34.5	96.6	1.2	SD FG CLEAN
5395.0-96.0	1060	33.5	95.2	1.6	SD FG CLEAN
5396.0-97.0	385	36.0	89.7	3.7	SD FG CLEAN
5397.0-98.0	545	34.6	93.3	2.3	SD FG CLEAN
5398.0-99.0	330	37.4	86.3	5.1	SD FG CLEAN
5399.0-00.0	270	34.9	88.7	3.9	SD FG CLEAN
5400.0-01.0	260	32.6	95.2	1.6	SD FG SLTY
5401.0-02.0	29	26.2	92.6	1.9	SD FG SLTY
5402.0-03.0	705	34.4	84.6	5.3	SD FG CLEAN
5403.0-04.0	225	30.7	93.7	1.9	SD FG CLEAN
5404.0-05.0	340	37.2	84.1	5.9	SD FG CLEAN
5405.0-06.0	700	27.8	90.9	2.5	SD FG SSLTY
5406.0-07.0	285	27.3	96.1	1.1	SD FG SSHY(LAM)
5407.0-08.0	1.3	30.7	91.7	2.6	SD FG SSHY(LAM)
5408.0-09.0	280	30.5	85.4	4.4	SD FG CLEAN
5409.0-10.0	150	30.3	88.6	3.5	SD FG SSHY(LAM)
5410.0-12.0					LOST CORE

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
5412.0-13.0	1800	38.1	85.6	5.5	SD FG CLEAN
5413.0-14.0	1510	34.8	94.8	1.8	SD FG VSSHY(LAM)
5414.0-15.0	845	35.5	96.1	1.4	SD FG CLEAN
5415.0-16.0	1750	36.3	94.2	2.1	SD FG CLEAN
5416.0-17.0	2120	34.7	87.4	4.4	SD FG CLEAN
5417.0-18.0	1050	35.6	89.0	2.0	SD FG CLEAN SFOSS
5418.0-19.0	1360	35.3	88.2	4.2	SD FG CLEAN SFOSS
5419.0-20.0	1620	35.8	92.8	2.6	SD FG CLEAN SFOSS
5420.0-21.0	1620	35.6	93.3	2.4	SD FG CLEAN
5421.0-22.5	1520	36.3	88.4	4.2	SD FG CLEAN SFOSS
5422.5-23.5	1050	37.1	88.7	4.2	SD FG VSSHY(LAM)
5423.5-26.0					MUD
5426.0-27.0	23	24.4	81.5	4.5	SD FG W/MANY SHALE INCL
5427.0-28.0	970	36.2	95.4	1.7	SD FG CLEAN
5428.0-29.0	930	35.7	95.0	1.8	SD FG CLEAN
5429.0-30.0	1020	36.5	94.7	1.9	SD FG CLEAN
5430.0-31.5	1700	36.9	96.0	1.5	SD FG CLEAN
5431.5-32.0					LOST CORE
6916.0-17.0	3890	33.0	89.4	3.5	SD MG CLEAN
6917.0-18.0	4230	32.4	86.0	4.6	SD MG CLEAN
6918.0-19.0	2810	32.7	83.5	5.4	SD MG CLEAN
6919.0-20.0	2950	35.3	77.2	8.1	SD MG CLEAN

DOE - LOUIS RECORDS
BRINE INJ. WELL No. 2
BAYOU CHOCTAW

DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
6920.0-21.0	4200	33.8	83,3	5,6	SD MG CLEAN
6921.0-22.0	4330	33,7	83.3	5,6	SD MG CLEAN
6922.0-23.0	3310	33.3	82,9	5,7	SD MG CLEAN
6923.0-24.0	3780	33,4	84,7	5,1	SD MG CLEAN
6924.0-25.0	4270	31.9	83,8	5,2	SD M-CG CLEAN
6925.0-26.0	4220	32.4	83,6	5,3	SD MG CLEAN
6926.0-27.0	4490	32,9	90,5	3,1	SD M-CG CLEAN
6927.0-28.0	4530	31,6	91,3	2,7	SD M-CG CLEAN
6928.0-30.0					LOST CORE

PART 2
SIDEWALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No. 2
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
	3970.0					EMPTY BOTTLE
1.0	4067.0	3600	31,3	89,7	3,2	SD F-MG CLEAN
1.0	4077.0	4500	32,1	90,2	3,2	SD M-CG CLEAN
1,3	4120.0	0.1	15.9	85,0	2,4	SILT VSHY(LAM) CALC
1.3	4150.0	4600	33,6	92,4	2,6	SD MG CLEAN
	4170.0					EMPTY BOTTLE
0.3	4190.0					SD MG CLEAN CALC
1,0	4210.0	5600	35,6	89,3	3,8	SD MG CLEAN
1.3	4520.0	3000	33,6	84,5	5,2	SD F-MG CLEAN
1.3	4550,0	3600	32.9	92.8	2,4	SD F-MG CLEAN
1.3	4580.0	2700	32,7	91,8	2,7	SD F-MG CLEAN
0.5	4650.0					MUDCAKE
0.5	4670.0	2500	31,5	84,6	4,8	SD F-MG SSLTY
1.0	4690.0	2200	32.9	84.5	5,1	SD FG CLEAN
1.0	4920.0	1100	31.2	85,6	4,5	SD VF-FG CLEAN

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
1.0	4950.0	1250	33.3	85.3	4.9	SD VF-FG CLEAN
1.0	4960.0	66	25.1	80.4	4.9	SD VF-FG SHY(LAM) CALC
0.8	4992.0	91	26.1	80.1	5.2	SD FG SHY
1.0	5000.0	1650	31.3	83.9	5.0	SD FG VSSHY
1.2	5010.0	1250	32.4	91.3	2.8	SD VFG CLEAN
1.0	5030.0	370	29.9	90.0	3.0	SD VFG SSHY FOSS.
1.0	5100.0	750	30.7	94.5	1.7	SD VFG SSHY FOSS
1.0	5110.0	185	27.3	76.3	6.5	SD VFG SSHY VSLTY CALC
1.0	5120.0	1400	31.4	93.8	1.9	SD VFG CLEAN
1.0	5130.0	1650	34.2	89.5	3.6	SD VFG SSLTY
1.2	5215.0	9.8	18.4	69.8	5.5	SD VFG VSHY(LAM)
	5220.0					EMPTY BOTTLE
	5225.0					EMPTY BOTTLE
0.5	5235.0	1350	32.1	80.0	6.4	SD VF-FG CLEAN
1.0	5250.0	2500	34.8	85.1	5.2	SD FG CLEAN
1.0	5270.0	1250	31.5	92.1	2.5	SD VFG CLEAN
1.0	5400.0	1100	30.7	85.1	4.6	SD VFG CLEAN
1.0	5410.0	900	32.2	84.1	5.1	SD VFG SLTY
1.0	5420.0	2750	34.1	83.3	5.7	SD VF-FG SSLTY
1.0	5425.0	440	28.8	82.6	5.0	SD VFG SLTY
1.0	5430.0	1550	33.3	75.5	8.1	SD VF-FG CLEAN
1.0	5450.0	1200	32.0	79.0	6.7	SD VFG SSLTY
1.0	5470.0	2750	32.1	94.3	1.8	SD FG CLEAN

DOE - LOUIS RECORDS
BRINE INJ. WELL No.2
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
1.0	5660.0	1900	31.7	84.6	4.9	SD FG CLEAN
1.0	5680.0	2200	33.1	81.4	6.2	SD FG CLEAN
0.5	5700.0					MUDCAKE
1.0	5720.0	2500	32.7	80.8	6.3	SD FG CLEAN
0.3	5740.0					SD FG CLEAN
0.5	5820.0					MUDCAKE
0.5	5830.0					SD FG CLEAN(50% MUD)
1.0	5840.0	1700	31.6	82.0	5.7	SD FG CLEAN
0.8	6230.0	1870	32.0	79.0	6.7	SD FG CLEAN
1.0	6240.0	2050	32.3	82.7	5.6	SD VF-FG CLEAN
0.1	6250.0					MUDCAKE
0.1	6260.0					SD FG CLEAN(60% MUD)
1.0	6360.0	1500	33.1	80.5	6.5	SD VF-FG CLEAN
1.0	6370.0	1400	32.4	91.3	2.8	SD VFG CLEAN
1.0	6380.0	1100	30.6	92.9	2.2	SD VF-FG CLEAN
1.0	6510.0	1380	33.3	87.0	4.3	SD VFG CLEAN
1.8	6520.0	69	24.7	82.6	1.3	SD VFG SHY SCALC
0.5	6530.0	2300	34.8	90.9	3.2	SD FG CLEAN
0.5	6540.0	64	27.7	78.8	5.9	SD VFG VSLTY
0.8	6550.0	2200	33.7	85.5	4.9	SD FG CLEAN
0.8	6560.0	2250	33.6	81.6	6.2	SD FG CLEAN SCALC
0.5	6570.0					EMPTY BOTTLE
0.5	6580.0	1670	32.6	90.9	3.0	SD FG CLEAN

DOE - LOUIS RECORDS
BRINE INJ. WELL No.2
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM. MD(*)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
1.0	6590.0	1370	32.8	87.3	4.2	SD FG CLEAN
1.0	6600.0	2600	34.8	82.5	6.1	SD F-MG CLEAN
1.0	6610.0	225	27.5	82.6	4.8	SD VF-FG SLTY
0.5	6620.0	520	29.5	61.3	11.4	SD VFG SSLTY
0.5	6630.0	1150	32.8	79.5	6.7	SD VFG CLEAN
0.5	6640.0	1250	31.0	81.0	5.9	SD FG SSLTY
1.3	6755.0	110	26.9	79.6	5.5	SD VFG SHY SSLTY
0.5	6760.0	1570	31.8	94.1	1.9	SD FG CLEAN
0.5	6765.0	650	29.1	81.9	5.3	SD VFG SSLTY
1.0	6770.0	850	32.5	83.2	5.5	SD VFG SSHY(LAM) SSLTY
1.8	6775.0	2.7	17.3	76.6	4.0	SILT VSHY(LAM)
1.0	6780.0	1270	34.8	87.7	4.3	SD VFG CLEAN SCALC
0.8	6785.0	980	30.5	84.4	4.8	SD VFG CLEAN SCALC
0.5	6790.0	1360	33.2	81.1	6.3	SD VF-FG CLEAN SCALC
1.0	6795.0	225	26.8	81.6	4.9	SD VFG SSHY SLTY
1.0	6800.0	1350	34.8	85.3	5.1	SD FG CLEAN
0.5	6805.0	1290	33.8	89.2	3.6	SD FG CLEAN
0.8	6810.0	4.4	21.0	86.3	2.9	SILT VSHY(LAM) VCALC
0.8	6815.0	3000	34.4	82.8	5.9	SD FG CLEAN
1.0	6820.0	1280	32.6	90.5	3.1	SD FG CLEAN
1.5	6825.0	1370	36.6	88.6	4.2	SD VF-FG CLEAN
0.5	6830.0	1310	32.4	90.1	3.2	SD FG CLEAN
0.8	6835.0	1200	30.8	88.2	3.6	SD FG CLEAN
0.5	6840.0	1650	33.8	86.6	4.5	SD FG CLEAN
0.8	6845.0	1420	34.2	90.0	3.4	SD FG CLEAN
0.5	6850.0	430	27.3	93.3	1.8	SD VFG SLTY
0.5	6855.0	1050	32.0	89.9	3.2	SD FG CLEAN
0.8	6860.0	1480	34.8	87.0	4.5	SD VFG CLEAN
0.5	6880.0	2200	34.7	88.2	4.1	SD FG CLEAN
0.3	6885.0					MUDCAKE

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
0.5	6890.0	2900	34.2	84.4	5.3	SD F-MG CLEAN
0.5	6895.0	1020	31.6	87.5	3.9	SD VFG CLEAN
0.5	6900.0					MUDCAKE
1.0	6904.0	5600	35.8	80.7	6.9	SD MG CLEAN
	6910.0					EMPTY BOTTLE
0.5	6914.0	6500	30.2	87.9	3.7	SD CG CLEAN
	6918.0					EMPTY BOTTLE
0.5	6922.0					MUDCAKE
0.3	6926.0					MUD W/TR FG SD
	6930.0					EMPTY BOTTLE
0.5	6935.0	5600	34.7	91.3	3.0	SD M-CG CLEAN
0.3	6940.0					MUDCAKE
0.5	6945.0	750	30.0	87.9	3.6	SD MG SLTY
0.3	6950.0					SD MG CLEAN
1.0	6960.0	4500	34.4	78.5	7.4	SD F-MG CLEAN
0.8	6965.0	2200	33.6	82.0	6.0	SD FG LIG(LAM)
1.0	6970.0	210	26.0	86.2	3.6	SD FG SHY(LAM)
0.5	6975.0					MUD W/TR FG SD
0.5	6980.0	1310	30.2	87.5	3.8	SD FG CLEAN
0.8	6985.0	900	30.8	81.8	5.6	SD FG CLEAN
1.0	6997.0	160	28.1	84.7	4.3	SD VFG SHY(LAM)
1.0	7007.0	990	30.6	88.9	3.4	SD FG VSSHY
0.8	7018.0	1100	30.4	90.1	3.0	SD VF-FG CLEAN
0.8	7025.0	255	28.8	86.7	3.8	SD FG SHY
1.0	7030.0	1400	32.7	84.3	5.2	SD FG CLEAN
1.3	7035.0	1850	34.7	80.5	6.8	SD FG CLEAN
1.8	7040.0	300	27.6	77.5	6.2	SD VF-FG SSHY(LAM)
1.0	7045.0	520	27.7	75.6	6.8	SD VF-FG SSHY(LAM)

SIDE WALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.3
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.0	3765.0	1550	30.6	83.3	5.1	35	SD FG CLEAN CALC NO FLU
1.2	3770.0	2300	31.4	86.3	4.3	35	SD FG CLEAN CALC NO FLU
1.2	3780.0	2200	31.2	86.8	4.1	35	SD FG CLEAN CALC NO FLU
1.0	3810.0	2500	31.8	85.4	4.6	35	SD F-MG CLEAN CALC NO FLU
1.0	3830.0	3800	31.9	88.8	3.6	35	SD MG CLEAN CALC NO FLU
1.0	3920.0	3000	32.0	88.2	3.8	35	SD F-MG CLEAN CALC NO FLU
1.0	3940.0	3100	31.6	89.7	3.3	35	SD MG CLEAN NO FLU
1.0	3960.0	3100	31.5	89.6	3.3	35	SD MG CLEAN NO FLU
1.0	4070.0	3820	32.0	85.0	4.8	35	SD MG CLEAN NO FLU
1.0	4090.0	3900	32.1	86.5	4.3	35	SD MG CLEAN NO FLU
0.3	4110.0						SD C-MG W/PEBBLES NO FLU
0.3	4150.0	5500	33.0	83.8	5.4	36	SD MG CLEAN NO FLU
0.8	4180.0	5600	33.7	88.9	3.7	37	SD MG CLEAN NO FLU
0.2	4190.0						SD FG SSLTY NO FLU
0.5	4210.0						SD C-MG W/PEBBLES NO FLU
0.5	4360.0	1900	31.1	85.7	4.4	35	SD FG CLEAN CALC NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.3
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.0	4410.0	1380	30.6	81.8	5.6	35	SD VF-FG SSLTY CALC NO FLU
1.0	4430.0	2050	31.0	83.5	5.1	35	SD FG CLEAN NO FLU
	4450.0						EMPTY BOTTLE
0.8	4470.0	1300	30.1	79.6	6.1	35	SD FG VSSHY NO FLU
0.5	4500.0						MUDCAKE
	4520.0						EMPTY BOTTLE
	4550.0						EMPTY BOTTLE
0.8	4580.0	2700	32.2	85.2	4.8	36	SD F-MG CLEAN NO FLU
	4600.0						EMPTY BOTTLE
	4610.0						EMPTY BOTTLE
	4620.0						EMPTY BOTTLE
	4630.0						EMPTY BOTTLE
1.0	4640.0	2460	31.9	86.8	4.2	36	SD F-MG CLEAN NO FLU
1.0	4660.0	2230	31.6	90.5	3.0	35	SD F-MG CLEAN NO FLU
	4670.0						EMPTY BOTTLE
1.0	4680.0	5100	33.8	87.8	4.1	37	SD MG CLEAN NO FLU
1.0	4690.0	2700	33.3	82.9	5.7	37	SD MG SSHY(LAM) CALC NO FLU
1.0	4720.0	2500	31.0	84.7	4.7	35	SD MG CLEAN NO FLU
1.0	4920.0	2840	33.1	92.3	2.5	37	SD FG CLEAN NO FLU
0.5	4930.0	2230	32.0	87.2	4.1	36	SD F-MG CLEAN NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.3
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	GAS DET	CRIT WTR%	DESCRIPTION
1.0	4980.0	3300	32.5	84.6	5.0	0	36	SD F-MG CLEAN NO FLU
1.0	5100.0	2100	31.5	90.7	2.9	0	35	SD FG CLEAN NO FLU
1.3	5110.0					0		SHALE CALC
1.3	5160.0	38	24.1	82.8	4.1	0	60	SD VFG SHY(LAM) NO FLU
1.2	5170.0	4800	33.0	83.6	5.4	0	36	SD MG CLEAN NO FLU
1.2	5180.0	2050	30.8	90.3	3.0	0	35	SD MG CLEAN NO FLU
1.3	5190.0	3.0	18.1	87.0	2.4	0	69	SD FG VSHY LMY NO FLU
1.0	5200.0	1750	30.8	88.9	3.4	0	35	SD FG CLEAN NO FLU
1.3	5227.0	4.1	19.1	76.2	4.6	0	70	SD VFG VSHY SLTY NO FLU
1.2	5400.0	1820	32.3	88.9	3.6	0	36	SD VF-FG CLEAN NO FLU
1.3	5430.0	2.6	16.1	86.8	2.1	0	66	SD VFG VSHY NO FLU
1.2	5476.0	3000	33.9	89.5	3.6	0	37	SD FG CLEAN SFOSS NO FLU
1.3	5488.0					0		SHALE CALC
1.2	5670.0	3600	33.2	90.8	3.1	0	36	SD F-MG CLEAN NO FLU
1.2	5680.0	4600	33.0	91.4	2.8	0	36	SD MG CLEAN NO FLU
1.0	5690.0	3370	33.5	88.5	3.9	0	37	SD FG CLEAN NO FLU
0.2	5700.0					0		SD F-MG CLEAN NO FLU
0.3	5707.0					0		SD F-MG CLEAN NO FLU
1.0	5720.0	2960	33.2	86.7	4.4	0	37	SD F-MG CLEAN NO FLU
1.0	5727.0	4.8	19.5	84.6	3.0	0	70	SD VFG VSHY(LAM) SLTY CALC NO FLU
1.0	6130.0	2420	31.5	86.8	4.1	0	35	SD FG CLEAN SCALC NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.3
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	GAS DET	CRIT WTR%	DESCRIPTION
1.2	6140.0	9.6	20.3	76.6	4.8	0	68	SD VF-FG VSHY(LAM) SFOSS NO FLU
1.3	6190.0	3100	33.2	87.5	4.1	0	36	SD FG CLEAN NO FLU
1.2	6200.0	2280	31.9	81.0	6.0	0	36	SD FG VSSHY NO FLU
1.0	6210.0	3.5	15.9	79.2	3.3	0	65	SD FG VSLTY LMY(HARD) MIN FLU
1.0	6220.0	420	27.8	77.5	6.3	0	39	SD FG VSSHY SLTY SLMY SPTS MIN FLU
1.3	6234.0	6.9	18.5	57.1	7.9	0	66	SD FG VSHY SFOSS SPT MIN FLU
1.2	6320.0	2650	32.4	86.2	4.5	0	36	SD FG CLEAN NO FLU
1.2	6330.0	1800	31.6	83.6	5.2	0	36	SD FG SLTY NO FLU
1.0	6342.0	180	26.7	78.8	5.7	0	46	SD FG SHY NO FLU
1.0	6470.0	3300	32.6	86.5	4.4	0	36	SD MG CLEAN NO FLU
1.0	6480.0	2900	33.7	85.7	4.8	0	37	SD FG CLEAN NO FLU
1.0	6490.0	4600	34.1	87.3	4.3	0	37	SD F-MG CLEAN NO FLU
1.0	6500.0	2650	32.7	88.6	3.7	0	36	SD FG SSLTY NO FLU
1.3	6510.0	3440	33.0	89.7	3.4	0	36	SD MG CLEAN NO FLU(I EMPTY BOTTLE)
1.0	6520.0	3320	32.9	85.0	4.9	0	36	SD F-MG CLEAN NO FLU
1.0	6530.0	3460	33.1	86.6	4.4	0	36	SD F-MG CLEAN NO FLU
0.8	6540.0	240	28.5	85.2	4.2	0	44	SD VFG VSLTY NO FLU
1.0	6550.0	2610	32.7	84.9	4.9	0	36	SD F-MG SSLTY NO FLU
1.0	6560.0	3230	32.8	90.2	3.2	0	36	SD F-MG CLEAN NO FLU
1.0	6570.0	1420	31.7	88.5	3.7	0	36	SD VF-FG SSLTY NO FLU
1.0	6580.0	2700	32.6	85.0	4.9	0	36	SD FG SSLTY NO FLU
1.2	6590.0	1.3	18.6	82.1	3.3	0	72	SILT VSHY(LAM) VCALC NO FLU
0.3	6599.0					0		SHALE SDY VCALC NO FLU
0.5	6720.0	2540	32.0	83.3	5.3	0	36	SD FG SSLTY NO FLU
1.0	6730.0	155	26.5	77.1	6.1	0	43	SD FG SHY(LAM) SCALC NO FLU
1.0	6741.0	26	23.2	73.7	6.1	0	62	SD FG SHY(LAM) CALC NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.3
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	GAS DET	CRIT WTR%	DESCRIPTION
0.5	6750.0	3310	33.8	90.9	3.1	0	37	SD FG CLEAN NO FLU
1.0	6754.0	3280	33.7	91.5	2.9	0	37	SD FG CLEAN NO FLU
0.5	6759.0	2900	33.1	86.2	4.6	0	36	SD VF-FG CLEAN NO FLU
1.0	6770.0	2750	32.8	95.0	1.6	0	36	SD VF-FG CLEAN NO FLU
1.0	6775.0	3150	33.0	92.2	2.6	0	36	SD FG CLEAN NO FLU
1.0	6780.0	1960	32.8	88.4	3.8	0	37	SD FG SLTY NO FLU
1.0	6790.0	1900	32.5	90.9	3.0	0	36	SD VF-FG SSLTY NO FLU
0.5	6792.0	1050	31.7	85.0	4.8	0	37	SD VFG SSLTY NO FLU
1.0	6800.0	1720	31.0	91.4	2.7	0	35	SD FG SSLTY NO FLU
1.0	6810.0	2250	31.6	84.6	4.9	0	35	SD FG SSLTY NO FLU
0.8	6820.0	0.6	17.1	71.5	4.9	0	72	SD FG VSHY NO FLU
1.2	6827.0					0		SHALE VSSDY NO FLU
1.4	6831.0	110	26.3	76.2	6.3	0	51	SD VFG SHY(LAM) NO FLU
1.0	6839.0	6400	34.9	87.7	4.3	0	38	SD M-CG CLEAN NO FLU
	6850.0							EMPTY BOTTLE
0.8	6860.0	5300	33.7	90.3	3.3	0	37	SD MG CLEAN NO FLU
0.5	6870.0	310	27.9	84.2	4.4	0	42	SD VF-FG VSLTY NO FLU
0.3	6880.0	285	27.2	85.2	4.0	0	42	SD VFG VSLTY NO FLU
1.0	6890.0	3200	33.0	78.7	7.0	0	36	SD F-MG CLEAN NO FLU
1.0	6900.0	3020	32.6	79.5	6.7	0	36	SD F-MG SSLTY NO FLU
1.2	6910.0	4250	34.3	80.9	6.6	0	37	SD F-MG CLEAN NO FLU
1.0	6920.0	3140	32.5	85.2	4.8	0	35	SD F-MG CLEAN NO FLU
0.5	6929.0	2950	33.0	85.7	4.7	0	36	SD FG CLEAN NO FLU
1.0	6940.0	3190	33.1	84.5	5.1	0	36	SD F-MG SSLTY NO FLU
1.0	6950.0	1500	31.6	83.1	5.3	0	36	SD VF-FG SSLTY NO FLU
1.0	6965.0	230	27.0	75.7	6.6	0	44	SD VF-FG SSHY-SHY NO FLU
	6970.0							EMPTY BOTTLE
1.3	6975.0					0		SHALE SLMY
1.0	6931.0	3.9	18.3	75.0	4.6	0	68	SD VF-FG SHY-VSHY VLMY(LAM) SPT MIN
1.0	6935.0	120	27.5	76.1	6.6	0	51	SD VF-FG SSHY LMY NO FLU
0.4	6939.0					0		MUDCAKE W/TR FG SD
1.0	6992.0	2830	32.7	89.6	3.4	0	36	SD FG CLEAN NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.3
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	GAS DET	CRIT WTR%	DESCRIPTION
1.0	7000.0					0		MUDCAKE W/TR FG SD
1.0	7010.0	3170	32.9	92.0	2.6	0	36	SD F-MG CLEAN CALC NO FLU
1.2	7020.0	2910	32.6	83.3	5.4	0	36	SD FG CLEAN NO FLU
1.3	7306.0	34	23.6	74.5	6.0	0	60	SD VFG SHY(LAM) NO FLU
1.0	7313.0	3190	32.9	90.3	3.2	0	36	SD F-MG CLEAN NO FLU
1.0	7320.0	4020	34.2	87.3	4.3	0	37	SD MG CLEAN NO FLU
	7330.0							EMPTY BOTTLE
1.0	7340.0	5700	34.8	84.6	5.3	0	38	SD MG CLEAN (W/PEBBLES) CALC NO FLU
1.0	7380.0	4200	34.2	88.5	3.9	0	37	SD MG CLEAN SCALC NO FLU
1.0	7390.0	1000	30.1	92.2	2.3	0	35	SD FG SSHY SCALC NO FLU
0.1	7399.0					0		SD FG CLEAN CALC NO FLU
1.0	7406.0	2570	33.3	87.3	4.2	0	37	SD FG CLEAN NO FLU

DEPTHS DOUBLE SHOT:4210,4360,6510,6792,6850

0
STOP

(1) ALTERED CORE
(3) INSUFFICIENT SAMPLE
(6) LOW PERMEABILITY
(*) PERMEABILITY VALUES FOR PERCUSSION TYPE SIDEWALL CORES DETERMINED EMPIRICALLY.

NOTE: CRIT WTR% IS AN ESTIMATE OF THE MAXIMUM WATER EACH SAMPLE COULD CONTAIN IN THE FORMATION IF IT IS HYDROCARBON PRODUCTIVE. IT IS SOLELY DEPENDENT UPON THE PERMEABILITY AND POROSITY AND HAS N RELATIONSHIP TO THE WATER % PORE MEASURED IN THE SAMPLE. IN PRODUCTIVE ZONES THE WATER SATURATION CALCULATED FROM THE INDUCTION LOG TRUE RESISTIVITY SHOULD BE LESS THAN THE CRITICAL WATER.

DOE - LOUIS RECORDS
BRINE INJ. WELL No.4
BAYOU CHOCTAW

SIDE WALL CORE ANALYSIS

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.0	6400.0	8.5	20.3	80.9	3.9	68	SD VFG VSHY VCALC NO FLU
1.0	6405.0	160	27.3	82.6	4.8	48	SD VFG SSHY SLTY CALC NO FLU
1.0	6410.0						SHALE
0.3	6415.0	46	24.0	82.8	4.1	53	SD VFG SHY NO FLU
0.5	6420.0	960	30.8	86.7	4.1	36	SD VFG CLEAN NO FLU
0.5	6425.0	1650	33.3	85.0	5.0	37	SD FG CLEAN NO FLU
0.5	6430.0	1600	32.3	81.3	6.1	37	SD FG CLEAN SCALC NO FLU
0.5	6435.0	1700	33.1	80.6	6.4	37	SD FG CLEAN NO FLU
0.5	6440.0	3000	34.7	88.3	4.0	38	SD FG CLEAN NO FLU
0.5	6445.0	1900	33.9	85.7	4.8	38	SD FG CLEAN SCALC NO FLU
0.3	6450.0	1950	33.1	87.0	4.3	37	SD FG CLEAN NO FLU
0.5	6455.0	2950	34.6	87.3	4.4	38	SD FG CLEAN SCALC NO FLU
0.3	6460.0	1050	31.0	87.3	3.9	35	SD FG CLEAN NO FLU
0.8	6465.0	2500	33.9	87.8	4.1	38	SD FG CLEAN NO FLU
	6470.0						EMPTY BOTTLE
	6475.0						EMPTY BOTTLE
	6480.0						EMPTY BOTTLE
	6485.0						EMPTY BOTTLE
	6490.0						EMPTY BOTTLE
	6495.0						EMPTY BOTTLE
1.0	6500.0	2050	33.1	85.5	4.8	37	SD FG CLEAN SCALC NO FLU
1.3	6505.0	1250	29.7	79.1	6.2	34	SD VF-FG SSLTY NO FLU
1.0	6510.0	1400	31.8	83.3	5.3	36	SD VF-FG CLEAN SCALC NO FLU
1.0	6515.0	1700	33.9	83.9	5.5	38	SD FG CLEAN CALC NO FLU
0.8	6520.0	1500	31.6	90.9	2.9	36	SD VF-FG CLEAN NO FLU
0.3	6525.0	1750	31.6	86.7	4.2	36	SD VF-FG CLEAN NO FLU
	6530.0						EMPTY BOTTLE
0.4	6535.0						MUDCAKE

DOE - LOUIS RECORDS
BRINE INJ. WELL No.4
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.0	6540.0	2200	33.4	88.0	4.0	37	SD FG CLEAN NO FLU
1.0	6545.0	1400	31.7	81.3	5.9	36	SD VFG CLEAN NO FLU
0.3	6550.0	1350	31.1	84.5	4.8	36	SD VFG CLEAN NO FLU
0.5	6555.0	1500	31.5	85.3	4.6	36	SD VFG CLEAN NO FLU
1.0	6560.0	1600	32.0	83.8	5.2	36	SD VF-FG CLEAN NO FLU
0.5	6565.0	1950	33.1	89.3	3.6	37	SD FG CLEAN NO FLU
0.4	6570.0						MUDCAKE W/TR FG SD
1.0	6575.0	510	29.9	83.3	5.0	39	SD VFG VSSHY VCALC NO FLU

(6) LOW PERMEABILITY

DOE - LOUIS RECORDS
BRINE INJ. WELL No.5
BAYOU CHOCTAW

SIDE WALL CORE ANALYSIS

REC I	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.2	5110.0	894.	29.6	86.0	4.2	36	SD FG SSLTY SCALC
1.0	5115.0	1250.	30.1	84.0	4.8	35	SD FG SSLTY
0.0	5125.0						SD FG SLTY
1.0	5130.0	1110.	28.6	81.9	5.2	34	SD VF-FG CLEAN
0.3	5135.0						SD FG CLEAN
1.0	5140.0	1700.	30.1	82.8	5.2	34	SD FG SLTY
1.0	5145.0	1780.	30.4	81.1	5.7	35	SD FG CLEAN
1.2	5150.0	242.	26.6	81.1	5.0	43	SD VFG SSHY SSLTY
0.8	5160.0	1330.	30.5	80.3	6.0	35	SD FG CLEAN SCALC
0.3	5165.0						SD FG CLEAN
1.5	5170.0	3.2	15.7	72.6	4.3	65	SD VF-SILT VSHY
1.2	5180.0	2750.	34.3	86.7	4.6	38	SD FG CLEAN
1.2	5185.0	476.	25.4	77.8	5.6	37	SD VFG SHY LAM
[illegible].0	5190.0	2220.	29.5	80.3	5.8	33	SD VFG CLEAN
[illegible].2	5200.0	93.	22.9	81.7	4.2	49	SD VFG SHY LAM
1.2	5205.0	40.	21.0	78.5	4.5	55	SD VF-SILT SHY LAM CALC
1.5	5215.0	120.	23.1	78.2	5.0	47	SD VF-SILT SSHY
1.2	5220.0	2.1	18.8	82.2	3.4	72	SD VFG VSHY LAM CALC
1.3	5230.0	17.	20.2	79.6	4.1	63	SD VFG SHY LAM SLTY CALC
1.3	5235.0	5.2	18.8	75.7	4.6	69	SD VFG VSHY LAM CALC
1.0	5240.0	60.	21.8	74.2	5.6	52	SD VFG SHY LAM SLTY
1.0	5245.0	10.	20.2	79.3	4.2	67	SD VFG SHY SLTY CALC
0.3	5250.0						SD FG CLEAN
1.0	5255.0	1940.	31.0	74.0	8.0	35	SD VFG CLEAN
0.3	5260.0						SD VFG CLEAN
1.5	5265.0	4.6	18.4	67.0	6.1	69	SD FG VSHY FOSS
1.2	5270.0	6.4	18.1	81.6	3.3	66	SLT VSHY VCALC
1.2	5275.0	4.1	19.1	78.7	4.1	71	SLT VSHY FOSS

SIDE WALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.5
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.[illegible]	5280.0	44.	23.5	90.1	2.3	58	SD VFG SHY
1.0	5285.0	233.	28.1	85.3	4.1	44	SD VFG LIG SSLTY
1.2	5290.0	9.4	19.8	85.3	2.9	67	SD VF-SLT VSHY
1.2	5295.0	19.	21.1	83.6	3.5	63	SD VF-SLT SHY
1.5	5300.0	39.	20.2	77.9	4.4	54	SD VFG SSHY SLTY
1.3	5305.0	1190.	29.6	92.3	2.3	35	SD FG CLEAN
1.2	5310.0	6.1	20.5	91.3	1.8	70	SD VFG VSHY SCALC
1.3	5315.0	16.	20.1	71.9	5.6	63	SD VFG SHY SLTY FOSS
1.0	5320.0	7.6	18.4	80.0	3.7	66	SD VFG VSHY CALC
1.2	5325.0	5.5	19.0	90.3	1.8	68	SD VF-SLT SHY CALC
1.2	5330.0	4.0	18.0	88.4	2.1	70	SD VF-SLT SHY CALC
0.3	5335.0						SD FG CLEAN
0.3	5340.0						SD VFG CLEAN
1.0	5345.0	56.	24.7	88.4	2.9	56	SD VFG SLTY
1.0	5355.0	1360.	29.4	84.3	4.6	34	SD VFG CLEAN
1	5365.0						MUDCAKE W/TR VFG SD
1.[illegible]	5370.0	1610.	28.6	86.7	3.8	33	SD FG CLEAN
1.0	5380.0	1140.	30.2	86.7	4.0	35	SD VFG CLEAN
0.8	5385.0	1590.	29.4	87.7	3.6	34	SD VF-FG CLEAN FOSS
0.8	5390.0	10.	19.8	85.6	2.9	66	SD VFG VSLTY

(3) INSUFFICIENT SAMPLE
(6) LOW PERMEABILITY

(*) PERMEABILITY VALUES FOR PERCUSSION TYPE SIDEWALL CORES DETERMINED EMPIRICALLY.

Part 1

CONVENTIONAL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.6
BAYOU CHOCTAW

CORE #1 4469'-4489' CUT 20' RECOVERED 19' 7-16-

7-16-

SMP NO	DEPTH	PERM MD HORZ(KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
	4469.0-70.0					LOST CORE
1	4470.0-71.0	410	27.8	80.2	5.5	SD CG CLEAN(LAM) W/SHALE(LAM) GR
2	4471.0-72.0	590	27.8	77.9	6.1	SD FG CLEAN(LAM) W/SHALE(LAM) GR
3	4472.0-73.0	77	26.7	83.3	4.4	SD FG SHY(LAM)
4	4473.0-74.0	40	24.5	91.7	2.0	SD FG SSHY-SHY
5	4474.0-75.0	1940	36.1	93.2	2.5	SD FG CLEAN
6	4475.0-76.0	1500	33.8	95.7	1.4	SD FG CLEAN
7	4476.0-77.0	1340	33.2	88.7	3.8	SD FG VSSHY (10% MUD)
8	4477.0-78.0	280	28.4	89.1	3.1	SD FG SSHY
9	4478.0-79.0	230	30.8	89.0	3.4	SD FG SSHY (10% MUD)
10	4479.0-80.0	790	34.8	86.8	4.6	SD FG VSSHY
11	4480.0-81.0	890	31.6	87.9	3.8	SD F-MG CLEAN (VSSLTY)
12	4481.0-82.0	1500	35.0	82.4	6.2	SD F-MG CLEAN
13	4482.0-83.0	46	23.5	91.4	2.0	SD F-MG SHY(LAM)
	4483.0-89.0					MUD

CORE #2 4489'-4509' CUT 20' RECOVERED 20' 7-16-

SMP NO	DEPTH	PERM MD HORZ(KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
14	4489.0-90.0	4210	35.9	84.2	5.7	SD F-MG CLEAN (VSSLTY)
15	4490.0-91.0	3850	34.6	86.7	4.6	SD F-MG CLEAN
16	4491.0-92.0	2650	36.0	88.0	4.3	SD F-MG CLEAN
17	4492.0-93.0	2270	36.1	89.8	3.7	SD F-MG CLEAN

MP O	DEPTH	PERM MD HORZ (KA)	POR %	WTR% PORE	GAS% BULK	DESCRIPTION
18	4493.0-94.0	990	31.9	89.4	3.4	SD F-MG SSLTY
19	4494.0-95.0	250	36.6	90.7	3.4	SD F-MG SSLTY (20% MUD)
20	4495.0-96.0	355	34.4	85.7	4.9	SD F-MG (VSSLTY) (35% MUD)
21	4496.0-97.0	1320	34.9	78.3	7.6	SD FG CLEAN
22	4497.0-98.0	6440	33.7	86.5	4.6	SD F-MG CLEAN
	4498.0-09.0					MUD
	CORE #3 4524'-4529' CUT 20' RECOVERED 5'					7-16-7
23	4524.0-25.0	86	26.8	75.7	6.5	SD MG SHY(LAM) LIG(LAM)
24	4525.0-26.0	280	30.8	92.3	2.4	SD MG SSLTY (20% MUD)
25	4526.0-27.0	1860	31.2	92.8	2.2	SD MG CLEAN
26	4527.0-28.0	3060	33.5	86.1	4.7	SD F-MG CLEAN
27	4528.0-29.0	280	28.5	84.5	4.4	SD MG SHY(LAM) LIG(LAM)

(Part 2)

SIDE WALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.6
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.3	4015.0	5600	31.9	88.2	3.8	35	SD CG CLEAN NO FLU
1.3	4020.0	5400	31.0	84.1	4.9	34	SD M-CG CLEAN NO FLU
1.3	4025.0	5800	29.6	85.6	4.3	33	SD CG CLEAN NO FLU
0.4	4030.0						SD M-CG (60% MUD) NO FLU
0.4	4035.0						SD CG CHERT PEBBLES
1.0	4040.0	5750	31.4	81.4	5.8	34	SD M-CG CLEAN NO FLU
1.0	4045.0	5700	30.5	84.2	4.8	33	SD M-CG CLEAN NO FLU
1.0	4050.0	5800	30.7	87.5	3.8	34	SD M-CG CLEAN NO FLU
1.0	4055.0	4500	32.5	84.8	4.9	35	SD MG CLEAN NO FLU
1.0	4060.0	6000	32.0	85.1	4.8	35	SD CG CLEAN NO FLU
1.0	4065.0	5900	30.4	84.2	4.8	33	SD CG CLEAN NO FLU
1.0	4070.0	5500	33.7	83.1	5.7	37	SD M-CG CLEAN NO FLU
1.0	4075.0	5100	33.0	87.3	4.2	36	SD MG CLEAN NO FLU
1.0	4080.0	3800	29.3	84.9	4.4	33	SD M-CG CLEAN NO FLU
1.0	4085.0	5500	33.2	88.5	3.8	36	SD MG CLEAN NO FLU
1.0	4090.0	730	25.9	77.5	5.8	34	SD F-MG CLEAN NO FLU
1.0	4095.0	4900	31.2	87.6	3.9	34	SD F-MG CLEAN NO FLU
1.0	4100.0	3600	33.2	86.2	4.6	36	SD F-MG CLEAN NO FLU
1.0	4105.0	5900	29.6	87.4	3.7	33	SD CG CLEAN NO FLU
0.3	4110.0	2250	31.0	83.3	5.2	35	SD F-MG SSLTY NO FLU
1.0	4115.0	4200	30.5	82.1	5.5	33	SD MG CLEAN NO FLU
1.0	4120.0	6100	30.0	86.5	4.0	33	SD CG CLEAN NO FLU
1.0	4125.0	3800	28.9	81.5	5.4	32	SD F-MG CLEAN NO FLU
1.0	4130.0	3300	30.2	87.1	3.9	33	SD MG CLEAN NO FLU
1.0	4135.0	1900	28.1	87.2	3.6	33	SD F-MG CLEAN NO FLU
1.0	4140.0	5000	31.2	83.8	5.1	34	SD F-MG CLEAN NO FLU
1.0	4145.0	4400	30.1	81.0	5.7	33	SD F-MG CLEAN NO FLU
1.0	4150.0	4350	23.8	95.0	4.0	32	SD M-CG FOSS NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.6
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.0	4155.0	3100	30.2	84.4	4.7	34	SD M-CG CLEAN NO FLU
1.0	4160.0	5400	29.9	84.9	4.5	33	SD M-CG SFOSS NO FLU
1.0	4165.0	27	23.8	80.6	4.6	63	SD VF-FG SHY(LAM) NO FLU
1.0	4170.0	32	26.3	81.6	4.8	64	SD VF-SILT SHY(LAM) CALC NO FLU
1.0	4175.0	170	27.4	84.1	4.4	47	SD VF-FG SHY NO FLU
	4180.0						EMPTY BOTTLE
1.0	4185.0	220	26.9	84.6	4.1	44	SD F-MG SHY SCALC NO FLU
1.0	4190.0	240	28.1	80.0	5.6	44	SD FG SHY(LAM) SCALC NO FLU
1.0	4195.0	115	26.4	78.7	5.6	51	SD FG SHY SFOSS NO FLU
1.2	4200.0	25	22.9	84.0	3.7	62	SD VF-SILT SHY(LAM) NO FLU
1.2	4350.0	12	21.9	83.6	3.6	67	SD VFG SHY-VSHY W/LS FRAGS MIN FLU
1.2	4365.0	4000	30.2	82.5	5.3	33	SD F-MG SSLTY NO FLU
1.2	4370.0	5000	31.2	85.9	4.4	34	SD M-CG SSLTY NO FLU
1.2	4375.0	5650	28.7	86.7	3.8	32	SD M-CG CLEAN NO FLU
1.2	4380.0	2200	30.7	86.9	4.0	35	SD F-MG CLEAN NO FLU
1.2	4385.0	5500	28.7	84.7	4.4	32	SD F-MG CALC NO FLU
1.2	4390.0	4700	29.8	85.2	4.4	33	SD MG SSLTY NO FLU
1.2	4395.0	5100	31.3	87.0	4.1	34	SD F-MG CLEAN NO FLU
1.2	4400.0	5600	32.4	84.5	5.0	35	SD MG CLEAN NO FLU
1.2	4405.0	5700	29.9	82.6	5.2	33	SD MG CLEAN NO FLU
1.2	4410.0	5800	30.3	84.5	4.7	33	SD MG CLEAN NO FLU
1.2	4415.0	5820	30.4	83.3	5.1	33	SD MG CLEAN NO FLU
1.2	4420.0	5750	29.7	86.4	4.1	33	SD MG CLEAN NO FLU
1.2	4425.0	5800	30.4	84.2	4.8	33	SD MG CLEAN NO FLU
1.2	4430.0	3750	30.6	84.9	4.6	34	SD F-MG CLEAN NO FLU
1.2	4435.0	3100	31.3	81.6	5.7	35	SD FG CLEAN NO FLU
1.2	4440.0	3200	31.9	83.9	5.1	35	SD FG CLEAN NO FLU
1.2	4445.0	3150	31.3	81.0	6.0	35	SD FG CLEAN NO FLU
1.2	4450.0	2800	30.0	82.9	5.1	34	SD FG CLEAN NO FLUO
1.2	4455.0	4200	30.9	88.2	3.6	34	SD F-MG CLEAN NO FLUO
1.2	4460.0	5100	31.3	82.5	5.5	34	SD F-MG CLEAN NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.6
BAYOU CHOCTAW

281

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.2	4465.0	6500	29.9	83.3	5.0	33	SD CG CLEAN NO FLUO
1.2	4470.0	5950	31.4	83.3	5.2	34	SD M-CG SSLTY NO FLU
1.3	4475.0	5400	29.7	85.3	4.4	33	SD MG CLEAN NO FLUOO
1.2	4480.0	5350	31.3	82.3	5.6	34	SD MG CLEAN NO FLU
1.2	4485.0	4850	30.5	86.2	4.2	33	SD F-MG CLEAN NO FLUO
1.2	4490.0	5050	29.4	81.5	5.4	33	SD F-MG CLEAN NO FLU
1.2	4495.0	5500	31.0	83.3	5.2	34	SD MG CLEAN NO FLUO
1.2	4500.0	6100	31.7	79.7	6.5	35	SD CG CLEAN NO FLU
1.2	4505.0	5200	29.1	81.5	5.4	32	SD F-MG CLEAN NO FLUO
1.2	4510.0	6050	28.2	88.5	3.2	32	SD CG CLEAN NO FLUO
1.2	4515.0	5600	32.4	87.7	4.0	35	SD MG CLEAN NO FLUO
1.2	4520.0	5200	31.3	88.1	3.7	34	SD F-MG CLEAN NO FLU
1.2	4525.0	4400	30.3	82.6	5.3	33	SD F-MG CLEAN NO FLU
0.3	4530.0	5950	31.3	84.6	4.8	34	SD CG W/PEBBLES NO FLU
0.3	4535.0						SD FG(80% MUD)
1.2	4540.0	5700	30.8	87.4	3.9	34	SD F-MG CLEAN NO FLUO
1.2	4545.0	5350	31.2	88.7	3.5	34	SD F-MG SLIG NO FLU
0.5	4550.0						MUDCAKE
1.0	4555.0	5600	32.7	85.3	4.8	36	SD MG CLEAN NO FLU
1.0	4560.0	5300	30.4	89.2	3.3	33	SD MG CLEAN NO FLU
1.0	4565.0	5650	31.8	85.9	4.2	35	SD M-CG CLEAN NO FLU
1.0	4570.0						SD MG (90% MUDCAKE)
1.0	4575.0	350	23.2	80.7	5.4	41	SD CG SHY NO FLU
1.0	4580.0	4800	28.9	84.3	4.5	32	SD MG CLEAN NO FLU
1.0	4585.0	4900	30.5	88.0	3.7	34	SD MG CLEAN NO FLU
1.0	4590.0	4600	31.8	90.6	3.0	35	SD F-MG CLEAN NO FLU
1.0	4595.0	4750	32.3	84.1	5.1	35	SD F-MG CLEAN NO FLU
1.2	4600.0	8.5	21.2	85.5	3.1	59	SD VF-SILT SHY NO FLU
1.2	4605.0	1350	30.0	82.1	5.4	35	SD FG VSSHY NO FLU
0.3	4615.0	-					SD FG
0.3	4620.0	3000	33.0	85.2	4.6	35	SD FG CLEAN NO FLU
0.5	4625.0	2650	32.2	85.7	4.6	35	SD FG CLEAN NO FLU

DOE - LOUIS RECORDS
BRINE INJ. WELL No.6
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.0	4630.0	3200	30.6	82.7	5.3	34	SD F-MG CLEAN NO FLU
1.0	4635.0						SD F-MG(50% MUD)
1.0	4655.0	9.2	19.5	76.9	4.5	66	SD FG VSHY(LAM) CALC NO FLU
1.3	4660.0	2.9	21.6	74.5	5.5	73	SD VF-SILT VSHY CALC NO FLU
0.5	4665.0						SD F-MG(80% MUD) SCALC
1.4	4670.0	135	24.4	57.1	10.5	47	SD VF-FG SHY(LAM) VCALC NO FLU
1.0	4675.0	79	24.1	80.0	4.8	53	SD VF-FG SHY(LAM) VCALC NO FLU
1.0	4680.0	1650	29.2	83.2	4.9	34	SD F-MG VSSHY NO FLU

SIDE WALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.7
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
0.8	6640.0	47	25.1	80.5	4.9	59	SD VFG SHY(LAM) SCALC NO FLU
0.5	6645.0	120	26.1	90.9	2.4	50	SD VFG SSHY LIG SSLTY(1 SMPL MG CLN)
0.5	6655.0	17	22.0	80.4	4.3	65	SD VFG SHY-VSHY(LAM) SCALC NO FLU
0.5	6660.0	1650	28.6	80.2	5.7	33	SD F-MG CLEAN NO FLU
0.5	6665.0	3000	32.7	88.2	3.9	36	SD F-MG CLEAN NO FLU
0.6	6670.0	220	27.5	80.4	5.4	45	SD FG SHY(LAM) SCALC NO FLU
0.5	6675.0	520	30.3	83.3	5.0	39	SD FG SSHY(LAM) NO FLU
0.5	6680.0	750	31.4	79.4	6.5	38	SD FG SHY(LAM) CALC NO FLU
0.5	6690.0	2200	34.1	88.9	3.8	38	SD FG CLEAN NO FLU
0.6	6695.0	2300	34.5	89.5	3.6	38	SD FG CLEAN NO FLU
0.6	6700.0	1650	32.5	91.9	2.6	37	SD FG CLEAN NO FLU
0.5	6705.0	2100	33.1	83.7	5.4	37	SD FG CLEAN NO FLU
0.3	6710.0						MUDCAKE W/TR FG SD
0.4	6720.0	2300	33.7	85.2	5.0	37	SD FG CLEAN NO FLU
0.5	6730.0	7.6	19.4	87.5	2.4	67	SD FG VSHY(LAM) NO FLU
0.4	6735.0	2050	33.0	90.1	3.3	37	SD FG CLEAN NO FLU
0.5	6740.0	2950	34.4	89.7	3.6	38	SD FG CLEAN NO FLU
0.5	6745.0	2100	33.6	90.1	3.3	37	SD FG CLEAN NO FLU
0.5	6750.0	2500	34.3	87.3	4.4	38	SD VFG CLEAN NO FLU
0.5	6755.0	1400	30.5	80.9	5.8	35	SD FG CLEAN NO FLU
0.3	6760.0						SD FG CLEAN NO FLU
0.4	6765.0	1950	32.2	80.7	6.2	36	SD FG CLEAN NO FLU
0.5	6770.0	2500	34.5	83.5	5.7	38	SD FG CLEAN NO FLU
0.4	6775.0	2000	32.7	81.0	6.2	37	SD FG CLEAN NO FLU
0.4	6780.0	2600	33.5	81.7	6.1	37	SD FG CLEAN NO FLU
0.3	6785.0						SD FG CLEAN NO FLU
0.5	6790.0	1750	31.5	85.0	4.7	36	SD FG CLEAN NO FLU
0.3	6795.0						SD FG CLEAN NO FLU

SIDEWALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.7
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
0.4	6800.0	2050	31.4	86.4	4.3	35	SD FG CLEAN NO FLU
0.5	6805.0	1600	30.9	81.2	5.8	35	SD FG CLEAN NO FLU
0.5	6810.0	2800	33.2	82.1	5.9	37	SD FG CLEA NO FLU
0.5	6815.0	2500	32.1	78.8	6.8	36	SD F-MG CLEAN CALC NO FLU
0.5	6820.0	3100	34.2	86.2	4.7	38	SD FG CLEAN NO FLU
0.4	6925.0	2950	34.1	86.7	4.5	37	SD FG CLEAN NO FLU
0.4	6830.0	2200	33.3	85.7	4.8	37	SD FG CLEAN NO FLU
0.4	6835.0	1800	28.3	77.5	6.4	33	SD F-MG CLEAN NO FLU
0.3	6840.0						SD F-MG CLEAN NO FLU
0.3	6845.0						SD F-MG CLEAN (90% MUDCAKE) NO FLU
0.5	6850.0	1600	31.8	84.2	5.0	36	SD VF-FG CLEAN NO FLU
0.3	6855.0						SD VF-FG CLEAN NO FLU
0.4	6860.0	2550	33.1	81.3	6.2	37	SD FG CLEAN NO FLU
0.4	6865.0	1950	29.1	91.5	2.5	33	SD F-MG CLEAN NO FLU
0.3	6870.0						SD FG CLEAN NO FLU (80% MUDCAKE) NO F
0.4	6875.0	1900	32.3	83.8	5.2	36	SD FG CLEAN NO FLU
0.5	6980.0	1250	33.5	84.7	5.1	38	SD VF-FG CLEAN NO FLU
0.1	6890.0						SD VFG CLEAN NO FLU
0.4	6905.0	850	29.4	79.1	6.2	36	SD VFG CLEAN NO FLU
0.5	6910.0	100	26.8	85.8	3.8	53	SD VFG SHY-VSHY(LAM) NO FLU
0.5	6920.0	24	22.1	85.7	3.2	61	SILT NO FLU
1.0	6325.0	46	24.5	74.2	6.3	59	SD VFG SHY(LAM) NO FLU
0.5	6930.0	51	22.7	77.4	5.1	55	SD VFG SHY(LAM) SCALC NO FLU
1.0	6940.0	15	20.4	84.2	3.2	64	SD VFG SHY-VSHY(LAM) SCALC NO FLU
0.5	6950.0	1300	32.4	89.7	3.3	37	SD VFG CLEAN NO FLU

(*) PERMEABILITY VALUES FOR PERCUSSION TYPE SIDEWALL CORES DETERMINED EMPIRICALLY.

DOE - LOUIS RECORDS
BRINE INJ. WELL No.9
BAYOU CHOCTAW

SIDE WALL CORE ANALYSIS

EC N	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
	4384.4						EMPTY BOTTLE
	4390.2						EMPTY BOTTLE
	4395.1						EMPTY BOTTLE
	4399.7						EMPTY BOTTLE
	4404.8						EMPTY BOTTLE
	4409.9						EMPTY BOTTLE
	4415.0						EMPTY BOTTLE
0.8	4419.5	2200	30.8	94.1	1.8	35	SD F-MG CLEAN
	4424.6						EMPTY BOTTLE
1.0	4429.7	3650	31.3	91.3	2.7	34	SD MG CLEAN
1.0	4434.7	3600	32.2	90.0	3.2	35	SD MG CLEAN
0.8	4440.0	7.7	19.3	78.1	4.2	67	SD FG VSHY
0.2	4445.0						MUDCAKE
0.8	4450.1	4500	29.6	92.8	2.1	33	SD CG CLEAN
0.8	4450.2	5600	30.5	87.2	3.9	33	SD CG CLEAN
0.3	4455.3						MUDCAKE
	4460.2						EMPTY BOTTLE
	4464.7						EMPTY BOTTLE
1.0	4469.8						MUDCAKE
	4475.0						EMPTY BOTTLE
1.0	4478.6	5100	34.0	86.1	4.7	37	SD MG CLEAN
	4484.8						EMPTY BOTTLE
	4490.4						EMPTY BOTTLE
	4495.1						EMPTY BOTTLE
	4499.9						EMPTY BOTTLE
	4504.8						EMPTY BOTTLE
	4509.9						EMPTY BOTTLE
	4515.3						EMPTY BOTTLE

SIDE WALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.9
BAYOU CHOCTAW

	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS BULK	CRIT WTR %	DESCRIPTION
	4519.7						EMPTY BOTTLE
	4519.8						EMPTY BOTTLE
	4524.7						EMPTY BOTTLE
..8	4525.3	7.9	21.9	76.1	5.2	70	SD MG VSHY
'.3	4529.3	4000	32.2	91.8	2.6	35	SD MG CLEAN
	4530.1						EMPTY BOTTLE
	4533.5						EMPTY BOTTLE
	4534.4						EMPTY BOTTLE
.0	4539.6	1650	33.0	85.3	4.9	37	SD FG CLEAN(1EMPTY BOTTLE)
	4544.5						EMPTY BOTTLE
	4544.8	1250	32.6	85.7	4.7	37	SD FG SSHY
	4544.9						EMPTY BOTTLE
.8	4550.0	5500	34.9	84.7	5.4	38	SD MG CLEAN
.8	4552.2	3000	32.9	90.1	3.3	36	SD MG CLEAN
0	4560.0	6000	31.8	87.1	4.1	35	SD CG CLEAN(1 EMPTY BOTTLE)
.0	4564.6	2700	32.6	89.9	3.3	36	SD F-MG CLEAN
.0	4569.8	5600	32.8	86.7	4.3	36	SD CG CLEAN
	4575.1						EMPTY BOTTLE
.3	4580.0	1560	29.5	84.2	4.7	34	SD FG SSLTY
.8	4582.5	2200	33.1	85.9	4.7	37	SD FG CLEAN
.7	4589.7	5600	33.3	84.7	5.1	36	SD CG CLEAN
.0	4595.0	4500	33.3	90.3	3.2	36	SD MG
.5	4599.9	14	23.0	77.6	5.2	68	SD FG SH-VSHY
.8	4605.1	3600	32.7	92.5	2.4	36	SD F-MG CLEAN
0.8	4609.4	2700	32.1	91.8	2.6	36	SD F-MG CLEAN
0.5	4614.5	3700	33.8	89.9	3.4	37	SD F-MG CLEAN (1EMPTY BOTTLE)
0.8	4619.7	3600	32.5	90.5	3.1	36	SD F-MG CLEAN
	4619.8						EMPTY BOTTLE
.8	4620.0	4400	33.3	91.8	2.7	36	SD CG CLEAN (2 EMPTY BOTTLES)
	4624.6						EMPTY BOTTLE
	4624.7						EMPTY BOTTLE
.5	4624.9	3000	32.6	84.7	5.0	36	SD MG CLEAN (1 EMPTY BOTTLE)

SIDE WALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.9
BAYOU CHOCTAW

.C %	DEPTH FEET	PERM MD (*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
	4625.0						EMPTY BOTTLE
.0	4625.1	1500	28.2	85.5	4.1	33	SD FG SSHY
:.5	4629.6	3000	33.9	93.5	2.2	37	SD MG CLEAN
,.8	4634.9	1450	29.2	85.0	4.4	34	SD FG SSHY
	4639.9						EMPTY BOTTLE
	4640.0						EMPTY BOTTLE
9	4644.7	2200	31.0	91.7	2.6	35	SD FG CLEAN
.8	4644.8	8.9	20.5	86.7	2.7	68	SD FG VFOSS
.5	4654.4	1750	28.5	85.6	4.1	33	SD FG VSSHY
	4655.0						EMPTY BOTTLE
:.3	4659.6	6.8	20.1	80.9	3.8	69	SD VFG VSHY CALC
.5	4665.1						SHALE CALC
:.0	4669.7	1850	32.2	88.1	3.8	36	SD FG CLEAN
	4670.1						EMPTY BOTTLE
.8	4674.6						MUDCAKE
	4679.8						EMPTY BOTTLE
	4680.0						EMPTY BOTTLE
	4685.2						EMPTY BOTTLE
-	4687.8	2.5	16.0	78.8	3.4		LS SHY(LAM)
	4694.9						SHALE
.	4695.0	1250	30.3	83.6	5.0	35	SD FG CLEAN
.	4699.1						SHALE

DEPTHS DOUBLE SHOTS: 4539.6, 4550, 4560
4575.1, 4619.5, 4620, 4624.9,

(6) LOW PERMEABILITY
(*) PERMEABILITY VALUES FOR PERCUSSION TYPE SIDEWALL CORES DETERMINED EMPIRICALLY.

SIDEWALL CORE ANALYSIS

SIDE WALL CORE ANALYSIS

DOE - LOUIS RECORDS
BRINE INJ. WELL No.10
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
0.5	3530.0	1950	33.6	82.7	5.8	38	SD VFG CLEAN
0.8	3570.0	1250	30.9	86.6	4.1	36	SD VFG CLEAN
0.8	3720.0	750	31.0	86.3	4.3	38	SD VFG SSHY
1.0	3760.0	2200	28.8	88.2	3.4	33	SD FG CLEAN
0.8	3800.0	3000	29.9	95.0	1.5	33	SD F-MG CLEAN
0.5	3860.0	900	30.0	86.1	4.2	36	SD VFG VSSHY
0.5	3880.0	2500	30.3	81.4	5.6	34	SD FG CLEAN
0.5	3910.0	1650	28.5	88.3	3.3	33	SD F-MG CLEAN
0.8	4010.0	1050	32.3	83.8	5.2	37	SD FG SSLTY
0.8	4040.0	4500	29.9	77.3	6.8	33	SD CG CLEAN
0.5	4070.0	610	27.6	87.9	3.3	37	SD VFG CLEAN
0.8	4090.0	1670	31.6	80.8	6.1	36	SD FG SLTY
1.0	4110.0	3100	30.1	78.7	6.4	33	SD MG CLEAN
1.0	4130.0	2900	29.4	83.1	5.0	33	SD MG CLEAN

DOE - LOUIS RECORDS
BRINE INJ. WELL No.10
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
0.8	4150.0	2000	29.9	82.9	5.1	34	SD F-MG SSLTY SCALC
0.5	4300.0	78	27.3	81.8	5.0	56	SD VFG SLTY
0.8	4351.0	720	30.8	85.7	4.4	38	SD VFG SSHY SSLTY
1.0	4380.0	6.5	19.8	76.6	4.6	69	SD VFG VSHY
0.8	4410.0	1700	31.2	85.3	4.6	35	SD FG SSLTY
0.3	4440.0						SD FG CLEAN
0.3	4470.0						SD FG CLEAN
0.5	4500.0	1000	31.4	81.4	5.9	36	SD VF-FG CLEAN
	4530.0						EMPTY BOTTLE
0.8	4560.0	1400	31.0	80.0	6.2	35	SD FG CLEAN
0.8	4592.0	310	24.9	74.5	6.3	40	SD VFG SHY
0.8	4620.0	2300	29.4	82.1	5.3	33	SD F-MG CLEAN
0.8	4652.0	1350	30.7	83.1	5.2	35	SD F-MG CLEAN
1.0	4680.0	950	31.1	86.9	4.1	36	SD VF-FG VSSHY
0.8	4870.0	1150	30.5	88.4	3.5	35	SD VF-FG VSSHY
1.0	4910.0	400	28.6	78.5	6.1	40	SD VF-FG SHY SCALC

DOE - LOUIS RECORDS
BRINE INJ. WELL No.10
BAYOU CHOCTAW

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
0.8	4940.0	530	28.4	79.7	5.8	38	SD VF-FG SSHY SCALC
0.5	5030.0	320	26.6	83.0	4.5	41	SD VF-FG SHY
0.8	5061.0	620	28.8	82.7	5.0	37	SD VF-FG SSHY
1.0	5080.0	45	23.4	71.1	6.8	57	SD VF-FG VSHY-SHY CALC
1.0	5100.0	56	25.8	79.5	5.3	57	SD VF-FG SHY(LAM) CALC
1.0	5120.0	130	27.2	81.3	5.1	50	SD VFG SSHY(LAM) SLTY
0.8	5150.0	1800	30.5	80.4	6.0	35	SD FG CLEAN
0.5	5180.0	84	27.3	80.0	5.5	55	SD VFG SLTY
0.5	5210.0	62	26.2	79.3	5.4	57	SD VFG SLTY
0.8	5240.0	34	24.9	80.2	4.9	62	SD VFG VSLTY
1.0	5268.0	29	24.6	77.9	5.4	63	SD VFG VSLTY
1.0	5301.0	25	21.9	88.8	2.5	61	SD VFG SHY-VSHY
0.8	5350.0	1600	31.7	87.7	3.9	36	SD VF-FG CLEAN
0.8	5370.0	73	25.5	78.0	5.6	55	SD VFG SLTY
1.0	5390.0	9.8	19.7	85.0	3.2	66	SD VF VSHY VLMY
0.5	5605.0	2250	31.7	86.8	4.2	35	SD FG CLEAN
0.8	5620.0	1150	32.0	80.7	6.2	37	SD VF-FG CLEAN

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
0.5	5640.0	2700	32.9	90.6	3.1	36	SD F-MG CLEAN
0.8	5660.0	1670	32.1	84.1	5.1	36	SD VF-FG CLEAN
1.0	5680.0	320	27.4	92.0	2.2	41	SD VFG SSHY-SHY
0.8	6010.0	1550	32.4	80.4	6.4	37	SD FG CLEAN
1.0	6160.0	370	27.4	84.5	4.2	40	SD VFG SSLTY
0.8	6190.0	64	23.3	86.8	3.1	53	SD VFG SHY
1.0	6280.0	1125	29.0	91.8	2.4	34	SD VFG CLEAN
1.0	6310.0	215	26.1	84.9	3.9	44	SD VFG SSLTY
0.8	6467.0	105	25.7	85.1	3.8	51	SD VFG SLTY
1.0	6470.0	195	26.3	75.9	6.3	45	SD VFG SHY(LAM)
1.0	6490.0	1500	32.3	87.7	4.0	37	SD VF-FG CLEAN
0.3	6510.0						SD FG CLEAN
0.8	6518.0	55	25.3	80.4	4.9	57	SD VFG VSLTY CALC
1.0	6530.0	800	30.2	82.3	5.4	37	SD VF-FG SSLTY
0.8	6550.0	1050	31.5	85.4	4.6	36	SD FG SSLTY
0.8	6670.0	250	28.1	80.0	5.6	44	SD VFG SSLTY
1.0	6700.0	320	26.9	84.4	4.2	41	SD VFG SSLTY

DOE - LOUIS RECORDS
BRINE INJ. WELL No.10
BAYOU CHOCTAW

REC N	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
0.5	6730.0	440	29.8	88.5	3.4	40	SD VF-FG SSLTY
0.5	6760.0	1120	29.1	80.2	5.8	34	SD VFG CLEAN
1.0	6790.0	900	28.8	77.4	6.5	35	SD FG SSLTY
1.0	6820.0	1130	31.0	83.3	5.2	36	SD FG SSLTY
0.5	6850.0	4500	32.1	82.4	5.7	35	SD M-CG CLEAN
0.8	6870.0	5600	34.2	80.0	6.9	37	SD M-CG CLEAN
0.8	6900.0	1650	30.0	78.9	6.3	34	SD FG CLEAN
0.8	6947.0	510	27.4	82.1	4.9	38	SD VFG VSSHY LIG(LAM)
0.5	7010.0	600	27.1	75.9	6.5	36	SD VFG SSLTY
0.8	7250.0	2350	35.8	82.3	6.4	39	SD F-MG CLEAN
0.5	7260.0	2600	33.0	75.8	8.0	37	SD F-MG CLEAN
0.5	7270.0	1750	29.7	79.5	6.1	34	SD FG CLEAN
	7280.0						EMPTY BOTTLE
0.5	7290.0	3700	31.6	80.4	6.2	35	SD F-CG SHY
0.8	7300.0	2550	32.1	80.6	6.3	36	SD F-MG CLEAN
0.3	7320.0						SD FG SSLTY
0.5	7340.0	1275	31.8	80.4	6.3	36	SD VFG CLEAN
	7350.0						EMPTY BOTTLE
0.8	7360.0	1650	33.8	85.4	4.9	38	SD FG SSLTY

REC IN	DEPTH FEET	PERM MD(*)	POR %	WTR% PORE	GAS% BULK	CRIT WTR%	DESCRIPTION
1.0	7380.0	1175	32.6	78.9	6.9	37	SD VFG CLEAN SCALC

(*) PERMEABILITY VALUES FOR PERCUSSION TYPE SIDEWALL CORES DETERMINED EMPIRICALLY.

APPENDIX II
BRINE INVASION FRONT MODEL

Figure A illustrates a model of the injection front of the injection wells in Bayou Choctaw field. The five data points used in developing this model were taken from Wells 2, 7, 8, 9, 10 and 12.

The major factor controlling the shape of the injection front is the density difference between the injected brine (S.G. 1.197) and the formation brine (S.G. 1.08). Geological considerations would suggest that the hydraulic gradient in the area of the injection field is in a south to south-east direction.

Well No. 12 was logged December 26, 1978, after Well No. 9 had injected approximately 600,000 bbls. of brine in Sand Interval No. 2 (4,345 to 4,702 feet). Well No. 9 is located approximately 40 feet to the northeast of Well No. 12.

Well No. 12 had an S.P. base line shift of approximately -20 mv. across Sand Interval No. 2 suggesting the sand interval contained a more saline fluid at the base than at the top. This is caused by the electro-chemical emf generating cell (mud filtrate/brine/ shale) at the base of the sand which generates more potential than the similar cell (mud filtrate/brine/shale) at the top of the sand.

Examination of the deep induction resistivity curve shows a lower resistivity zone from 4,630 feet to 4,700 feet. Our interpretation is that heavy brine injected into an interval 357 feet thick has segregated due to specific gravity differences between the formation brine and the injected brine and occupies only an interval 70 feet thick over a distance of 40 feet laterally.

Well No. 10 is located approximately 90 feet west of Well No. 12 and had approximately 497,932 bbls. of brine injected prior to the logging of Well No. 12 on December 26, 1978, in Sand Interval No. 7 (7,224 to 7,392 feet). A study of the log of Well NO. 12 indicates brine fills the interval 7,370 to 7,403 feet. The formation resistivity (Rt from Induction Log) of the entire interval in Sand Interval No. 7 of Well No. 10 originally was approximately 0.20 ohms. The resistivity of the upper part of Sand Interval No. 7 in Well No. 12 was approximately the same, but the bottom 33 feet of the sand (7,370 to 7,403 feet) is approximately 0.125 ohm.

There is also a shale-base-line shift of approximately 20 mv. across Sand Interval No. 7 in Well No. 12, indicating there is a transition from saltier water at the base of the sand to less salty at the top.

Well No. 8 is located approximately 125 feet east of Well No. 12 (bottom hole location) and had approximately 199,700 barrels of brine injected prior to the logging of Well No. 12 on December 26, 1978 in Sand Interval No. 3 between 5,050 feet and 5,280 feet.

A spinner survey run on Well No. 8 on March 12, 1979 indicated that 75 percent of the brine was injected in the interval 5,050 feet to 5,120 feet. The induction curve of Well No. 12 indicates a brine layer of approximately 5 feet in thickness from 5,033 feet to 5,038 feet above a distinct but not very prominent shale interval. There is another brine layer approximately 6 feet thick from 5,120 feet to 5,126 feet above an even less prominent shale interval which despite its insignificant appearance must be continuous between Wells 8 and 12. (Correlation is difficult in this interval because of the high salinity of the drilling mud used in Well No. 8, Run 2.) A shale-base-line shift across Sand Interval No. 3 in Well No. 12 cannot be positively identified.

Well No. 7 is approximately 200 feet east of Well No. 12 and had approximately 308,425 barrels of brine injected when Well No. 12 was logged on December 26, 1978 in Sand Interval No. 6 between 6,630 feet and 6,900 feet.

Although the completion interval was 6,630 feet to 6,900 feet, a spinner survey run in Well No. 7 on March 22, 1979 indicated that 100 percent of the fluid entered the upper interval of the sand occurring at 6,630 feet to 6,820 feet, which correlates with a shale interval at 6,826 feet in Well No. 12. Examination of the Induction curve indicates a layer of brine approximately 3 feet thick from 6,823 feet to 6,826 feet lies above this shale interval. There is no indication of brine in the lower interval of Well No. 12 (6,834 to 6,918 feet). Therefore, the shale interval is continuous for the 200 feet separating the wells, and the brine injected over an interval of 190 feet has segregated by gravity to an interval of approximately 3 feet. A shale-base-line shift in this interval cannot be positively identified.

To approximate a value for the radius of the brine filled volume near the top of the injection interval, we used data from the Davis backflow test of Well No. 2.

On the basis of the investigation conducted by Davis[3], after backflowing only about 100,000 gallons, the chloride content of the produced fluid decreased from that of the injected brine to approximately that of original formation water.

The radius of a cylinder of formation containing 100,000 gallons of brine was calculated to be approximately 7 feet; therefore, the nearest formation water was only about 7 feet from the wellbore, and because of the gravity segregation between the high density injection brine (S.G. 1.197) and lower density formation water (S.G. 1.08), this nearest point should be near the top of the formation.

The fact that after the injection of 230,000 or more barrels of brine into Well No. 2, the nearest point of formation water is only seven feet away from the wellbore is additional supporting evidence for the gravity segregation model.

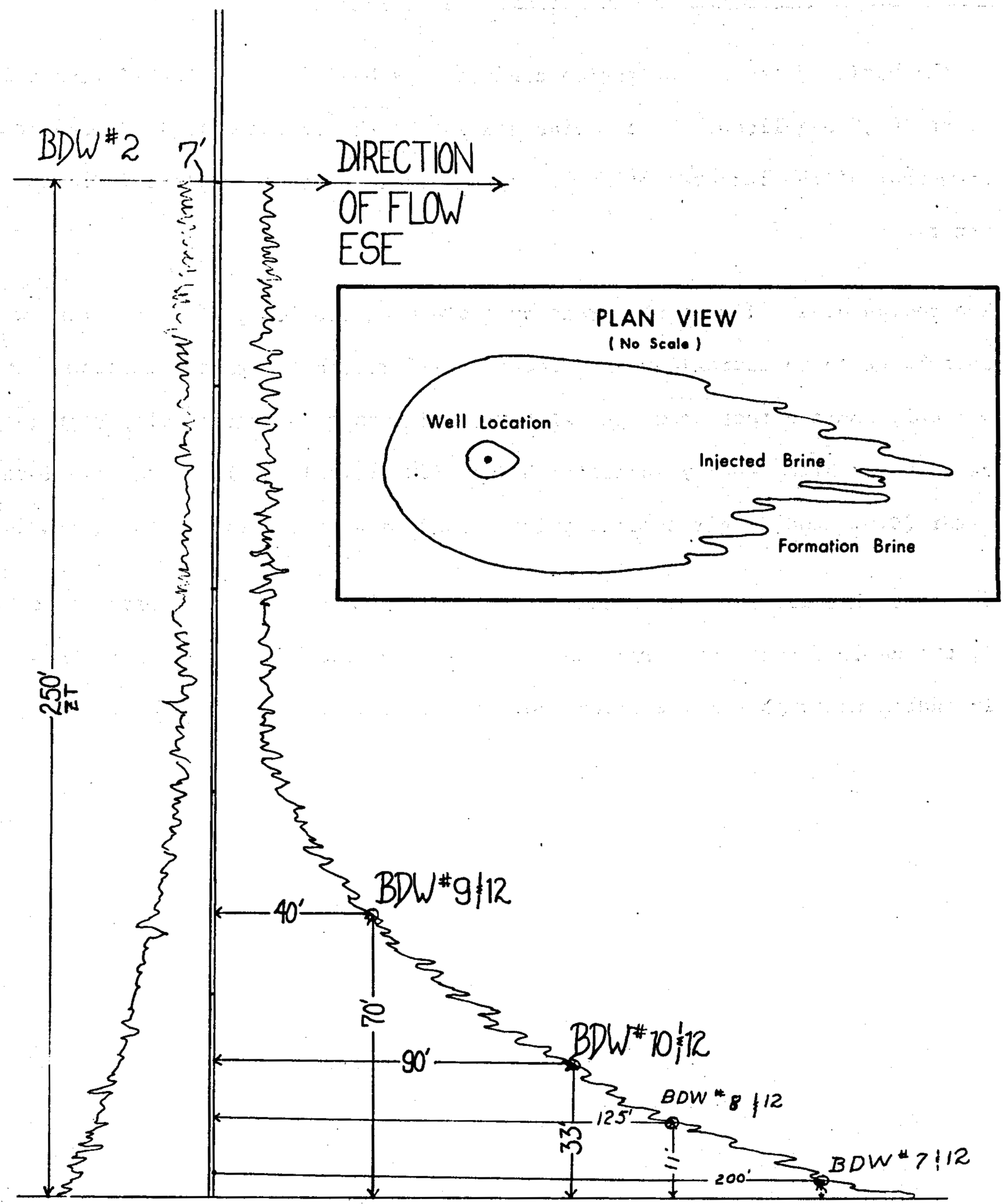


FIGURE A
BRINE FLOW MODEL
SHOWING DENSITY SEGREGATION
(BASED ON DATA FROM BDWs 2, 7, 8, 9, 10 & 12)

APPENDIX III
FORMATION PRESSURE AND TEMPERATURE
BAYOU CHOCTAW INJECTION FIELD

Bottom Hole Temperature

Stabilized bottom hole temperatures from the Bayou Choctaw Injection Field were not available. Only temperature data taken during logging runs, after cementing, and after brine injection were available. The best value we arrived at using thermometer runs after the longest period of no circulation was a gradient of 1° F per 100 feet.

$$BHT(F^\circ) = 76 + \frac{(Depth(ft) \times 1.0)}{100}$$

This value is appreciably lower than the 1.5° per 100 feet interpolated from the geothermal temperature estimated by standard methods, but agrees well with all the other temperature data we have available.

Formation Pressure

The only formation pressures prior to brine injection available were from wireline formation test results in Well No. 1. These are:

3180 psi @ 6790' gradient 0.4696 psi/ft.

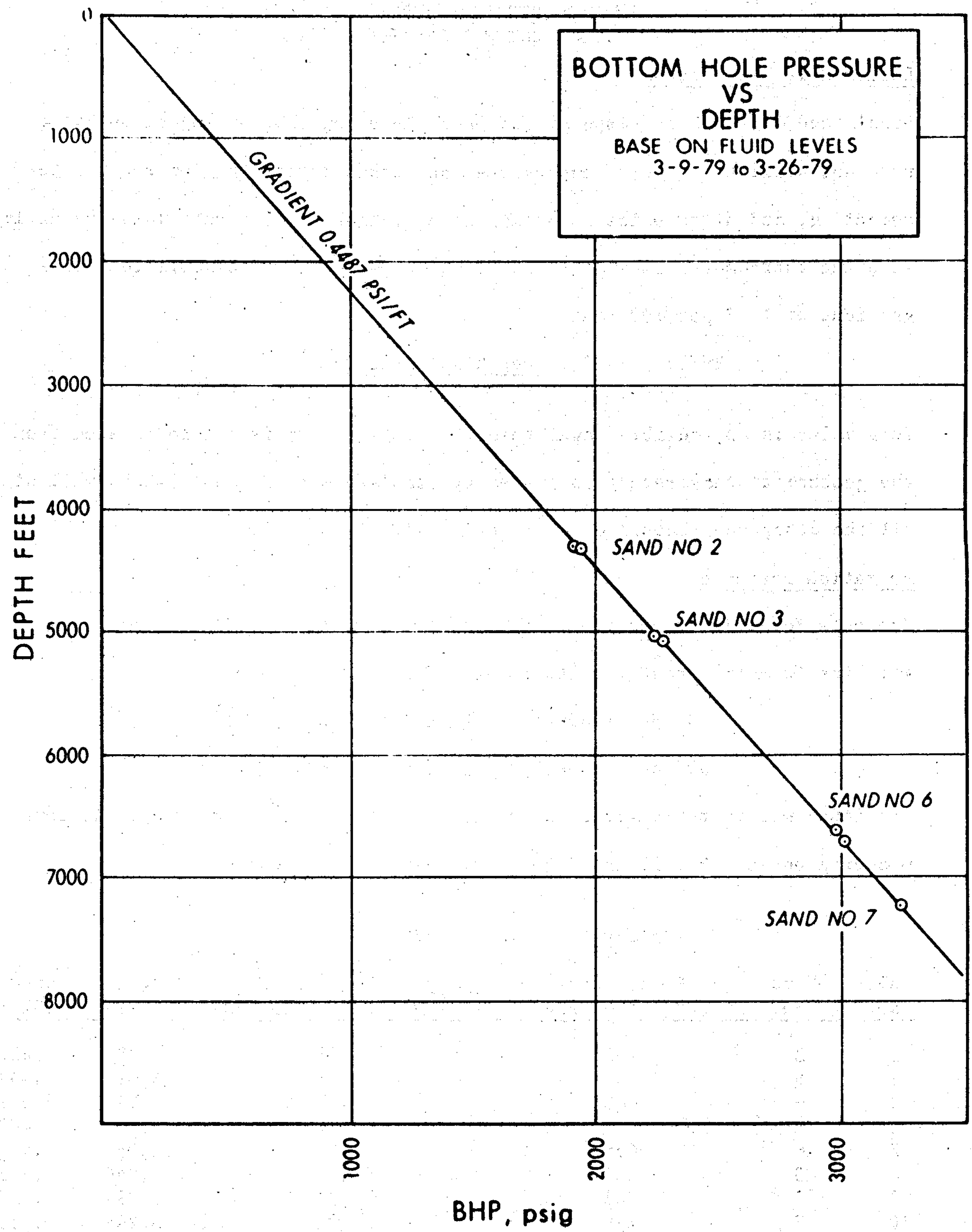
2600 psi @ 5581' gradient 0.4673 psi/ft.

The gauge was probably giving an erroneously high reading as the fluid levels measured between 3-9-79 and 3-26-79 all gave lower gradients.

Fluids Levels (taken 3-9-79 to 3-26-79)

Well No.	Sand No.	Fluid Level (Ft. below BHF)	Top of Completion Interval (Ft. below BHF)	BHP PSI	Gradient PSI/foot
1	3	482	5,052	2,285	.4522
2	6	680	6,706	3,013	.4493
3	6	640	6,619	2,990	.4516
6	2	498	4,321	1,912	.4423
7	6	625	6,610	2,993	.4527
8	3	542	5,033	2,246	.4461
9	2	542	4,329	1,894	.4374
10	7	720	7,209	3,244	.4500

The best fit passing through the origin gives a gradient of 0.4487 psi/foot.


BOTTOM HOLE PRESSURE
VS
DEPTH
BASE ON FLUID LEVELS
3-9-79 to 3-26-79
GRADIENT 0.4487 PSI/FT
SAND NO 2
SAND NO 3
SAND NO 6
SAND NO 7
DEPTH FEET
0
1000
2000
3000
4000
5000
6000
7000
8000
1000
2000
3000
BHP, psig

APPENDIX IV

RESERVOIR DATA SHEETS

COMPANY: KEPLINGER & ASSOCIATES
LEASE & WELL NO: 2,3 and 7
RUN DEPTH: 6871'
DATE: March 12, 1979 - March 16, 1979.

SUPERVISOR: Gus Mistrot
FIELD & COUNTY OR PARISH: BAYOU CHOCTAW
STATUS OF WELLS: SHUT-IN

DATE & TIME	BOTTOM HOLE PRESSURE (PSIA) PROBE # 282 WELL #2	PROBE #389 WELL # 3	PROBE # 300 WELL # 7	REMARKS
3-12-79				
07:30:00				Arrive on location. Talk with Stan Lambert (Texas Brine) and try to coordinate well tests.
10:30:00				Start rigging up on wells # 2, #3, and #7.
14:00:00				Rigged up on all 3 wells, and start in hole on well #3. From 14:00:00 hours until 03:00:00 hours (3/13/79) experienced multiple problems with rope sockets etc,...
3-13-79		•		Run depths 6871'.
03:30:00	3101.44	3110.84	3125.27	*(Subtract 10 PSIA on all pressures on Well # 3 due to different temperatures.)
04:00:00	3101.26	3110.73	3125.28	
04:30:00	3101.44	3110.72	3125.30	
05:00:00	3101.42	3110.66	3125.28	
05:30:00	3101.29	3110.71	3125.28	
06:00:00	3101.64	3110.70	3125.27	
06:30:00	3101.43	3110.84	3125.29	
07:00:00	3101.70	3110.79	3125.28	
07:30:00	3101.68	3110.76	3125.28	
08:00:00	3101.83	3110.72	3125.29	
08:30:00	3101.93	3110.77	3125.27	
09:00:00	3101.92	3110.77	3125.26	
09:30:00	3101.90	3110.71	3125.26	
10:00:00	3099.41	3110.74	3125.25	
10:17:00	3099.47	3111.15	3125.26	Start injection in well # 3.
10:17:10		3111.65		
10:17:20		3111.95		
10:17:30		3112.19		
10:17:40		3112.38		
10:17:50		3112.45		
10:18:00	3099.63	3112.53	3125.27	
10:18:10		3113.20		
10:18:20		3115.79		
10:18:30		3126.61		
10:18:40		3118.75		
10:18:50		3232.78		
10:19:00	3099.72	3274.81	3125.28	
10:19:10		3329.84		
10:19:20		3373.59		

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE # 282 WELL #2	PROBE #389 WELL #3	PROBE #300 WELL #7	REMARKS
3-13-79				
10:19:30		3609.93		
10:19:40		3855.10		
10:19:50		3865.13		
10:20:00	3099.81	3874.87	3125.28	
10:20:10		3860.84		
10:20:20		3837.23		
10:20:30		3818.76		
10:20:40		3805.37		
10:20:50		3810.59		
10:21:00	3099.93	3804.04	3125.29	
10:21:10		3811.95		
10:21:20		3821.56		
10:21:30		3832.83		
10:21:40		3847.01		
10:21:50		3859.86		
10:22:00	3100.03	3872.39	3125.29	
10:22:10		3885.98		
10:22:20		3897.30		
10:22:30		3908.11		
10:22:40		3919.21		
10:22:50		3928.68		
10:23:00	3100.05	3937.15	3125.28	
10:23:10		3946.13		
10:23:20		3953.52		
10:23:30		3966.47		
10:23:40		4021.53		
10:23:50		4067.24		
10:24:00	3100.02	4097.85	3125.27	
10:24:10		4099.63		
10:24:20		4069.81		
10:24:30		4056.79		
10:24:40		4044.16		
10:24:50		4037.07		
10:25:00	3100.07	4032.45	3125.28	
10:25:10		4026.82		
10:25:20		4022.02		
10:25:30		4017.36		
10:25:40		4011.84		
10:25:50		4007.01		
10:26:00	3100.15	4002.28	3125.29	
10:26:10		3997.01		
10:26:20		3992.37		
10:26:30		3987.92		
10:26:40		3983.16		

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE #282 WELL # 2	PROBE # 389 WELL #3	PROBE #300 WELL # 7	REMARKS
3-13-79				
10:26:50		3979.23		
10:27:00	3100.18	3975.76	3125.27	
10:27:10		3972.61		
10:27:20		3982.00		
10:27:30		4014.86		
10:27:40		4049.88		
10:27:50		4077.19		
10:28:00	3100.24	4102.21	3125.30	
10:28:10		4127.64		
10:28:20		4147.25		
10:28:30		4164.98		
10:28:40		4182.81		
10:28:50		4196.75		
10:29:00	3100.33	4209.33	3125.30	
10:29:10		4165.87		
10:29:20		4107.88		
10:29:30		4059.07		
10:30:00	3100.32	3934.92	3125.29	
10:31:00	3100.41	3766.99	3125.28	Injection Pressure = 1050 PSI.
10:32:00	3100.47	3673.17	3125.31	
10:33:00	3100.48	3618.08	3125.32	
10:34:00	3100.45	3821.81	3125.32	
10:35:00	3100.34	4092.43	3125.31	
10:36:00	3100.20	4273.79	3125.31	
10:37:00	3099.96	4341.16	3125.31	
10:38:00	3099.77	4368.07	3125.32	
10:39:00	3099.82	4382.81	3125.33	
10:40:00	3100.00	4393.22	3125.35	
10:41:00	3100.13	4404.62	3125.37	
10:42:00	3100.21	4415.06	3125.34	
10:43:00	3100.36	4423.07	3125.38	
10:44:00	3100.43	4427.72	3125.38	
10:45:00	3100.57	4430.99	3125.39	
10:46:00	3100.66	4433.48	3125.40	
10:47:00	3100.77	4436.82	3125.39	
10:48:00	3100.82	4440.61	3125.40	
10:49:00	3100.89	4442.95	3125.44	
10:50:00	3100.99	4444.34	3125.43	
10:51:00	3101.08	4445.32	3125.42	
10:52:00	3101.18	4444.88	3125.42	
10:53:00	3101.24	4443.86	3125.43	
10:54:00	3101.33	4443.33	3125.47	
10:55:00	3101.43	4444.88	3125.47	
10:56:00	3101.46	4445.58	3125.46	

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE #282 WELL #2	PROBE #389 WELL #3	PROBE #300 WELL # 7	REMARKS
3-13-79				
10:57:00	3101.54	4445.06	3125.46	
10:58:00	3101.62	4444.58	3125.49	
10:59:00	3101.69	4443.90	3125.48	
11:00:00	3101.74	4443.91	3125.51	
11:05:00	3102.02	4442.69	3125.51	
11:10:00	3102.24	4443.36	3125.55	
11:15:00	3102.40	4445.15	3125.59	
11:20:00	3102.57	4446.17	3125.66	
11:25:00	3102.70	4447.42	3126.65	
11:30:00	3102.80	4449.03	3125.66	
12:00:00	3103.28	4452.18	3125.79	
12:30:00	3103.53	4459.07	3125.90	
13:00:00	3103.69	4469.00	3126.02	
13:30:00	3103.74	4474.04	3126.07	
13:38:00		4474.71		Injection pumps were switched due to mechanical problems. Injection pressure dropped to 900 PSI.
13:39:00		4441.72		
13:40:00		4240.04		
13:41:00		4232.67		
13:42:00		4268.22		
13:43:00		4297.47		
13:44:00		4315.58		
13:45:00		4325.98		
13:46:00		4332.00		
13:47:00		4336.06		
13:48:00		4339.03		
13:49:00		4341.16		
13:50:00		4342.81		
13:51:00		4343.78		
13:52:00		4344.95		
13:53:00		4345.80		
13:54:00		4346.76		
13:55:00		4347.40		
13:56:00		4348.09		
13:57:00		4348.19		
13:58:00		4348.48		
13:59:00		4348.62		
14:00:00	3103.95	4349.03	3126.14	
14:05:00		4350.20		
14:10:00		4350.91		
14:15:00		4351.32		
14:20:00		4351.37		
14:25:00		4351.90		
14:30:00	3104.04	4351.95	3126.14	

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE #282 WELL #2	PROBE #389 WELL #3	PROBE #300 WELL #7	REMARKS
3-13-79				
14:35:00		4351.44		
14:40:00		4351.98		
14:45:00		4352.80		
14:50:00		4458.04		Injection pressure back up to 1020 PSI.
14:55:00		4461.80		
15:00:00	3104.10	4461.92	3126.19	
15:30:00	3104.22	4458.26	3126.26	
16:00:00	3104.39	4463.04	3126.30	
16:30:00	3104.45	4463.74	3126.34	
17:00:00	3104.47	4463.72	3126.41	
17:30:00	3104.56	4464.99	3126.46	
18:00:00	3104.69	4467.34	3126.51	
18:30:00	3104.71	4465.78	3126.56	
19:00:00	3104.78	4466.10	3126.57	
19:30:00	3104.83	4467.19	3126.60	
20:00:00	3104.93	4465.37	3126.66	
20:30:00	3104.95	4465.40	3126.68	
21:00:00	3105.04	4464.93	3126.69	
21:30:00	3105.06	4464.31	3126.72	
22:00:00	3105.13	4463.18	3126.75	
22:30:00	3105.13	4463.74	3126.76	
23:00:00	3105.13	4464.02	3126.77	
23:30:00	3105.26	4463.23	3126.78	
3-14-79				
00:00:00	3105.25	4463.61	3126.83	
00:30:00	3105.32	4463.34	3126.86	
01:00:00	3105.38	4464.25	3126.85	
01:30:00	3105.35	4463.80	3126.90	
02:00:00	3105.43	4463.21	3126.89	
02:30:00	3105.47	4462.53	3126.91	
03:00:00	3105.52	4461.92	3126.95	
03:30:00	3105.54	4463.26	3126.95	
04:00:00	3105.56	4463.87	3127.00	
04:30:00	3105.61	4463.87	3127.00	
05:00:00	3105.64	4464.37	3127.01	
05:30:00	3105.61	4463.82	3126.99	
06:00:00	3105.68	4464.77	3127.06	
06:30:00	3105.70	4464.78	3127.08	
07:00:00	3105.73	4464.60	3127.09	
07:30:00	3105.75	4466.41	3127.08	
08:00:00	3105.82	4499.77	3127.13	
08:15:00	3105.83	4276.03	3127.15	Switched pumps due to misunderstanding with Duci.

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE # 282 WELL # 2	PROBE #389 WELL # 3	PROBE #300 WELL # 7	REMARKS
3-14-79				
08:16:00		4439.01		Injection Pressure dropp to 700 PSI.
08:17:00		4486.69		
08:18:00		4500.34		
08:19:00		4504.88		
08:20:00		4506.03		
08:21:00		4506.37		
08:22:00		4507.13		
08:23:00		4507.35		
08:24:00		4507.70		
08:25:00		4508.02		
08:26:00		4508.78		
08:27:00		4509.12		
08:28:00		4509.72		
08:29:00		4509.91		
08:30:00	3105.90	4510.58	3127.16	Injection Pressure back up to point prior to last dropage.
09:00:00	3105.91	4515.71	3127.20	Increase to 1120 PSI.
09:30:00	3105.96	4517.86	3127.21	
10:00:00	3105.90	4520.05	3127.24	
10:30:00	3105.88	4520.01	3127.26	
11:00:00	3106.01	4520.76	3127.28	
11:30:00	3106.02	4522.23	3127.29	
12:00:00	3106.04	4523.46	3127.29	
12:30:00	3106.06	4524.34	3127.30	
13:00:00	3106.09	4524.74	3127.32	
13:30:00	3106.08	4526.23	3127.32	
14:00:00	3106.10	4525.83	3127.34	
14:30:00	3106.10	4526.70	3127.36	
15:00:00		4526.64	3127.38	Lost signal on well # 2 from 14:38:00 until 15:24:00 (Land line parted)
15:30:00	3106.10	4526.94	3127.39	
16:00:00	3106.16	4527.11	3127.40	
16:30:00	3106.15	4530.15	3127.42	Injection eratic due to washing back of filters on injection pump.
17:00:00	3106.17	4514.43	3127.45	
17:30:00	3106.21	4265.25	3127.46	
18:00:00	3100.21	3495.08	3127.37	
18:30:00	3102.52	4525.88	3127.34	At 17:30:00 pump went out until 18:00:00. Began building back up at 18:00.
19:00:00	3104.68	4533.67	3127.39	
19:30:00	3105.53	4538.11	3127.40	
20:00:00	3105.95	4540.08	3127.39	
20:30:00	3106.09	4543.59	3127.46	
21:00:00	3106.18	4544.13	3127.50	
21:30:00	3106.14	4546.19	3127.55	
22:00:00	3106.16	4546.31	3127.56	
22:30:00	3106.25	4547.04	3127.57	

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE # 282 WELL #2	PROBE #389 WELL # 3	PROBE # 300 WELL # 7	REMARKS
3-14-79				
23:00:00	3106.27	4547.61	3127.56	
23:30:00	3106.24	4548.94	3127.57	
3-15-79				
00:00:00	3106.30	4549.95	3127.58	
00:30:00	3106.29	4550.72	3127.58	
01:00:00	3106.30	4552.64	3127.76	
01:30:00	3106.29	4552.33	3127.61	
02:00:00	3106.32	4554.49	3127.62	
02:30:00	3106.30	4555.72	3127.62	
03:00:00	3106.36	4556.18	3127.62	
03:30:00	3106.33	4557.10	3127.67	
04:00:00	3106.40	4557.34	3127.67	
04:30:00	3106.36	4556.60	3127.67	
05:00:00	3106.36	4556.35	3127.69	
05:30:00	3106.38	4556.08	3127.69	
06:00:00	3106.37	4556.71	3127.68	
06:30:00	3106.39	4557.16	3127.69	
07:00:00	3106.44	4554.62	3127.72	
07:30:00	3106.44	4554.44	3127.75	
08:00:00	3106.50	4554.60	3127.74	
08:30:00	3106.54	4555.45	3127.74	
09:00:00	3106.57	4554.28	3127.74	
09:30:00	3106.58	4556.72	3127.75	Stopped injection in Well # 3.
10:00:00	3106.47	3239.56	3127.72	
10:30:00	3106.45	3116.07	3127.54	
11:00:00	3106.52	3113.87	3127.41	
11:30:00	3106.48	3113.52	3127.27	
12:00:00	3106.37	3113.30	3127.19	
12:30:00	3106.31	3113.17	3127.03	
13:00:00	3106.21	3113.05	3126.96	
13:30:00	3106.18	3113.15	3126.92	
14:00:00	3106.17	3112.98	3126.87	
14:30:00	3106.10	3113.00	3126.84	
15:00:00	3106.07	3113.08	3126.78	
15:30:00	3105.97	3113.05	3126.73	
16:00:00	3105.97	3113.01	3126.69	
16:30:00	3100.88	3113.01	3126.67	
17:00:00	3099.07	3112.94	3126.64	
17:30:00	3103.48	3112.95	3126.60	
18:00:00	3104.91	3112.89	3126.57	
18:30:00	3105.47	3112.86	3126.55	
19:00:00	3105.76	3112.84	3126.53	
19:30:00	3105.84	3112.81	3126.49	

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE # 282 WELL # 2	PROBE # 389 WELL # 3	PROBE #300 WELL # 7	REMARKS
3-15-79				
20:00:00	3105.75	3112.80	3126.46	
20:30:00	3105.62	3112.75	3126.44	
21:00:00	3105.55	3112.71	3126.40	
21:30:00	3105.54	3112.69	3126.38	
22:00:00	3105.44	3112.66	3126.34	
22:30:00	3105.45	3112.67	3126.30	
23:00:00	3105.44	3112.65	3126.31	
23:30:00	3105.38	3112.60	3126.28	
3-16-79				
00:00:00	3105.35	3112.57	3126.27	
00:30:00	3105.37	3112.58	3126.21	
01:00:00	3105.33	3112.55	3126.22	
01:30:00	3105.32	3112.52	3126.19	
02:00:00	3105.24	3112.53	3126.18	
02:30:00	3105.22	3112.48	3126.16	
03:00:00	3105.15	3112.49	3126.14	
03:30:00	3105.21	3112.47	3126.15	
04:00:00	3105.15	3112.47	3126.13	
04:30:00	3105.14	3112.42	3126.13	
05:00:00	3105.13	3112.43	3126.10	
05:30:00	3105.12	3112.43	3126.11	
06:00:00	3105.15	3112.43	3126.07	
06:30:00	3105.15	3112.41	3126.09	
07:00:00	3105.09	3112.40	3126.07	
07:30:00	3105.14	3112.39	3126.06	
08:00:00	3105.11	3112.40	3126.05	
08:30:00	3105.13	3112.39	3126.05	Start out of hole with Pressure Probes in wells # 2, and # 3.
09:00:00			3126.03	
09:30:00			3126.03	
11:00:00				By 11:00:00 hours we were out of hole on all 3 wells.

Rig up on well # 3 with Temperature Probe and Pressure Probe. Go into hole taking gradient stops and logging from 6400' to 6914' T.D. Corrected 11' with CCL (11'Deep).

58.3	Surface
71.4	1,000'
77.9	2,000'
84.0	3,000'
93.4	4,000'
101.2	5,000'
108.3	6,000'
114.1	6,500'

As/ Temperature Log B.H.T.
70.5 BHT

BOTTOM HOLE PRESSURE (PSIA)

DATE & TIME	PROBE #282 WELL #2	PROBE # 389 WELL # 3	PROBE # 300 WELL # 7	REMARKS
3-16-79				
15:00:00				Rig up on Well # 2 with Temperature Probe and CCL. Go into hole taking gradient stops and logging from 6400' to 6968 T.D. Temperature As/ Log. Corrected 7' (7' high).

TEMP.	DEPTH
58.4	Surface
67.8	1,000'
77.9	2,000'
87.1	3,000'
97.4	4,000'
106.8	5,000'
116.4	6,000'
66.7	B.H.T.

DATE & TIME	PROBE #282 WELL #2	PROBE # 389 WELL # 3	PROBE # 300 WELL # 7	REMARKS
19:00:00				Stopped rigging down due to nightfall.
3-17-79				
				Finished rigging down and returned to Houstor base.

APPENDIX V

BAYOU CHOCTAW

WELL INJECTION HISTORIES:

WELLS 2 TO 11

See PLATE IV For

Hole Locations And Injection

Sand Assignment

VI - Volume Injected To
Date Indicated

ZT - Zone Thickness Of
Injection Interval

BAYOU CHOCTAW FIELD

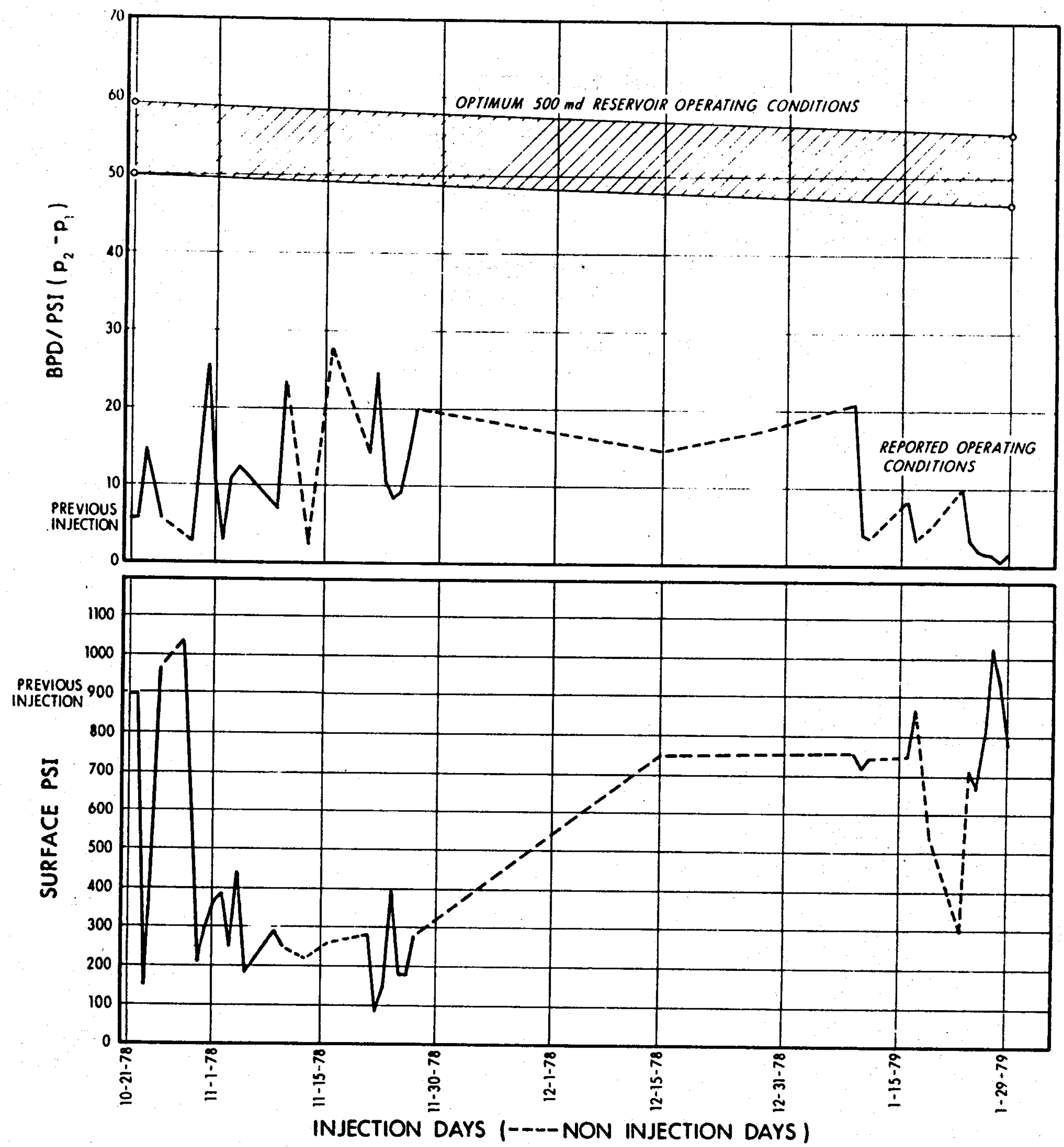
BPD/PSI Vs. INJECTION DAYS

WELL No 2 SAND No 6

PAD 1

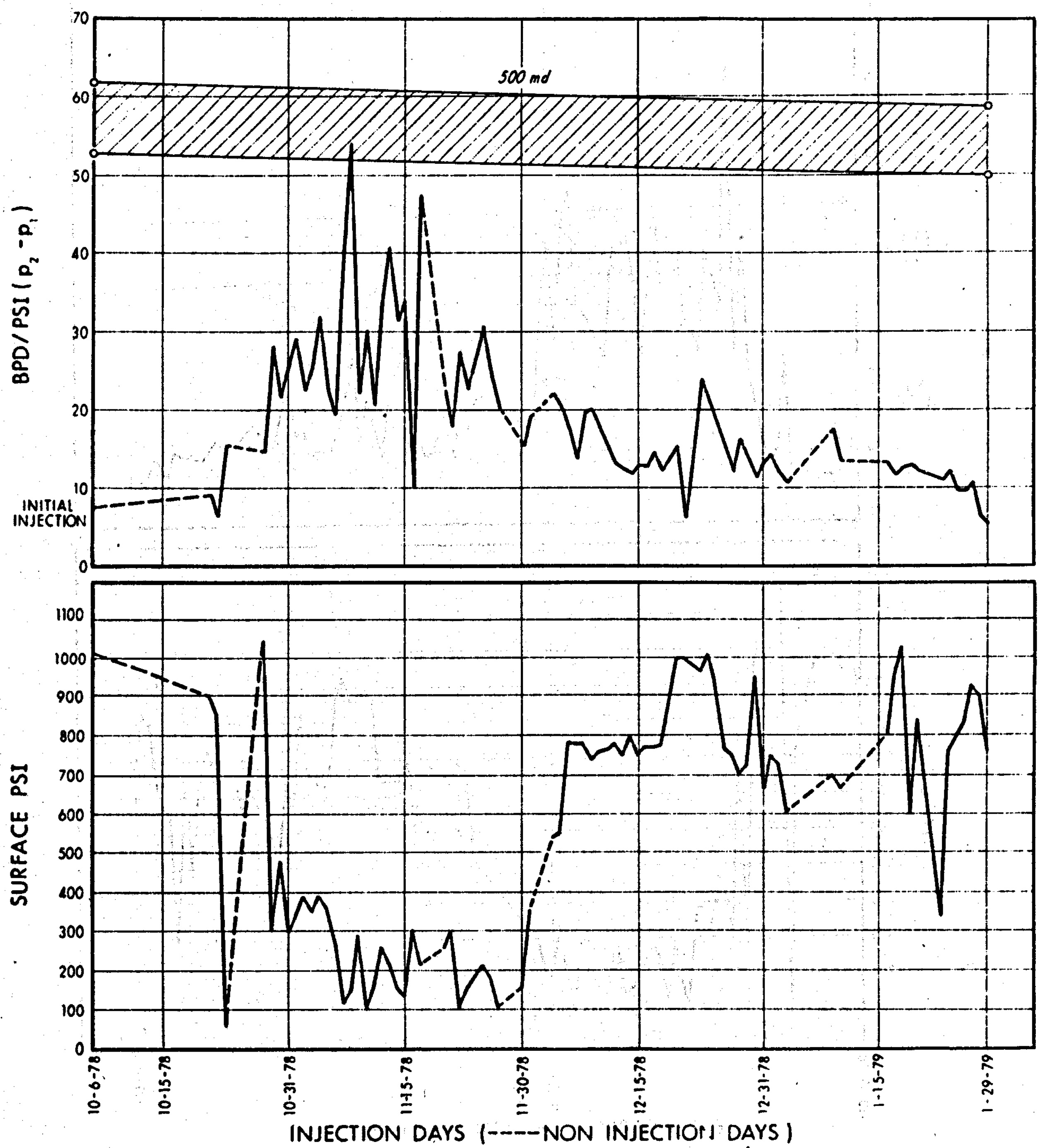
VI 563,000 BBLS. (THIS PERIOD ONLY)

ZT 238'



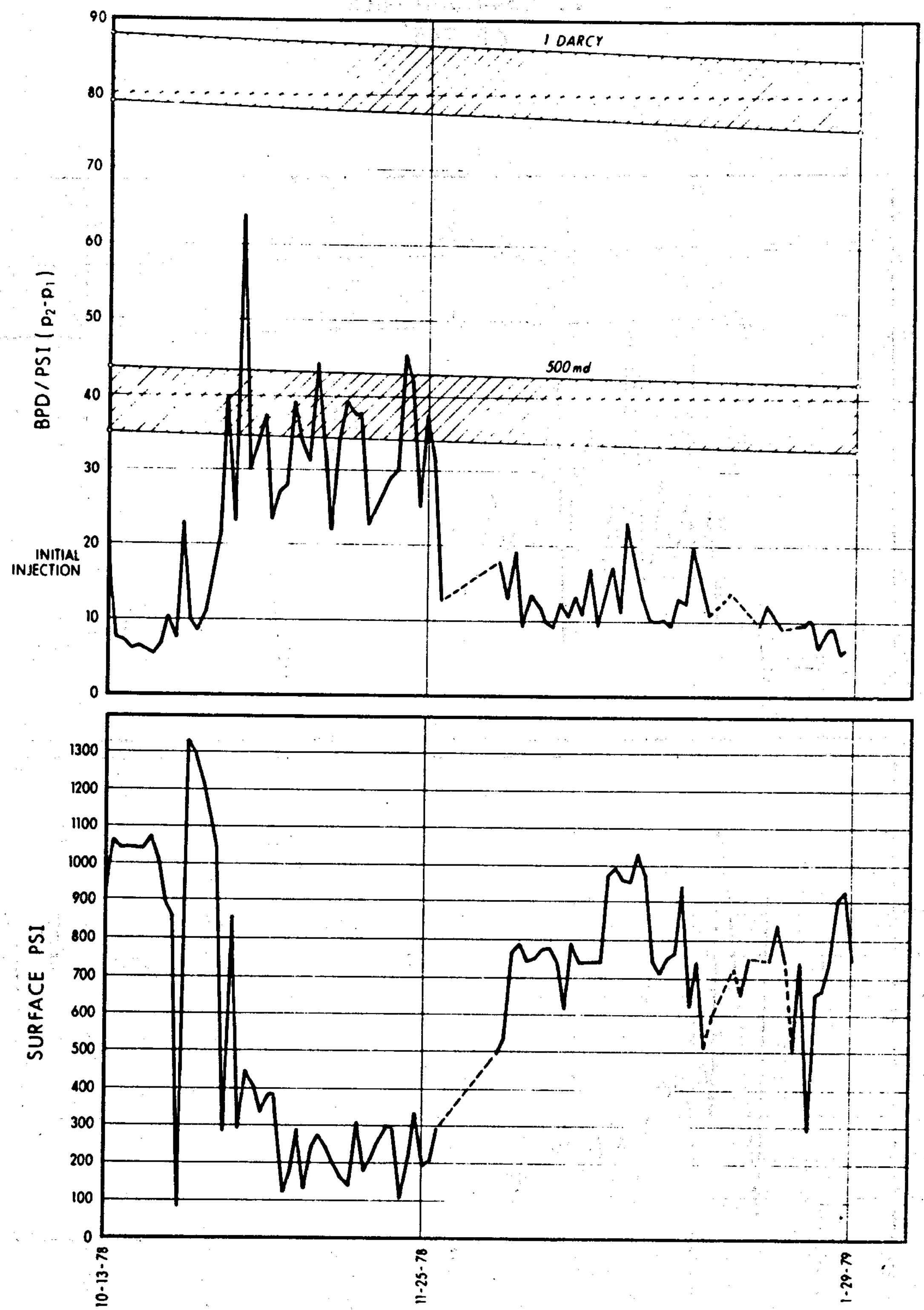
BAYOU CHOCTAW FIELD

BPD/PSI Vs. INJECTION DAYS
WELL No.3 SAND No.6
PAD 2
VI 1,344,000 BBLS.
ZT 245'



BAYOU CHOCTAW FIELD

BPD/PSI Vs. INJECTION DAYS
WELL No.4 SAND No.5
PAD 2
VI 1,036,000 BBLS
ZT 172'



INJECTION DAYS (----NON INJECTION DAYS)

BAYOU CHOCTAW FIELD

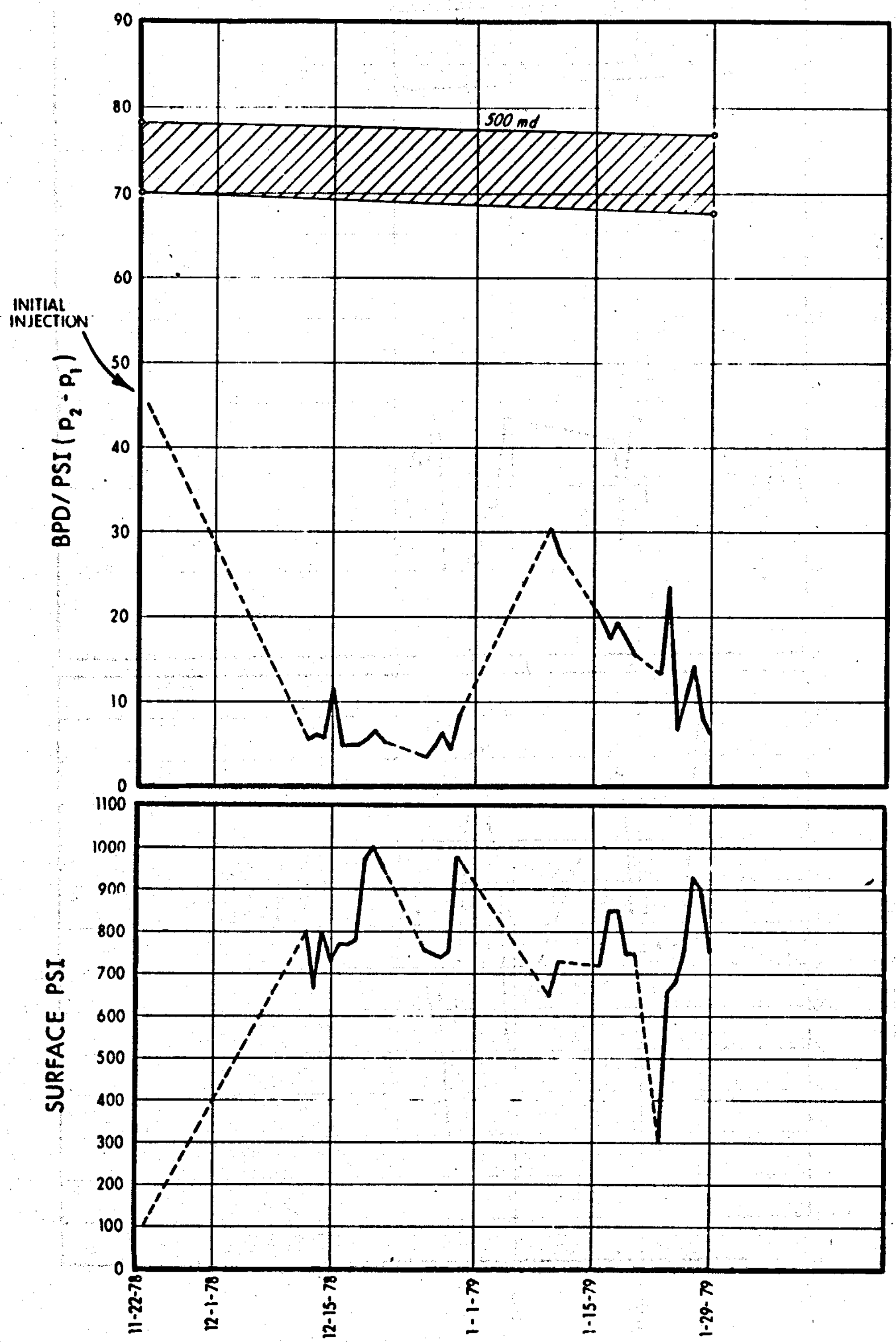
BPD / PSI Vs. INJECTION DAYS

WELL No. 5 SAND No. 3

PAD 2

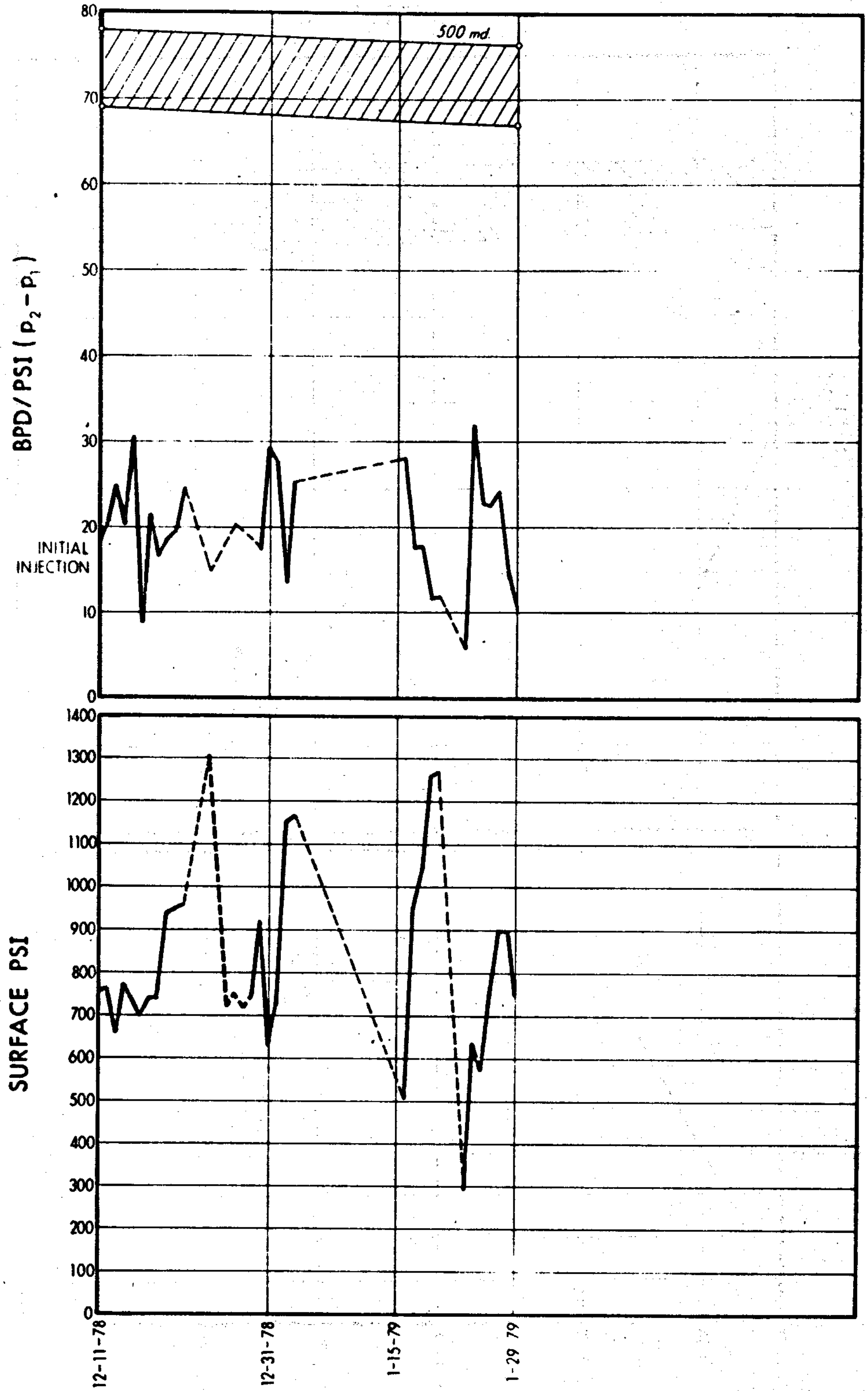
VI 346,000 BBLS.

ZT 312'



BAYOU CHOCTAW FIELD

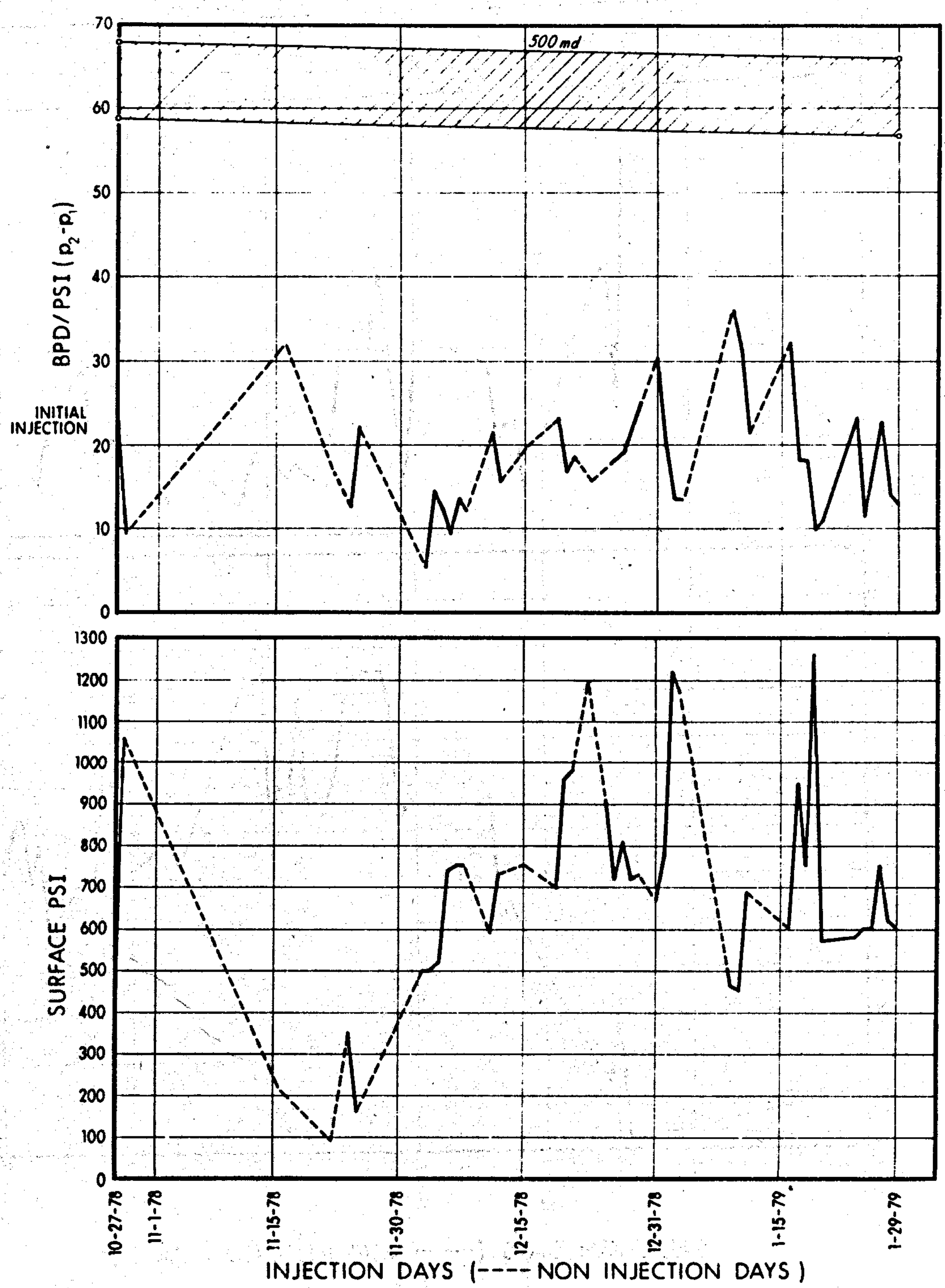
BPD/PSI Vs. INJECTION DAYS
WELL No. 6 SAND No. 2
PAD 2
VI 579,000 BBLS.
ZT 310'



INJECTION DAYS (----NON INJECTION DAYS)

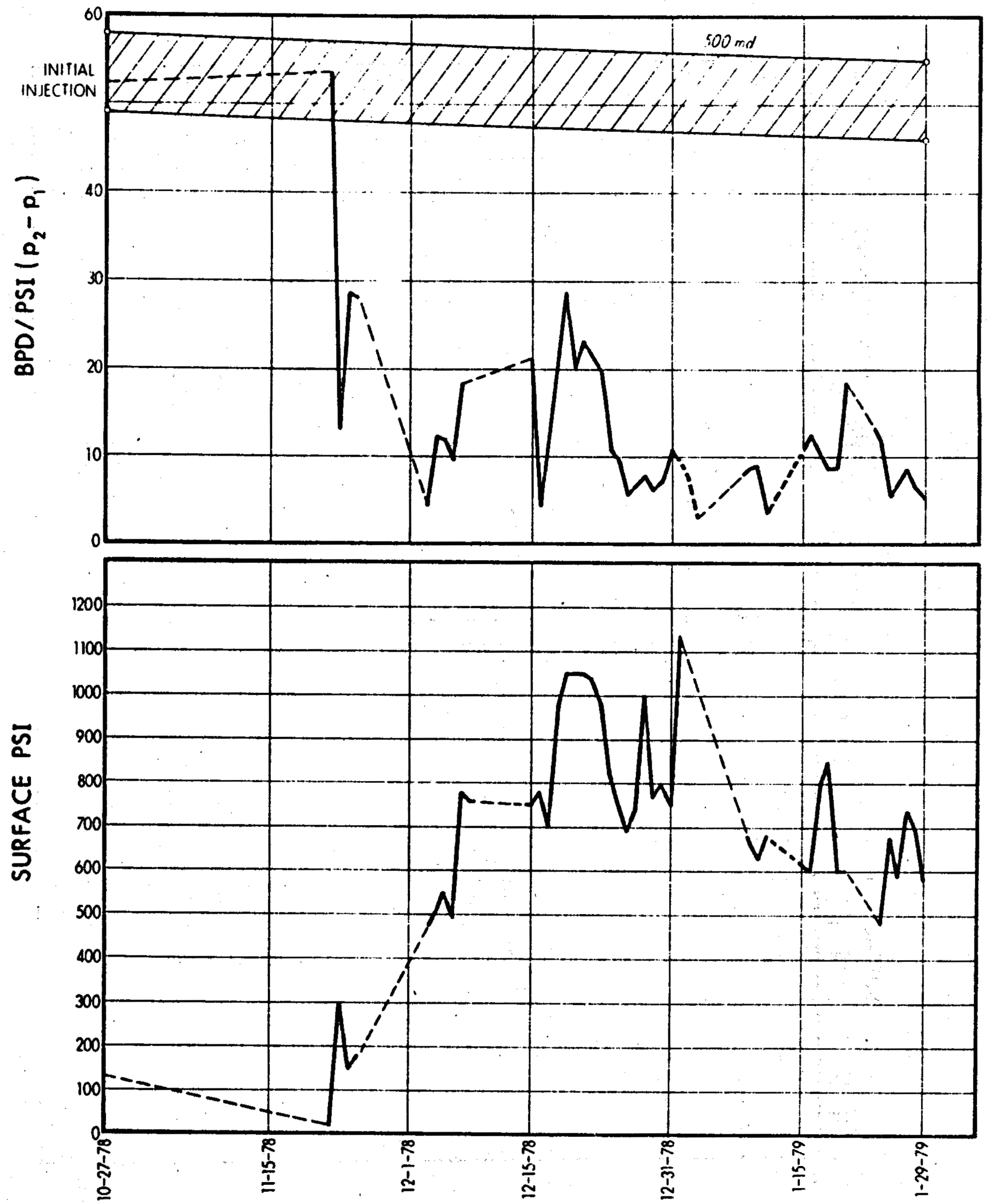
BAYOU CHOCTAW FIELD

BPD / PSI Vs. INJECTION DAYS
WELL No. 7 SAND No. 6
PAD 3
VI 706,000 BBLS.
ZT 270'



BAYOU CHOCTAW FIELD

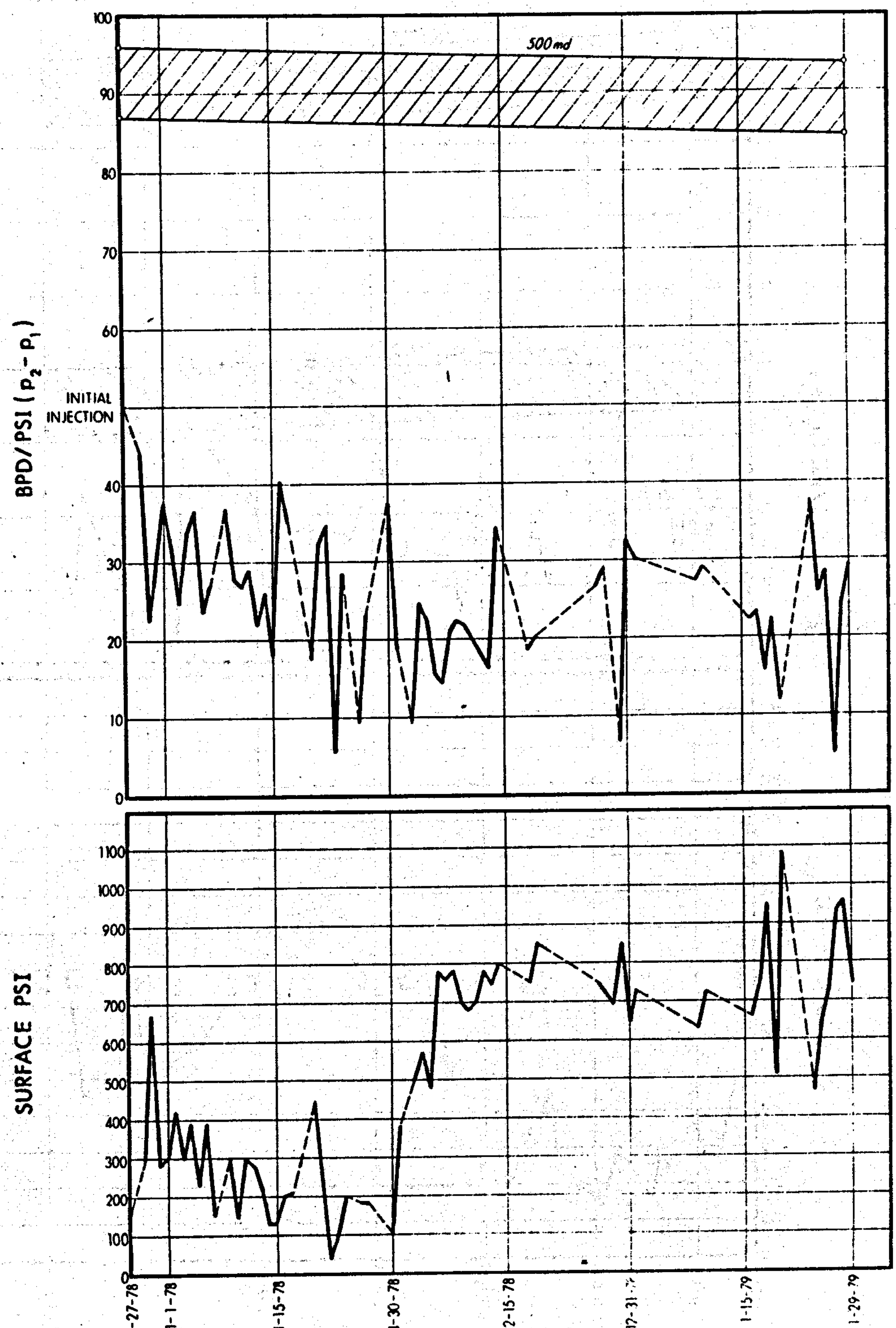
BPD/PSI Vs. INJECTION DAYS
WELL No. 8 SAND No. 3
PAD 3
VI 387,000 BBLS.
ZT 230'



INJECTION DAYS (----NON INJECTION DAYS)

BAYOU CHOCTAW FIELD

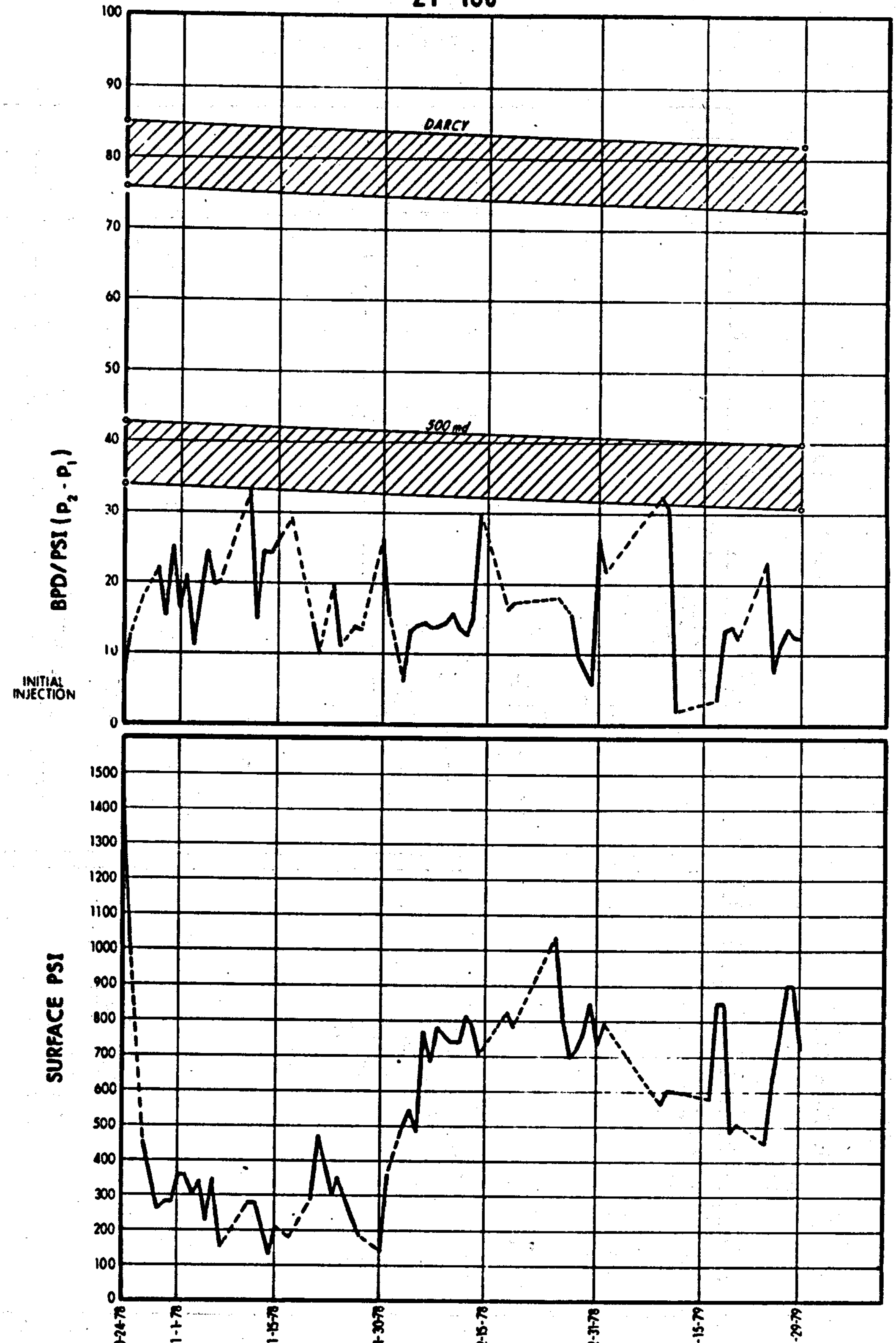
BPD/PSI Vs. INJECTION DAYS
WELL No. 9 SAND No. 2
PAD 3
VI 878,000 BBLS.
ZT 357'



INJECTION DAYS (----NON INJECTION DAYS)

BAYOU CHOCTAW FIELD

BPD / PSI Vs. INJECTION DAYS
WELL No. 10 SAND No. 7
PAD 3
VI 633,000 BBLS.
ZT 168'



INJECTION DAYS (----NON INJECTION DAYS)

BAYOU CHOCTAW FIELD

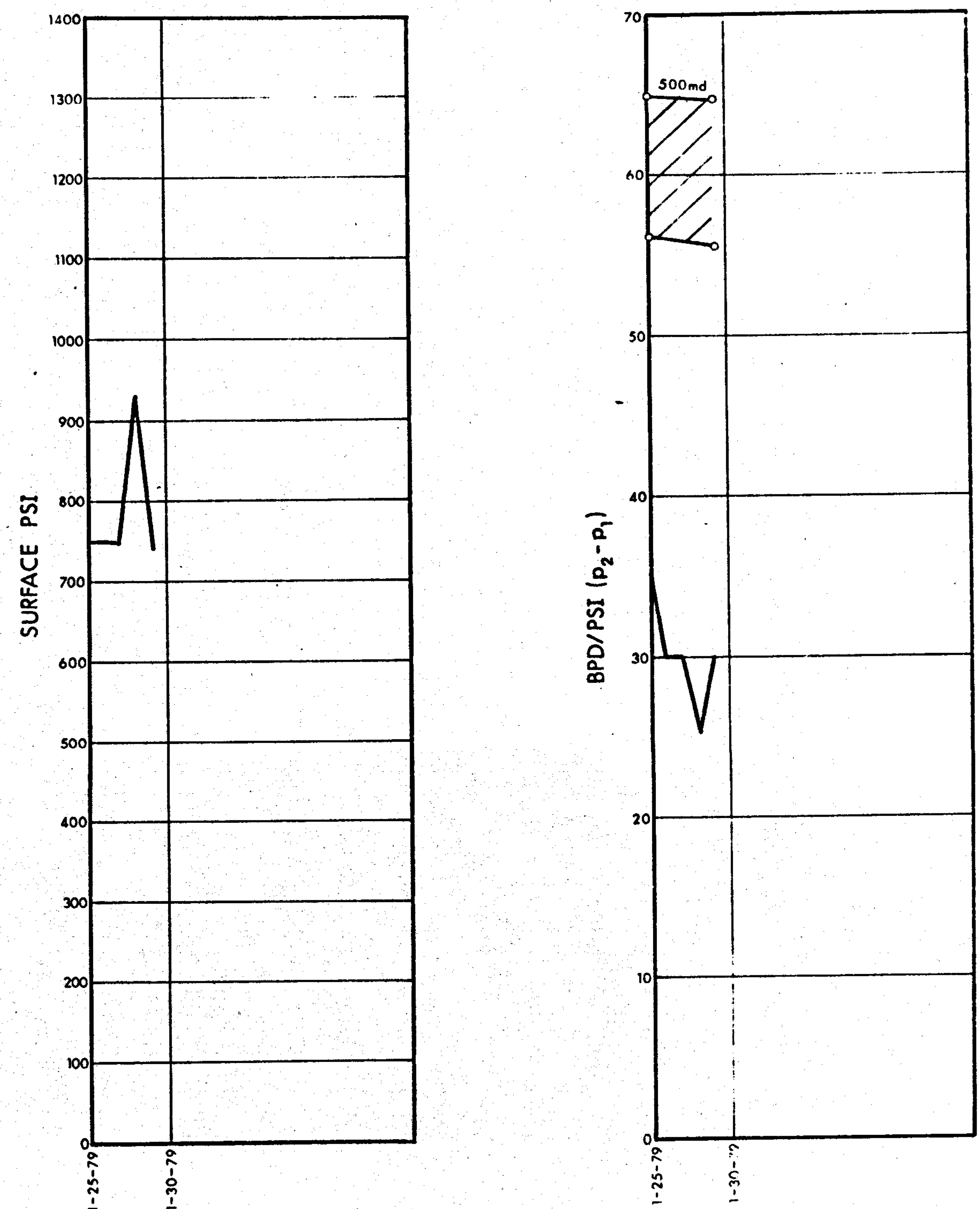
BPD/PSI Vs. INJECTION DAYS

WELL No. 11 SAND No. 2

PAD 1

VI 126,000 BBLS.

ZT 263'



INJECTION DAYS (----NON INJECTION DAYS)

APPENDIX VI

CHEMISTRY, TURBIDITY, AND SUPPLEMENTARY CHEMICAL DATA FOR WEST HACKBERRY BRINES

TABLE VI-1. Chemistry of West Hackberry brines.

Date	pH	ρ, g/mℓ	Dissolved Fe	$SO_4^{=}$	Ca^{++}	HCO_3^-	Cl^-	$S^=$
			Constituent, mg/ℓ					
Sample location: Pond inflow								
January 5, 1979	--	--	0.75	--	--	--	--	--
January 6, 1979	--	--	--	--	--	--	--	--
January 7, 1979	7.6	1.192	0.24	1475	660	294	184,000	--
January 9, 1979	7.5	1.184	0.17	1475	640	293	176,000	--
January 10, 1979	--	--	--	--	--	--	--	3.0
January 11, 1979	7.9	1.000	0.57	7	42	342	1,906	--
January 12, 1979	7.7	1.098	0.30	--	--	--	94,700	--
January 13, 1979	7.9	1.010	0.48	68	--	--	13,640	--
January 14, 1979	7.5	1.171	0.15	--	--	--	155,000	--
January 15, 1979	7.9	1.000	0.61	--	--	--	1,130	--
Sample location: Pond outflow								
January 5, 1979	7.6	1.185	0.75	--	--	--	--	--
January 6, 1979	7.6	1.183	0.42	1250	569	296	175,000	--
January 7, 1979	--	--	--	--	--	--	--	--
January 9, 1979	7.6	1.185	0.18	1375	628	293	176,000	--
January 10, 1979	--	--	--	--	--	--	--	<0.1
January 11, 1979	7.6	1.189	0.11	1450	640	291	183,000	--
January 12, 1979	7.7	1.175	0.26	--	--	--	173,000	--
January 13, 1979	7.6	1.166	0.90	1200	--	--	160,000	--
January 14, 1979	7.7	1.169	0.32	--	--	--	161,000	--
January 15, 1979	7.6	1.165	0.24	--	--	--		--
Sample location: Injection Site								
January 5, 1979	--	--	0.60	--	--	--	--	--
January 6, 1979	7.6	1.183	0.28	1250	580	303	173,000	--
January 7, 1979	--	--	--	--	--	--	--	--
January 9, 1979	7.6	1.186	0.26	1250	609	293	176,000	--
January 11, 1979	7.6	1.187	0.19	1375	621	--	179,000	--
January 12, 1979	7.6	1.177	0.18	--	--	--	172,000	--
January 13, 1979	7.6	1.167	0.48	1125	--	--	160,000	--
January 14, 1979	7.6	1.163	0.95	--	--	--	155,000	--
January 15, 1979	7.7	1.167	0.45	--	--	--	156,000	--

TABLE VI-2. Turbidity at West Hackberry.

Date	Turbidity, NTU, of indicated sample					
	Pond Input		Pond Output		Injection Site	
	Daily Average	Range	Daily Average	Range	Daily Average	Range
January 6, 1979	—	—	1.42	1.0-2.5	4.3	1.3-7.4
January 7, 1979	—	—	2.05	1.6-2.5	--	--
January 8, 1979	0.74	0.6-1.0	1.15	0.98-1.6	--	--
January 9, 1979	0.60	0.26-1.4	0.71	0.61-0.85	--	--
January 10, 1979	1.77	0.54-4.4	1.24	0.66-1.61	--	--
January 11, 1979	0.95	0.7-1.2	1.63	1.20-2.0	2.0	2.0
January 12, 1979	1.35	0.9-1.8	13.0	2.2-20.0	--	--
January 13, 1979	0.75	0.75	4.8	4.8	--	--
January 14, 1979	0.86	0.71-1.0	3.43	3.1-4.0	--	--
January 15, 1979	0.62	0.58-0.65	2.3	2.2-2.4	--	--

TABLE VI-3. Supplementary chemical data for West Hackberry brines.

Constituent	Pond Inflow		Ponded Brine		Injection Site	
	1/5/79	1/12/79	1/5/79	1/12/79	1/9/79	1/12/79
Total solids,[a] mg/ℓ	4,731	153,640	301,800	274,739	300,041	276,456
Sodium,[a] mg/ℓ	1,736	60,028	117,995	107,313	117,238	107,948
Iron, mg/ℓ	0.58	0.46	0.48	0.36	0.24	0.20
Barium, mg/ℓ	ND[b]	ND	ND	ND	ND	ND
Calcium, mg/ℓ	44	240	428	489	487	503
Magnesium, mg/ℓ	11	9	9	9	9	9
Chloride, mg/ℓ	2,577	92,576	181,770	165,563	180,712	166,406
Bicarbonate, mg/ℓ	348	349	297	290	295	300
Carbonate, mg/ℓ	ND	ND	ND	ND	ND	ND
Sulfate, mg/ℓ	14	438	1,300	1,075	1,300	1,290
Sulfide, mg/ℓ	0.05	ND	ND	ND	—	ND
Specific gravity	1.003	1.105	1.190	1.183	1.191	1.183
pH	7.85	7.72	7.74	7.70	7.70	7.70
Resistivity,[a] ohm-m	—	0.060	—	0.045	0.043	0.044

[a]Calculated.

[b]None detected.

APPENDIX VII

CHEMISTRY, TURBIDITY, AND SUPPLEMENTARY CHEMICAL DATA FOR BAYOU CHOCTAW BRINES

TABLE VII-1. Chemistry of Bayou Choctaw brines.

Date	pH	ρ, g/mℓ	Solids, ppm	Constituent, mg/ℓ						
				Fe Filtrate	Fe Total	$SO_4^{=}$	Ca^{++}	HCO_3^{-}	Cl^{-}	H_2S
Sample location: Cavern 18										
January 27, 1979	6.86	1.196	—	—	0.33	833	465	148	193,000	—
February 1, 1979	6.79	1.197	—	—	—	—	—	—	190,500	<0.1
Sample location: Cavern 19										
February 1, 1979	6.49	1.197	—	—	—	—	—	—	191,400	<0.1
Sample location: Ponded brine										
January 25, 1979	6.85	1.195	3	0.14	0.30	700	398	148	190,000	—
January 26, 1979	6.68	1.198	—	—	0.34	—	—	—	191,000	—
January 27, 1979	6.79	1.196	—	—	0.37	—	—	—	192,000	—
Sample location: Injection pad										
January 25, 1979	7.0	1.189	78	0.17	0.88	650	380	159	187,000	—
January 26, 1979	6.81	1.189	6	—	0.53	—	—	—	183,500	—
January 27, 1979	6.83	1.188	—	—	0.46	—	—	—	182,000	—
Sample location: Cavern Lake water										
January 29, 1979	7.8	1.0	—	0.36	1.0	17	0.28	103	53	—
January 30, 1979	—	—	40	—	—	—	—	—	—	—
January 31, 1979	—	—	—	—	—	—	—	—	—	<0.1

TABLE VII-2. Chemistry of Bayou Choctaw weak (leach) brine.

Date	Time	pH	ρ, g/mℓ	Constituent, mg/ℓ						
				Solids ppm	Fe Filtrate	Fe Total	$SO_4^{=}$	Ca^{++}	HCO_3^{-}	Cl^{-}
January 29, 1979	0850	—	1.179	—	—	—	—	—	—	168,300
	0930	—	1.177	—	—	—	—	—	—	167,400
	1010	—	1.177	—	—	—	—	—	—	169,200
	1100	—	1.182	—	—	—	—	—	—	168,300
	1150	—	1.178	—	—	—	—	—	—	169,206
	1330	6.63	1.176	10	0.35	0.68	1250	1200	101	167,400
	1530	6.41	1.176	—	—	—	—	—	—	166,500
January 30, 1979	1330	6.41	1.173	—	0.30	0.83	—	—	—	163,900
January 31, 1979	0800	6.34	1.168	—	0.60	0.97	—	—	—	157,700
February 1, 1979	0830	6.50	1.166	—	0.43	1.33	—	—	—	157,700
February 2, 1979	0820	6.50	1.165	23	0.62	1.2	980	920	92	155,000
February 3, 1979	0815	6.40	1.162	—	0.55	1.6	—	—	—	154,200

TABLE VII-3. Daily average turbidity at Bayou Choctaw.

Date	Turbidity, NTU, of indicated sample				
	Cavern 18	Ponded Strong brine	Injection pad	Weak brine	Cavern Lake water
January 25, 1979	0.7	1.6	8.8	—	70
January 26, 1979	—	1.4	4.4	—	—
January 27, 1979	—	1.5	4.0	—	—
January 28, 1979	—	—	—	—	—
January 29, 1979	—	—	—	5.6	—
January 30, 1979	—	—	—	12.3	—
January 31, 1979	—	—	—	7.5	—
February 1, 1979	—	—	—	9.2	—
February 2, 1979	—	—	—	15.1	—
February 3, 1979	—	—	—	17.0	—

TABLE VII-4. Supplementary chemical data for Bayou Choctaw brines.

Constituent	Pond inflow, 1/26/79	Ponded brine, 1/26/79	Weak brine, 1/26/79	Weak brine, 2/1/79	Cavern Lake water 1/26/79	Well water, 1/30/79
Total solids,[a] mg/ℓ	312,051	312,810	273,649	253,463	215	756
Sodium,[a] mg/ℓ	122,227	122,606	106,315	96,407[b]	41	98
Potassium, mg/ℓ	—	—	—	1,382	—	—
Iron, mg/ℓ	0.26	0.32	0.66	0.4	1.3	0.27
Barium, mg/ℓ	ND[c]	ND	ND	ND	ND	ND
Calcium, mg/ℓ	296	232	928	960	18	69.6
Magnesium, mg/ℓ	13	11	72	690	6	26.9
Chloride, mg/ℓ	188,533	189,062	164,966	153,130	52	63.3
Bicarbonate, mg/ℓ	272	274	168	94	83	495.9
Carbonate, mg/ℓ	ND	ND	ND	ND	ND	ND
Sulfate, mg/ℓ	710	625	1,200	800	14	2.0
Total organic carbon, mg/ℓ	6	6	5	—	13.4	—
Specific gravity	1.204	1.208	1.181	1.168	1.001	1.003
pH	6.86	6.83	6.52	6.43	7.18	7.64
Resistivity,[a] ohm-m	—	—	0.045	0.043	>10	—

[a]Calculated.

[b]97,000 mg/ℓ by atomic absorption.

[c]None detected.

APPENDIX VIII

CHEMISTRY, TURBIDITY, AND SUPPLEMENTARY CHEMICAL DATA FOR BRYAN MOUND BRINES

TABLE VIII-1. Chemistry of Bryan Mound brines.

Date	pH	ρ, g/mℓ	Constituent, mg/ℓ					
			Fe filtrate	Fe total	$SO_4^{=}$	Ca^{++}	HCO_3^-	Cl^-
Sample location: Cavern 5								
February 25, 1979	6.80	1.198	1.35	1.70	3000	901	110	196,700
Sample location: Cavern 4[a]								
February 27, 1979	11.05	1.196	0.02	0.07	3500	921	--	189,600
Sample location: Ponded brine								
February 23, 1979	6.89	1.194	--	--	--	--	--	189,600
	6.80	1.194	0.26	1.0	2300	921	110	190,500
February 24, 1979	6.86	1.193	--	--	--	921	--	192,200
February 25, 1979	6.94	1.197	0.34	1.7	2375	921	110	192,200
	6.97	1.195	--	--	--	--	--	--
February 26, 1979	6.71	1.192	0.63	1.8	--	--	--	184,300
February 27, 1979	6.95	1.177	0.34	1.8	2150	840	116	175,400
	6.79	1.188	--	--	--	--	--	180,700
February 28, 1979	6.90	1.190	0.45	1.95	--	--	--	185,200
	6.87	1.190	0.30	1.8	--	--	--	189,600
Sample location: Injection site								
February 26, 1979	6.70	1.193						
February 27, 1979	6.93	1.180						
Sample location: River water								
February 24, 1979	8.08	1.0	0.28	0.43	80	58	153	240

[a]This sample also contains 32 mg/ℓ Na_2CO_3 and 100 mg/ℓ NaOH.

TABLE VIII-2. Daily average turbidity at Bryan Mound.

Date	Turbidity, NTU, of indicated sample			
	Cavern 5	Ponded Strong brine	Injection site	River water
February 23, 1979	--	9.5	--	--
February 24, 1979	--	9.0	--	32
February 25, 1979	2.3	11.9	--	--
February 26, 1979	--	15.3	12	--

TABLE VIII-3. Supplementary chemical data for Bryan Mound brines.

Constituent	Cavern 4, 2/27/79	Cavern 5, 2/25/79	Ponded brine, 2/26/79	Injection site, 2/26/79	River water 2/26/79	Connate water[a]
Total solids,[b] mg/ℓ	317,482	291,830	278,769	308,314	528	117,217
sodium,[b] mg/ℓ	123,648	113,498	108,371	119,452	110	40,492
Potassium, mg/ℓ	298	284	274	1,158	5	440
Iron, mg/ℓ	0.02	1	1	0.8	1	3
Barium, mg/ℓ	ND[c]	ND	ND	ND	ND	15
Strontium, mg/ℓ	40	—	—	40	—	203
Calcium, mg/ℓ	590	740	742	585	43	2,940
Magnesium, mg/ℓ	0.2	14	11	13	12	1,158
Chloride, mg/ℓ	189,855	175,429	167,503	184,951	146	71,422
Bicarbonate, mg/ℓ	ND	114	117	114	133	89
Carbonate, mg/ℓ	17	ND	ND	ND	8	ND
Sulfate, mg/ℓ	3,000	1,750	1,750	2,000	70	15
Hydroxide, mg/ℓ	34	—	—	—	—	—
Total organic carbon, mg/ℓ	16	6	6	39	16	35
Specific gravity	1.204	1.203	1.199	1.198	1.000	1.083
pH	10.7	6.54	7.22	6.92	8.02	6.80
Resistivity,[b] ohm-m	0.038	0.052	0.054	0.039	10	0.070

[a]Old bottled sample of undetermined quality from Injection Well 1 (supplied by Parsons-Gilbane).

[b]Calculated.

[c]None determined.

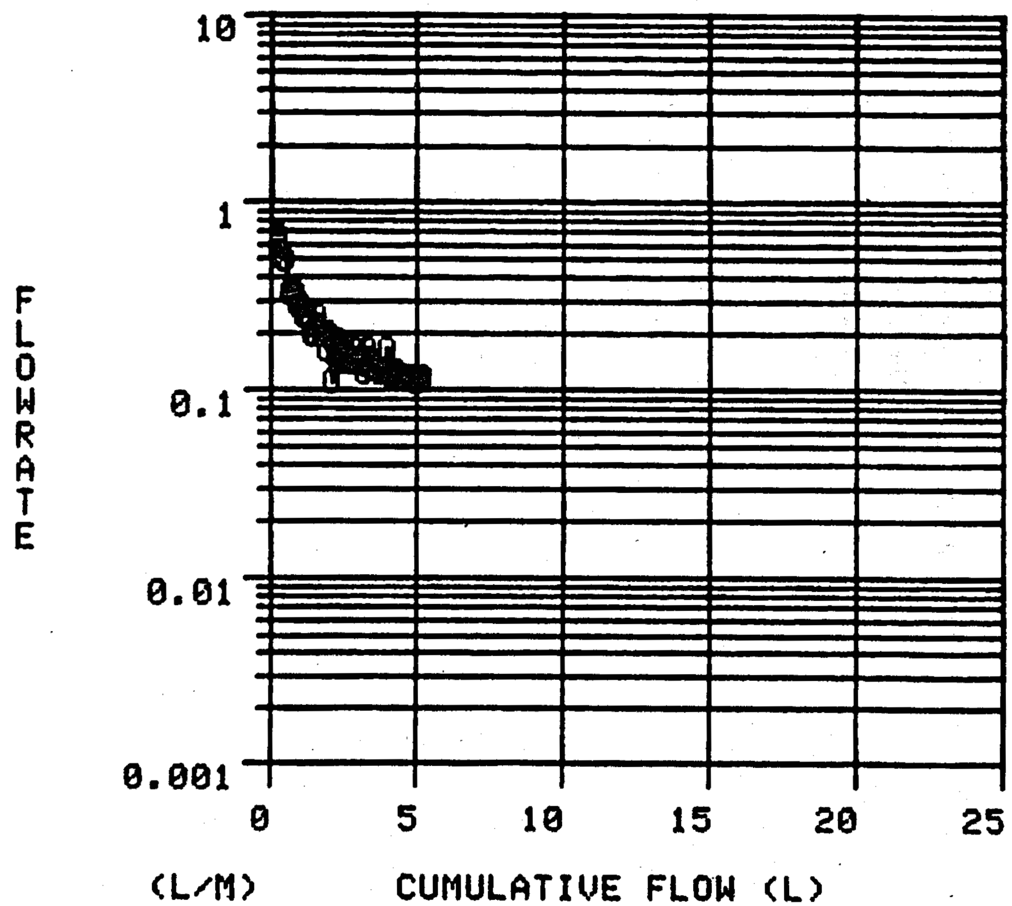
APPENDIX IX

INJECTIVITY DATA FROM MEMBRANE FILTER
TESTS PERFORMED AT
WEST HACKBERRY

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-10P
DATE: 8 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 1.85 VOL(L): 5.3

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
0.200	0.35	0.571
0.300	0.50	0.667
0.400	0.70	0.500
0.500	0.90	0.500
0.600	1.20	0.333
0.700	1.50	0.333
0.800	1.80	0.333
0.900	2.15	0.286
1.000	2.50	0.286
1.100	2.90	0.250
1.200	3.30	0.250
1.300	3.70	0.250
1.400	4.20	0.200
1.500	4.70	0.200
1.600	5.10	0.250
1.700	5.60	0.200
1.800	6.10	0.200
1.900	6.70	0.167
2.000	7.20	0.200
2.100	8.10	0.111
2.200	8.75	0.154
2.300	9.30	0.182
2.400	9.90	0.167
2.500	10.60	0.143



336

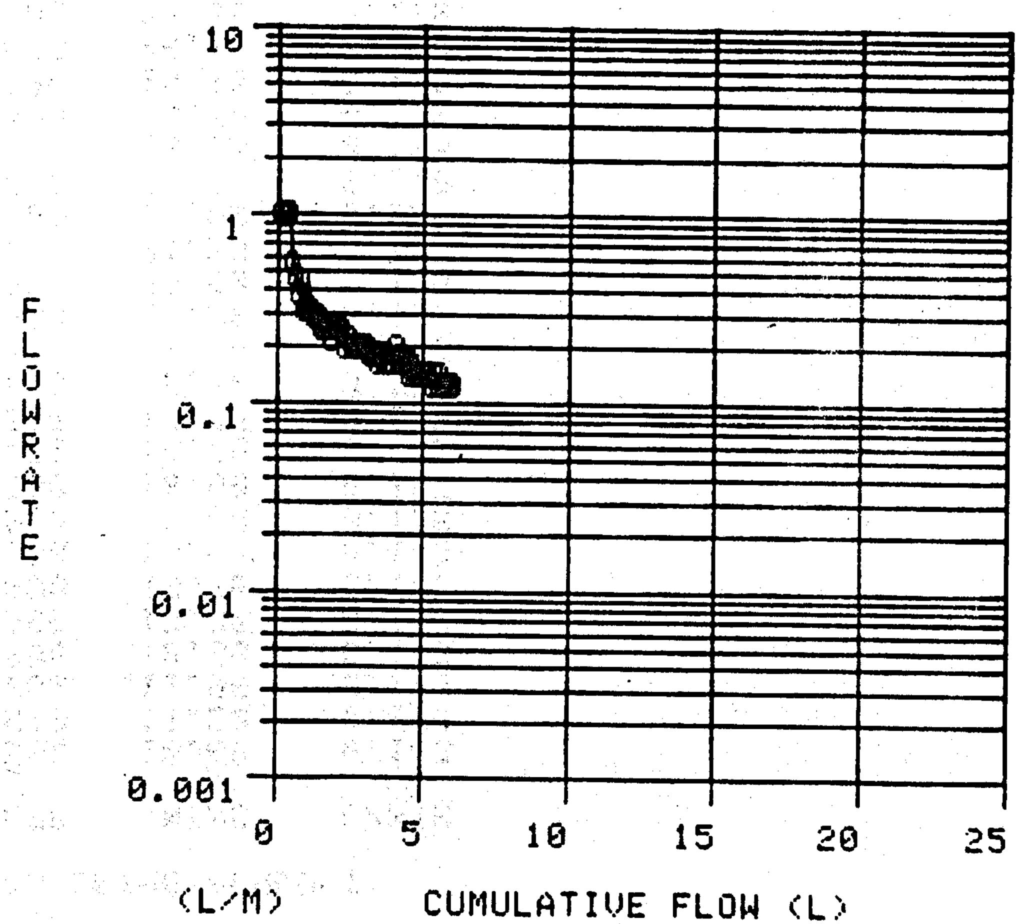
RAW BRINE PONDOUT

LITRES	MINS	L/MIN
2.500	10.60	0.143
2.600	11.20	0.167
2.700	11.90	0.143
2.800	12.60	0.143
2.900	13.30	0.143
3.000	13.90	0.167
3.100	14.60	0.143
3.200	15.40	0.125
3.300	16.00	0.167
3.400	16.75	0.133
3.500	17.45	0.143
3.600	18.20	0.133
3.700	19.00	0.125
3.800	19.80	0.125
3.900	20.60	0.125
4.000	21.20	0.167
4.100	22.00	0.125
4.200	22.85	0.118
4.300	23.65	0.125
4.400	24.50	0.118
4.500	25.35	0.118
4.600	26.20	0.118
4.700	27.05	0.118
4.800	27.90	0.118
4.900	28.80	0.111
5.000	29.70	0.111
5.100	30.55	0.118
5.200	31.40	0.118

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-16P
DATE: 10 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 1.12 VOL(L): 6

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
0.100	0.10	1.000
0.200	0.20	1.000
0.300	0.30	1.000
0.400	0.40	1.000
0.500	0.58	0.556
0.600	0.79	0.476
0.700	1.05	0.385
0.800	1.28	0.435
0.900	1.60	0.313
1.000	1.90	0.333
1.100	2.22	0.313
1.200	2.55	0.303
1.300	2.90	0.286
1.400	3.25	0.286
1.500	3.65	0.250
1.600	4.05	0.250
1.700	4.45	0.250
1.800	4.90	0.222
1.900	5.30	0.250
2.000	5.70	0.250
2.100	6.10	0.250
2.200	6.50	0.250
2.300	7.00	0.200
2.400	7.45	0.222



RAW BRINE PONDOUT

LITRES	MINS	L/MIN
2.400	7.45	0.222
2.500	7.90	0.222
2.600	8.40	0.200
2.700	8.90	0.200
2.800	9.40	0.200
2.900	9.90	0.200
3.000	10.40	0.200
3.100	10.90	0.200
3.200	11.45	0.182
3.300	12.00	0.182
3.400	12.55	0.182
3.500	13.15	0.167
3.600	13.70	0.182
3.700	14.30	0.167
3.800	14.90	0.167
3.900	15.50	0.167
4.000	16.10	0.167
4.100	16.60	0.200
4.200	17.20	0.167
4.300	17.80	0.167
4.400	18.40	0.167
4.500	19.10	0.143
4.600	19.70	0.167
4.700	20.40	0.143
4.800	21.10	0.143
4.900	21.80	0.143
5.000	22.50	0.143
5.100	23.20	0.143
5.200	23.90	0.143
5.300	24.70	0.125
5.400	25.40	0.143

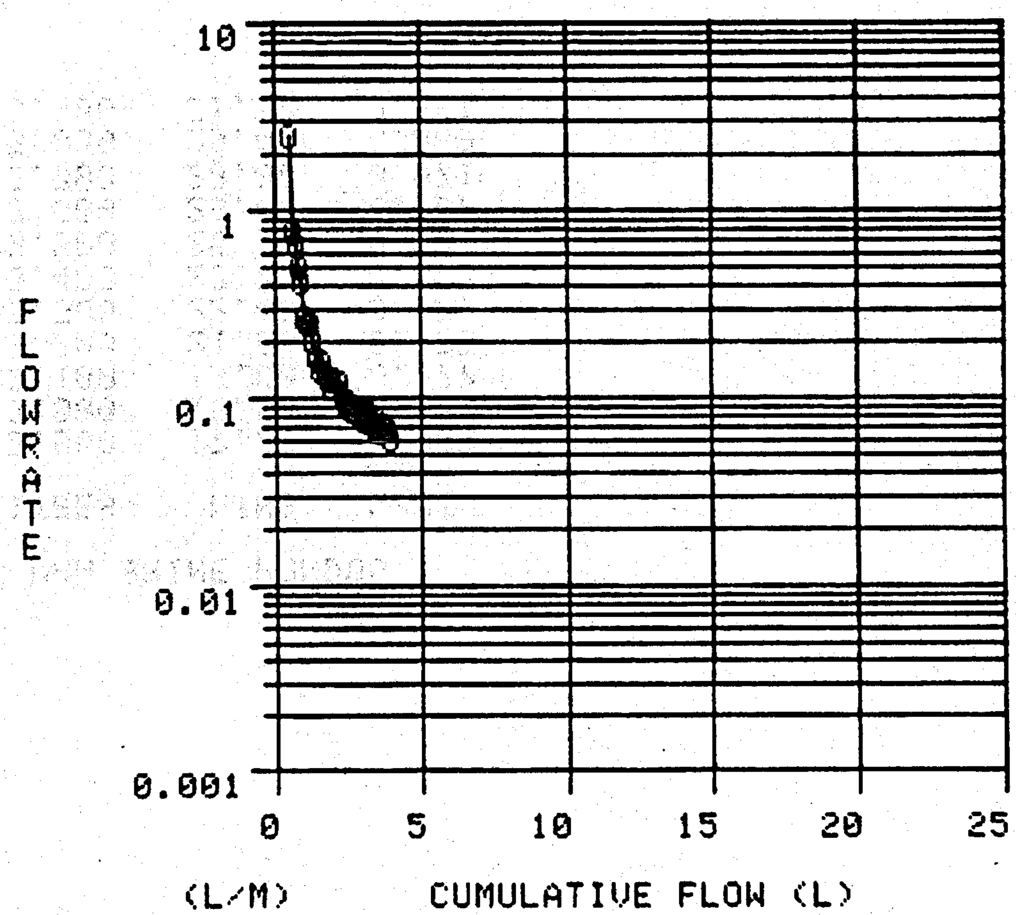
RAW BRINE PONDOUT

LITRES	MINS	L/MIN
5.400	25.40	0.143
5.500	26.20	0.125
5.600	26.90	0.143
5.700	27.70	0.125
5.800	28.50	0.125
5.900	29.30	0.125
6.000	30.10	0.125

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-19P
DATE: 11 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 1.69 VOL(L): 3.9

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
0.500	0.20	2.500
0.600	0.33	0.769
0.700	0.48	0.667
0.800	0.68	0.500
0.900	0.92	0.417
1.000	1.30	0.263
1.100	1.70	0.250
1.200	2.10	0.250
1.300	2.60	0.200
1.400	3.20	0.167
1.500	3.90	0.143
1.600	4.55	0.154
1.700	5.30	0.133
1.800	6.10	0.125
1.900	6.95	0.118
2.000	7.75	0.125
2.200	9.40	0.121
2.300	10.40	0.100
2.400	11.50	0.091
2.500	12.55	0.095
2.600	13.70	0.087
2.700	14.85	0.087
2.800	16.00	0.087
2.900	17.20	0.083



341

RAW BRINE PONDOUT

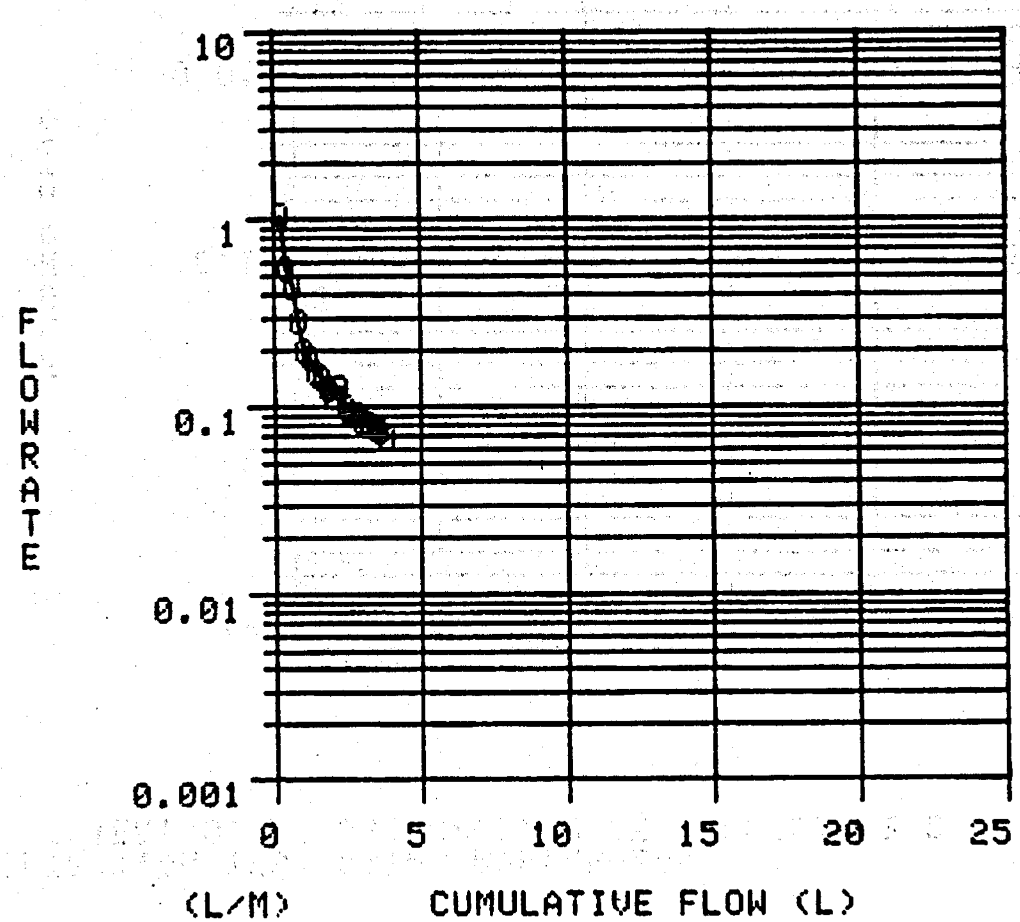
LITRES	MINS	L/MIN
2.900	17.20	0.083
3.000	18.50	0.077
3.100	19.80	0.077
3.200	21.00	0.083
3.300	22.40	0.071
3.400	23.70	0.077
3.500	25.10	0.071
3.600	26.60	0.067
3.700	28.00	0.071
3.800	29.45	0.069
3.900	31.10	0.061

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-20P
DATE: 11 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): .95 VOL(L): 3.8

343

RAW BRINE PONDOUT

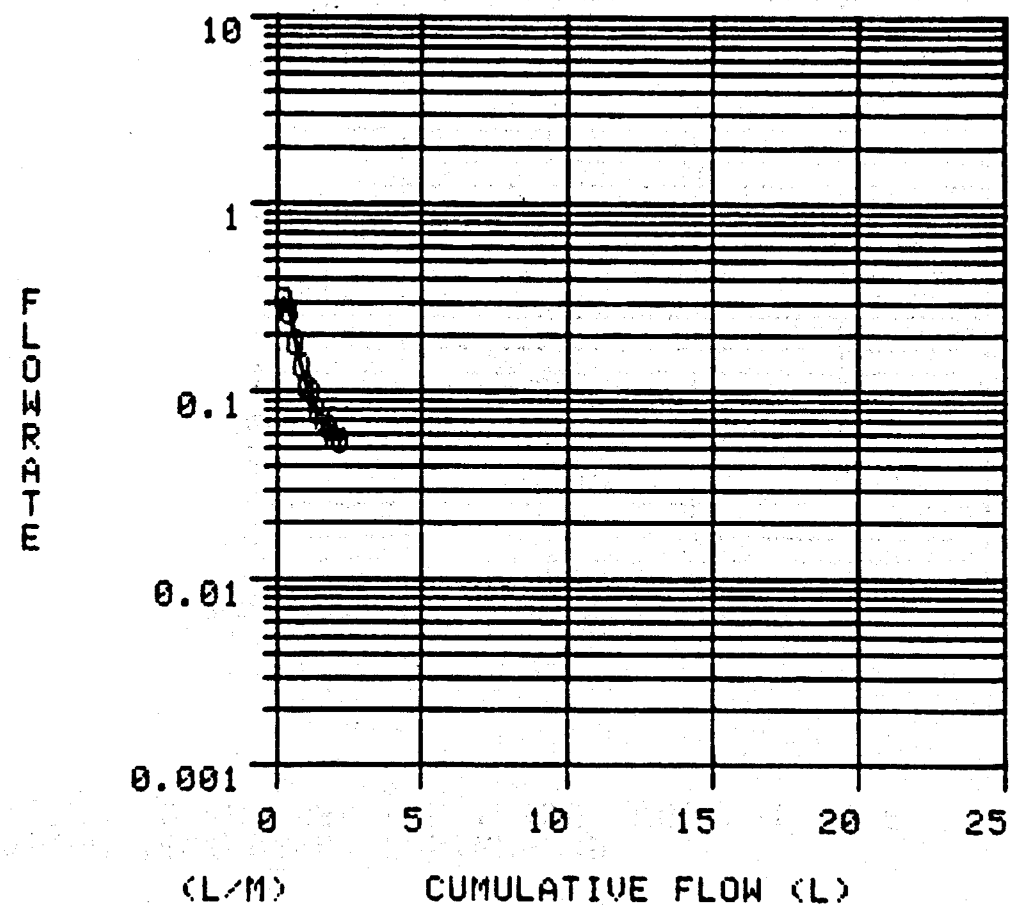
LITRES	MINS	L/MIN
0.200	0.19	1.053
0.400	0.55	0.556
0.600	1.00	0.444
0.800	1.70	0.286
1.000	2.70	0.200
1.200	3.80	0.182
1.400	5.10	0.154
1.600	6.50	0.143
1.800	8.10	0.125
2.000	9.83	0.116
2.200	11.40	0.127
2.400	13.40	0.100
2.600	15.60	0.091
2.800	17.80	0.091
3.000	20.20	0.083
3.200	22.63	0.082
3.400	25.20	0.078
3.600	27.90	0.074
3.800	30.80	0.069



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-24P
DATE: 14 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 8.65 VOL(L): 2.2

RAW BRINE PONDOUT

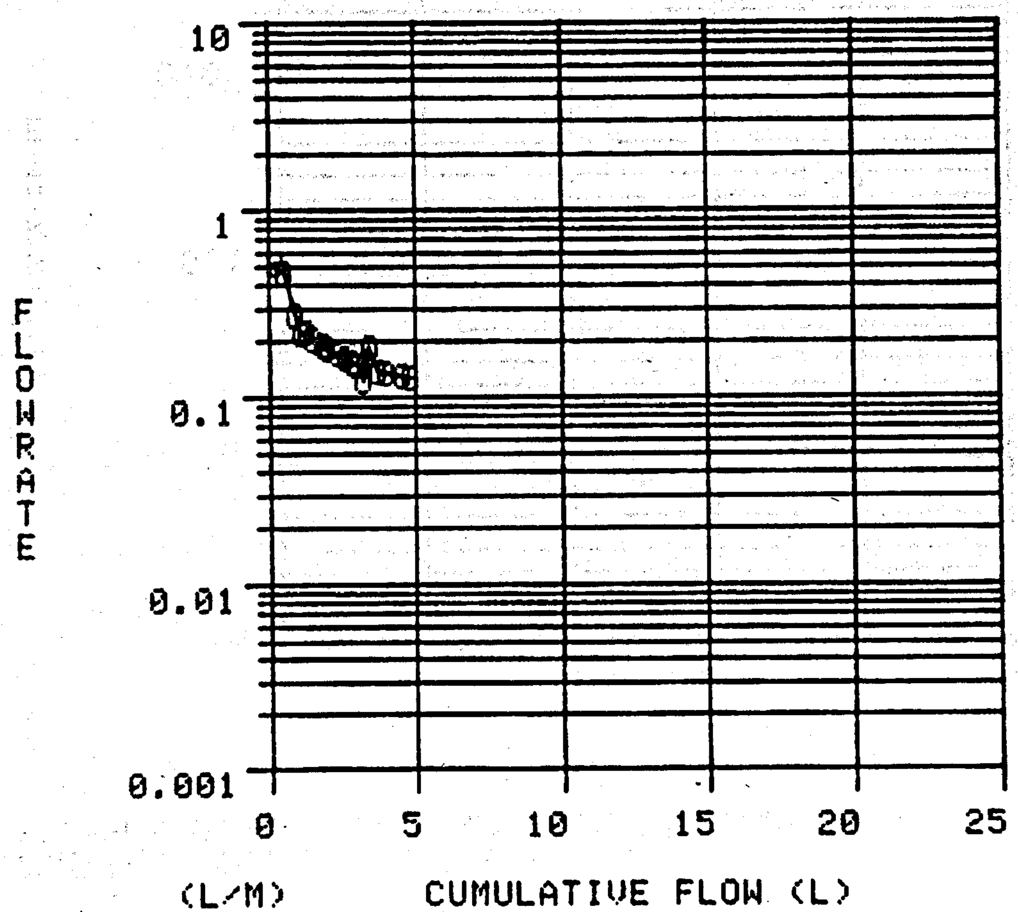
LITRES	MINS	L/MIN
0.200	0.65	0.308
0.400	1.40	0.267
0.600	2.50	0.182
0.800	3.95	0.138
1.000	5.85	0.105
1.200	7.90	0.098
1.400	10.45	0.078
1.600	13.30	0.070
1.800	16.38	0.065
2.000	19.85	0.058
2.200	23.45	0.056



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-1I
DATE: 9 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 1.68 VOL(L): 4.8

RAW BRINE: INJECTION PAD

LITRES	MINS	L/MIN
0.200	0.38	0.526
0.500	1.02	0.469
0.900	2.48	0.274
1.100	3.38	0.222
1.300	4.27	0.225
1.500	5.25	0.204
1.800	6.83	0.190
2.000	7.93	0.182
2.300	9.68	0.171
2.600	11.50	0.165
2.800	12.80	0.154
3.000	14.13	0.150
3.200	15.75	0.123
3.400	16.82	0.187
3.700	18.98	0.139
4.000	21.18	0.136
4.500	25.00	0.131
4.800	27.33	0.129

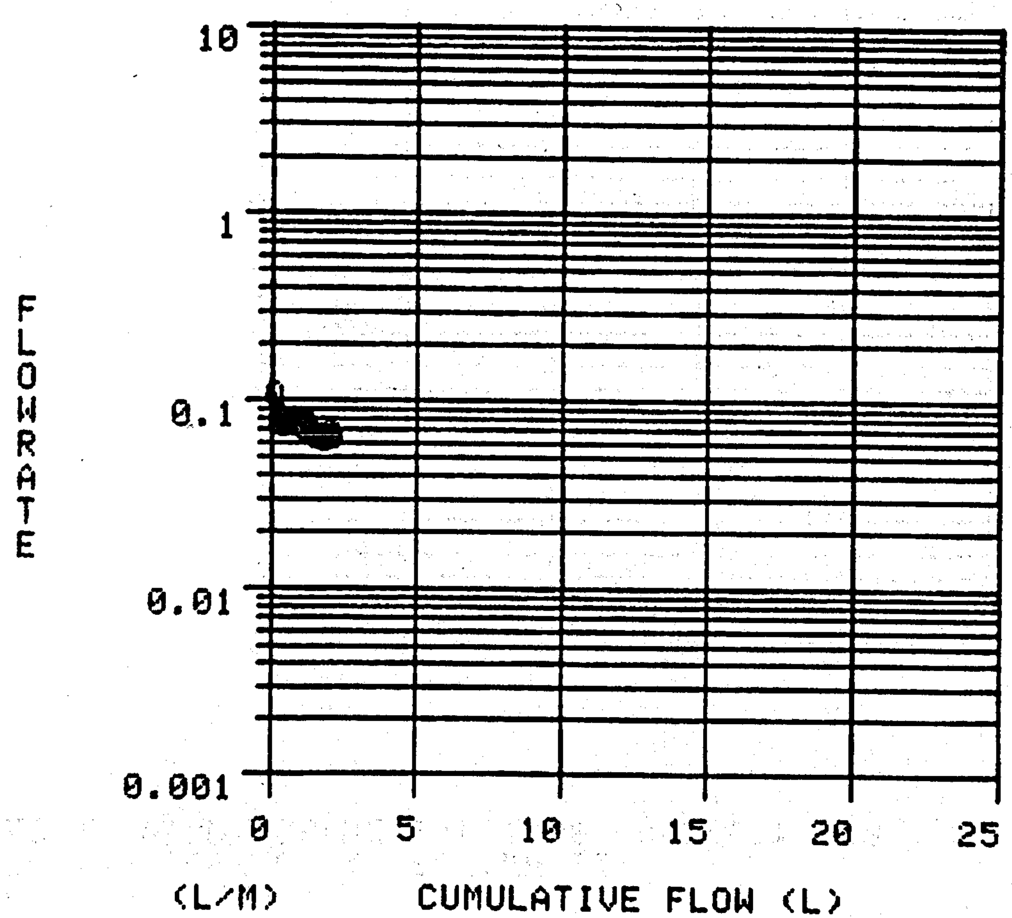


345

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-2I
DATE: 10 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): .23 VOL(L): 2.2

RAW BRINE: INJECTION PAD

LITRES	MINS	L/MIN
0.100	0.92	0.109
0.200	2.22	0.077
0.300	3.43	0.083
0.400	4.75	0.076
0.500	6.08	0.075
0.600	7.38	0.077
0.700	8.67	0.078
0.800	9.97	0.077
0.900	11.28	0.076
1.000	12.63	0.074
1.150	14.73	0.071
1.300	16.87	0.075
1.400	18.35	0.068
1.500	19.87	0.066
1.600	21.40	0.065
1.700	22.95	0.065
1.800	24.52	0.064
1.900	26.07	0.065
2.000	27.63	0.064
2.100	29.07	0.069
2.200	30.60	0.065

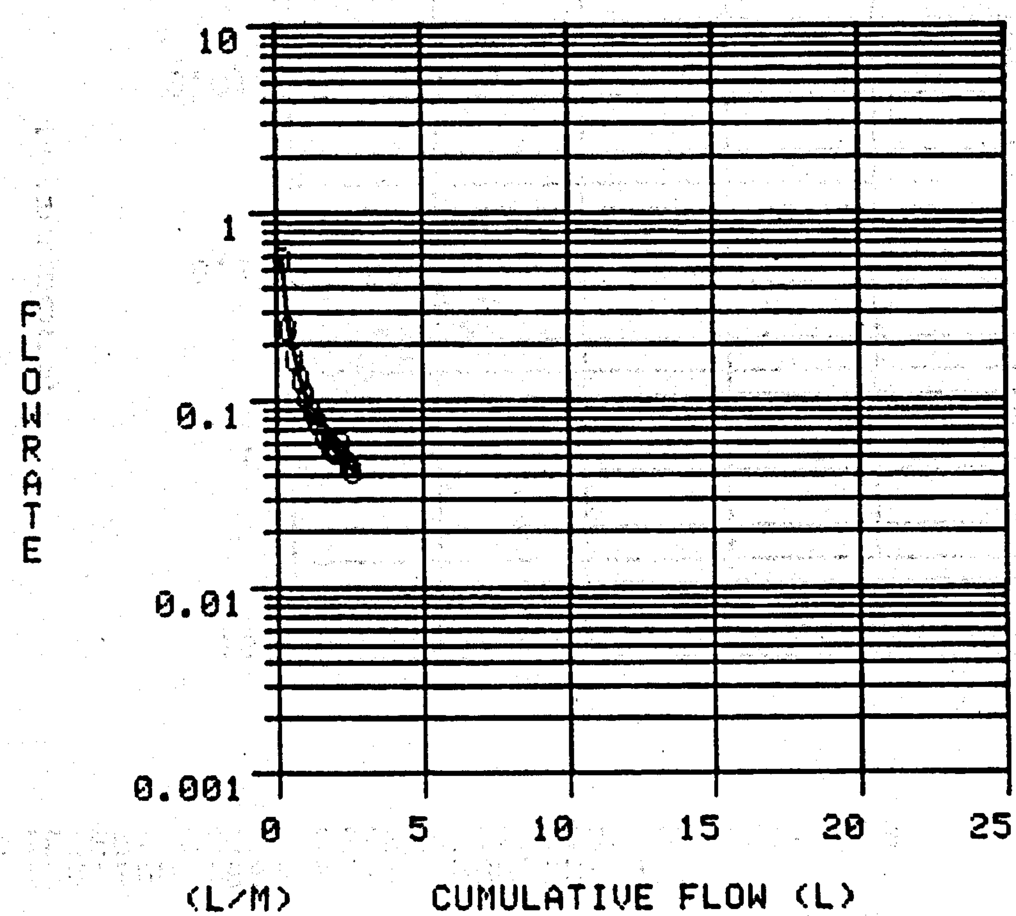


SPR MEMBRANE FILTRATION TEST DATA RUN:WH-22P

DATE: 13 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 8.04 VOL(L): 2.6

RAW BRINE: INJECTION PAD

LITRES	MINS	L/MIN
0.200	0.35	0.571
0.400	1.17	0.244
0.600	2.35	0.169
0.800	3.88	0.131
1.000	5.78	0.105
1.200	8.05	0.088
1.400	10.65	0.077
1.600	13.70	0.066
1.800	17.12	0.058
2.000	20.82	0.054
2.200	24.20	0.059
2.400	28.55	0.046
2.600	33.22	0.043

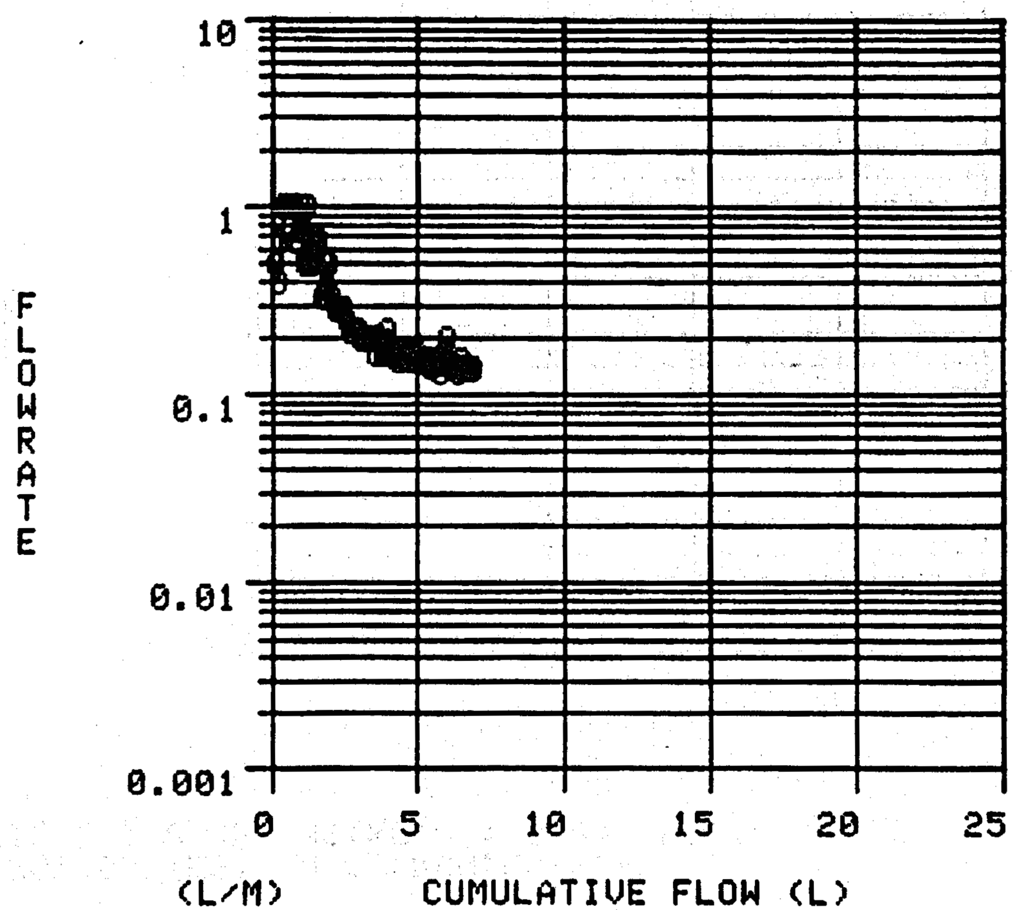


347

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-11P
DATE: 8 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): .13 VOL(L): 6.9

COL C: NO CHEMICAL FEED

LITRES	MINS	L/MIN
0.100	0.20	0.500
0.200	0.45	0.400
0.300	0.60	0.667
0.400	0.70	1.000
0.500	0.80	1.000
0.600	0.90	1.000
0.700	1.00	1.000
0.800	1.15	0.667
0.900	1.30	0.667
1.000	1.40	1.000
1.100	1.60	0.500
1.200	1.70	1.000
1.300	1.90	0.500
1.400	2.10	0.500
1.500	2.25	0.667
1.600	2.40	0.667
1.700	2.70	0.333
1.800	2.90	0.500
1.900	3.20	0.333
2.000	3.40	0.500
2.100	3.70	0.333
2.200	4.05	0.286
2.300	4.40	0.286
2.400	4.75	0.286



COL C: NO CHEMICAL FEED

LITRES	MINS	L/MIN
2.400	4.75	0.286
2.500	5.10	0.286
2.600	5.50	0.250
2.700	5.95	0.222
2.800	6.40	0.222
2.900	6.85	0.222
3.000	7.30	0.222
3.100	7.80	0.200
3.200	8.30	0.200
3.300	8.80	0.200
3.400	9.30	0.200
3.500	9.80	0.200
3.600	10.40	0.167
3.700	10.90	0.200
3.800	11.50	0.167
3.900	12.10	0.167
4.000	12.55	0.222
4.100	13.10	0.182
4.200	13.70	0.167
4.300	14.35	0.154
4.400	14.95	0.167
4.500	15.60	0.154
4.600	16.20	0.167
4.700	16.80	0.167
4.800	17.45	0.154
4.900	18.10	0.154
5.000	18.70	0.167
5.100	19.35	0.154
5.200	20.00	0.154
5.300	20.65	0.154
5.400	21.35	0.143

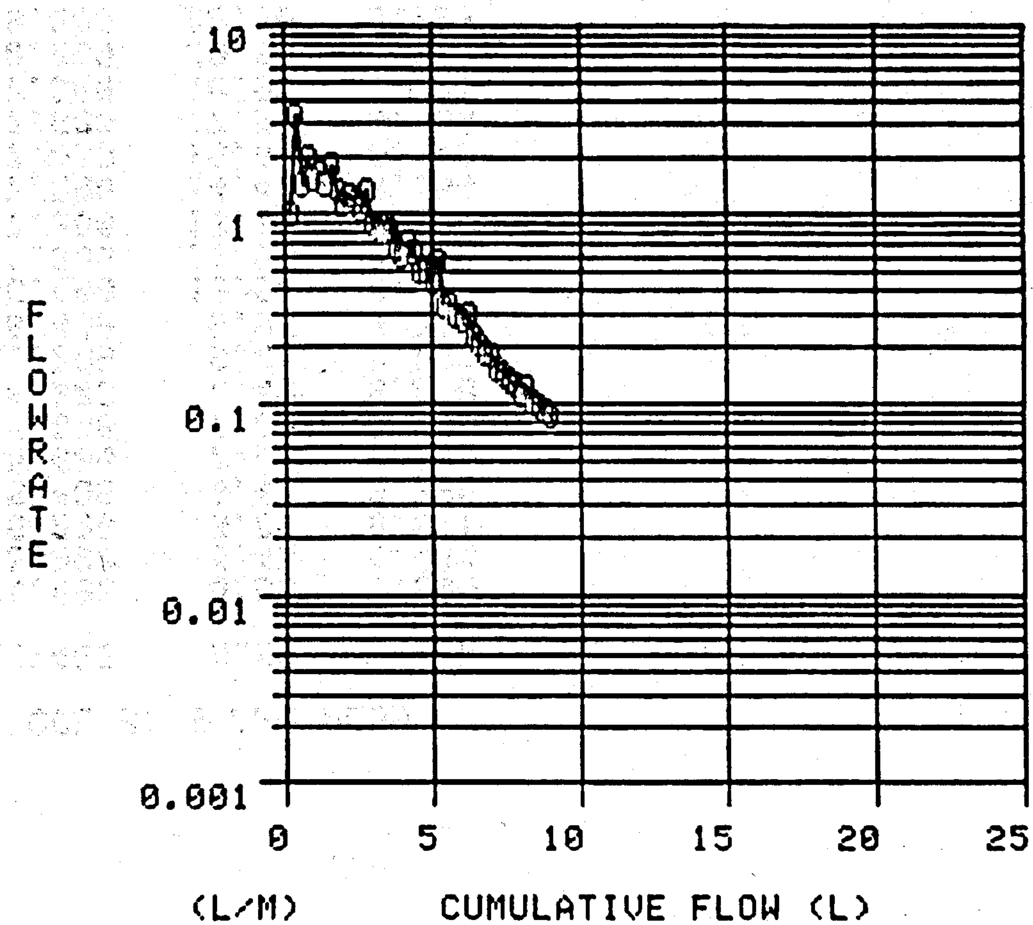
COL C: NO CHEMICAL FEED

LITRES	MINS	L/MIN
5.400	21.35	0.143
5.500	22.00	0.154
5.600	22.67	0.149
5.700	23.35	0.147
5.800	24.10	0.133
5.900	24.70	0.167
6.000	25.20	0.200
6.100	25.90	0.143
6.200	26.60	0.143
6.300	27.30	0.143
6.400	28.05	0.133
6.500	28.70	0.154
6.600	29.42	0.139
6.700	30.13	0.141
6.800	30.85	0.139
6.900	31.57	0.139

SPP MEMBRANE FILTRATION TEST DATA RUN:WH-21P
DATE: 11 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L):.022 VOL(L): 9.0

COL B: 3 PPM ALUM

LITRES	MINS	L/MIN
0.200	0.20	1.000
0.400	0.26	3.333
0.600	0.40	1.429
0.800	0.50	2.000
1.000	0.63	1.538
1.200	0.75	1.667
1.400	0.89	1.429
1.600	1.00	1.818
1.800	1.15	1.333
2.000	1.33	1.111
2.200	1.49	1.250
2.400	1.66	1.176
2.600	1.85	1.053
2.800	2.00	1.333
3.000	2.23	0.870
3.200	2.47	0.833
3.400	2.72	0.800
3.600	2.96	0.833
3.800	3.27	0.645
4.000	3.60	0.606
4.200	3.88	0.714
4.400	4.20	0.625
4.600	4.60	0.500
4.800	5.00	0.500



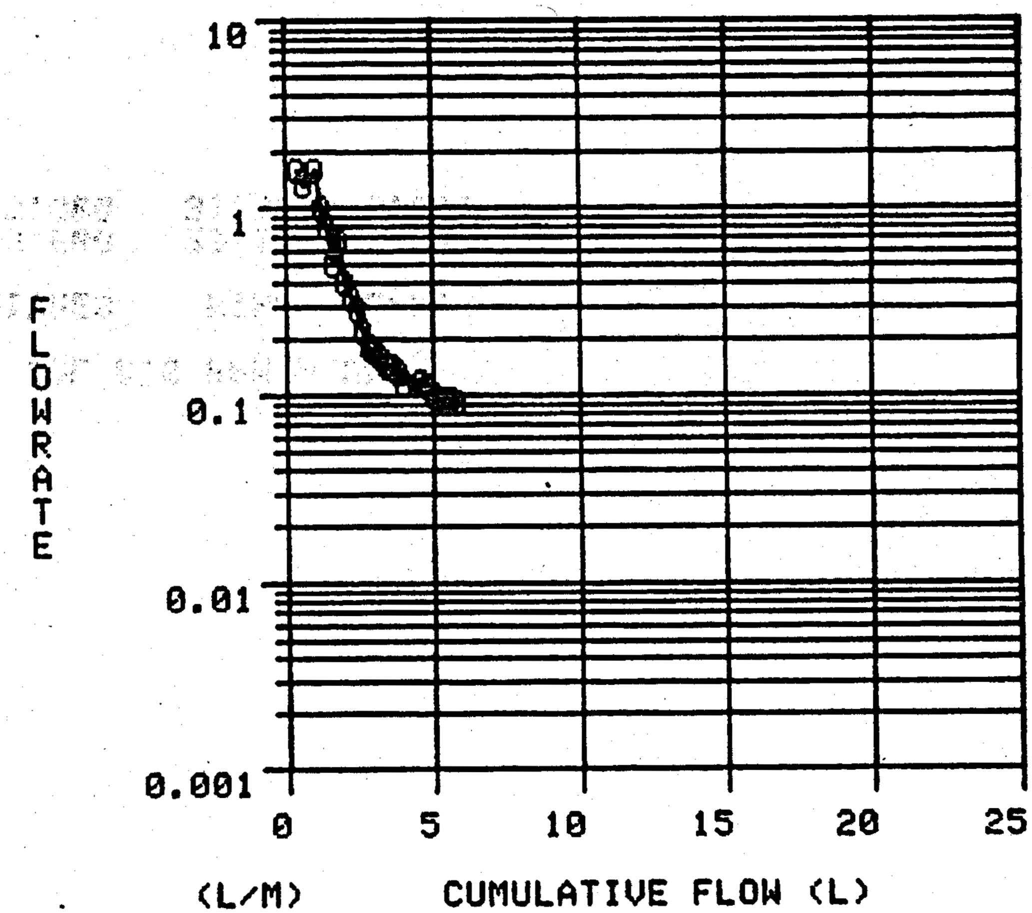
COL B: 3 PPM ALUM

LITRES	MINS	L/MIN
4.000	5.00	0.500
5.000	5.45	0.444
5.200	5.80	0.571
5.400	6.41	0.328
5.600	7.00	0.339
5.800	7.68	0.294
6.000	8.40	0.278
6.200	9.07	0.299
6.400	9.95	0.227
6.600	10.90	0.211
6.800	11.98	0.185
7.000	13.10	0.179
7.200	14.40	0.154
7.400	15.80	0.143
7.600	17.30	0.133
7.800	18.90	0.125
8.000	20.68	0.112
8.200	22.30	0.123
8.400	24.25	0.103
8.600	26.32	0.097
8.800	28.50	0.092
9.000	30.82	0.086

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-25P
DATE: 14 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): .29 VOL(L): 5.8

COL D:6 PPM ALUM

LITRES	MINS	L/MIN
0.400	0.25	1.600
0.600	0.40	1.333
1.000	0.65	1.600
1.200	0.85	1.000
1.400	1.10	0.800
1.600	1.50	0.500
1.800	1.80	0.667
2.000	2.30	0.400
2.200	2.90	0.333
2.400	3.60	0.286
2.600	4.50	0.222
2.800	5.60	0.182
3.000	6.75	0.174
3.200	8.00	0.160
3.400	9.40	0.143
3.600	10.80	0.143
3.800	12.30	0.133
4.000	14.00	0.118
4.600	19.00	0.120
4.800	20.80	0.111
5.000	22.80	0.100
5.200	24.90	0.095
5.400	27.00	0.095
5.600	29.10	0.095



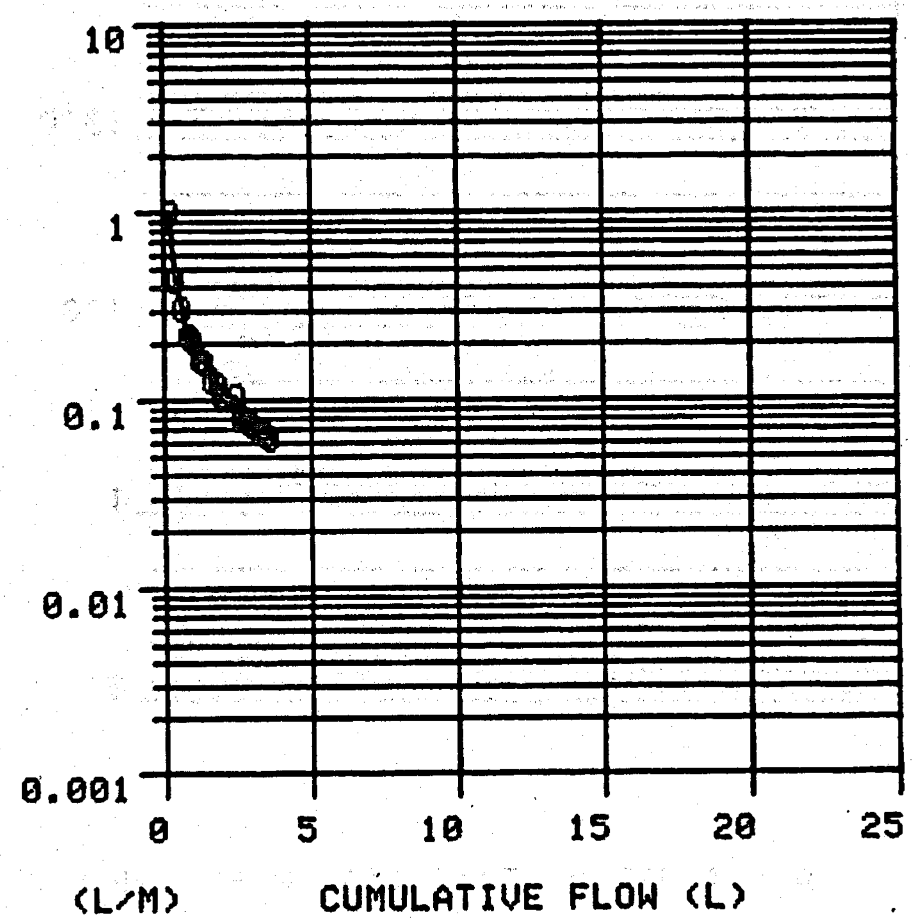
COL D:6 PPM ALUM

LITRES	MINS	L/MIN
5.600	29.10	0.095
5.800	31.30	0.091

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-26P
DATE: 14 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 2.56 VOL(L):3.6

COL C: NO CHEMICAL FEED

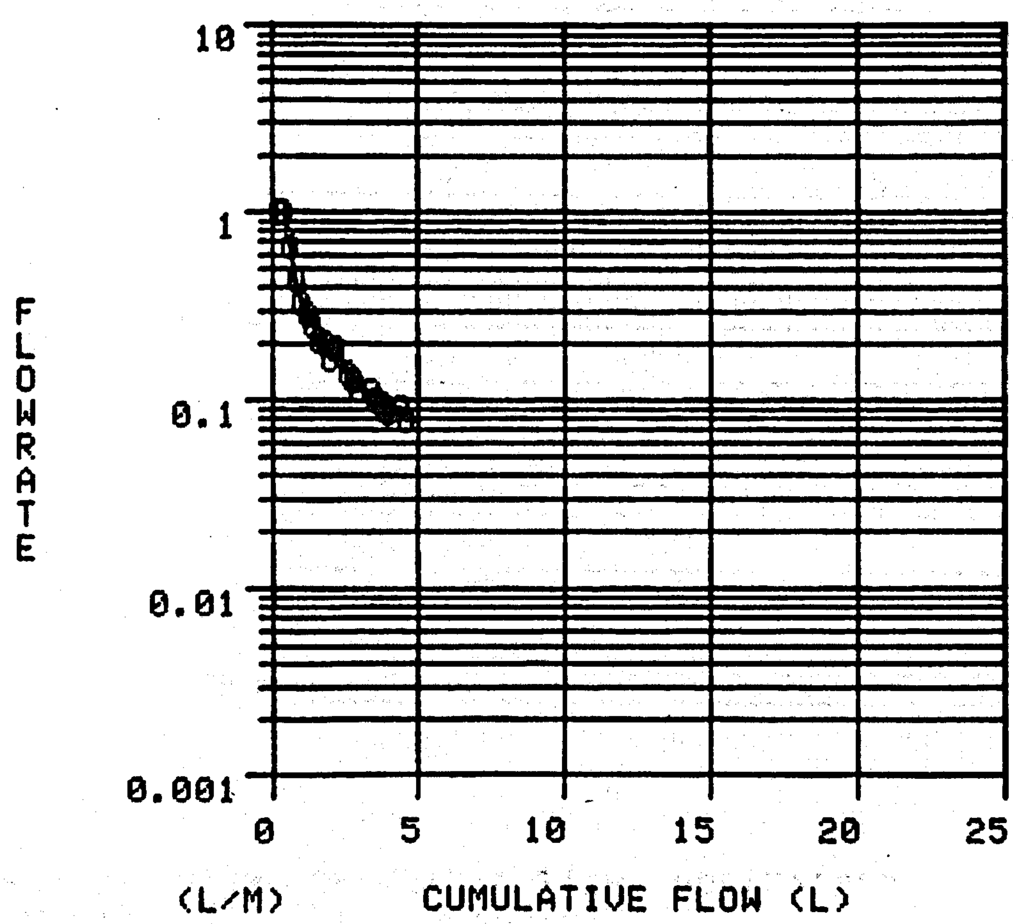
LITRES	MINS	L/MIN
0.200	0.20	1.000
0.400	0.65	0.444
0.600	1.30	0.308
0.800	2.20	0.222
1.000	3.15	0.211
1.200	4.35	0.167
1.400	5.60	0.160
1.600	7.15	0.129
1.800	8.80	0.121
2.000	10.70	0.105
2.400	14.50	0.105
2.600	16.90	0.083
2.800	19.45	0.078
3.000	22.15	0.074
3.200	25.00	0.070
3.400	28.00	0.067
3.600	31.15	0.063



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-27P
DATE: 14 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 1.72 VOL(L): 4.6

COL A: NO CHEMICAL FEED

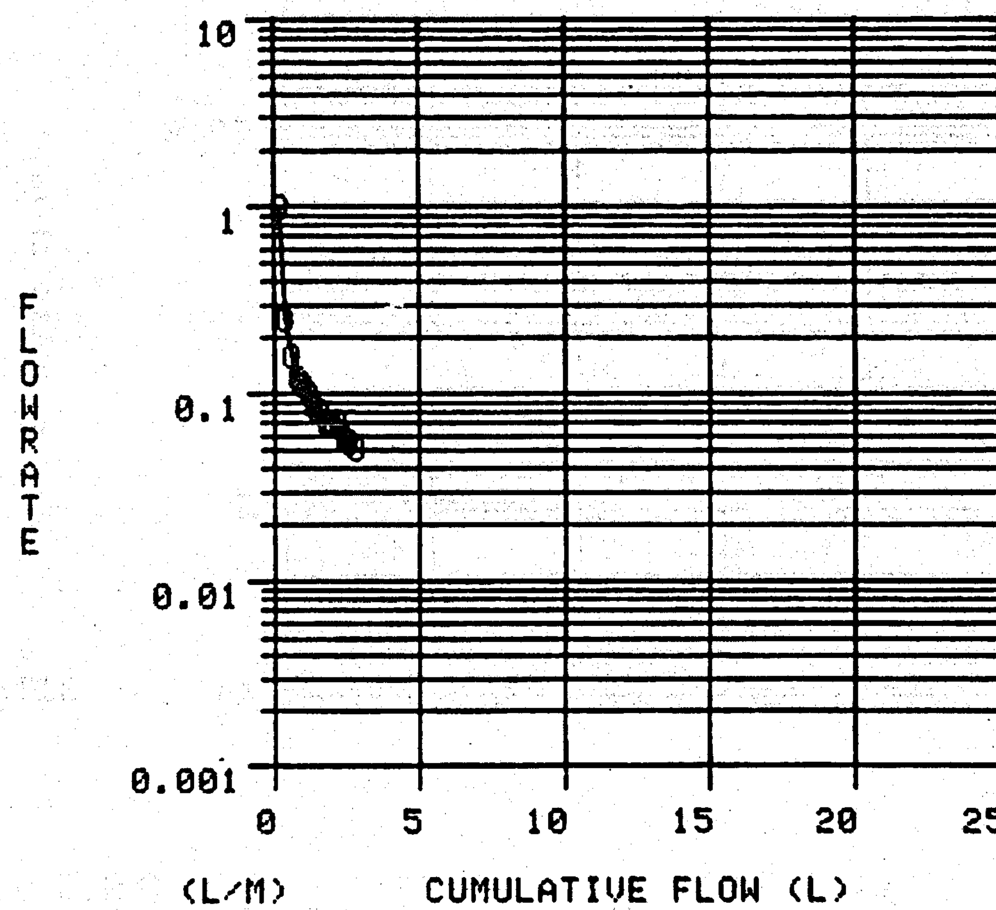
LITRES	MINS	L/MIN
0.200	0.20	1.000
0.400	0.40	1.000
0.600	0.70	0.667
0.800	1.15	0.444
1.000	1.75	0.333
1.200	2.45	0.286
1.400	3.25	0.250
1.600	4.20	0.211
1.800	5.20	0.200
2.000	6.40	0.167
2.200	7.45	0.190
2.600	10.30	0.140
2.800	11.85	0.129
3.000	13.60	0.114
3.400	17.20	0.111
3.600	19.20	0.100
3.800	21.30	0.095
4.000	23.60	0.087
4.400	28.00	0.091
4.600	30.55	0.078



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-31P
DATE: 15 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 1.95 VOL(L): 2.8

COL D: 4 PPM FeCl

LITRES	MINS	L/MIN
0.200	0.20	1.000
0.400	1.00	0.250
0.600	2.25	0.160
0.800	3.90	0.121
1.000	5.70	0.111
1.200	7.70	0.100
1.400	10.00	0.087
1.600	12.50	0.080
1.800	15.35	0.070
2.000	18.20	0.070
2.200	21.00	0.071
2.400	24.45	0.058
2.600	28.10	0.055
2.800	32.00	0.051

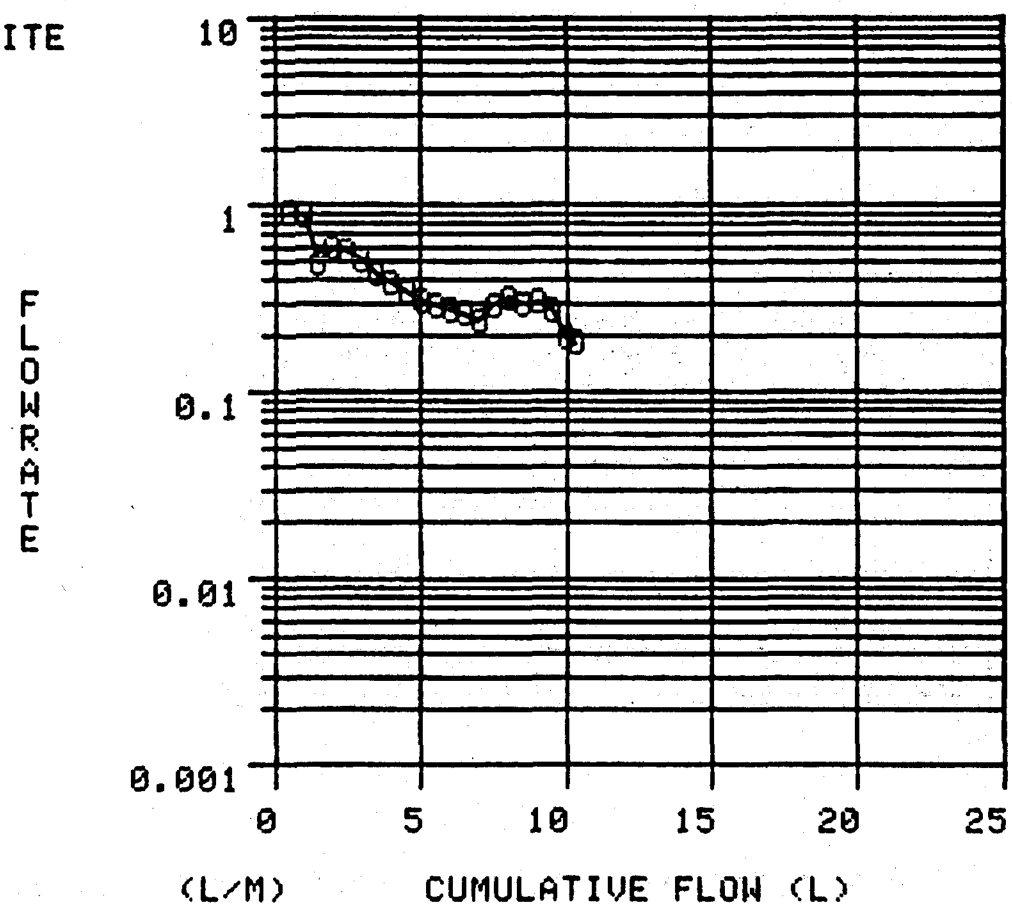


SPR MEMBRANE FILTRATION TEST DATA RUN:WH-3I
DATE: 10 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): .09 VOL(L): 10.3

358

1UM PREFILTERED INJECTION SITE

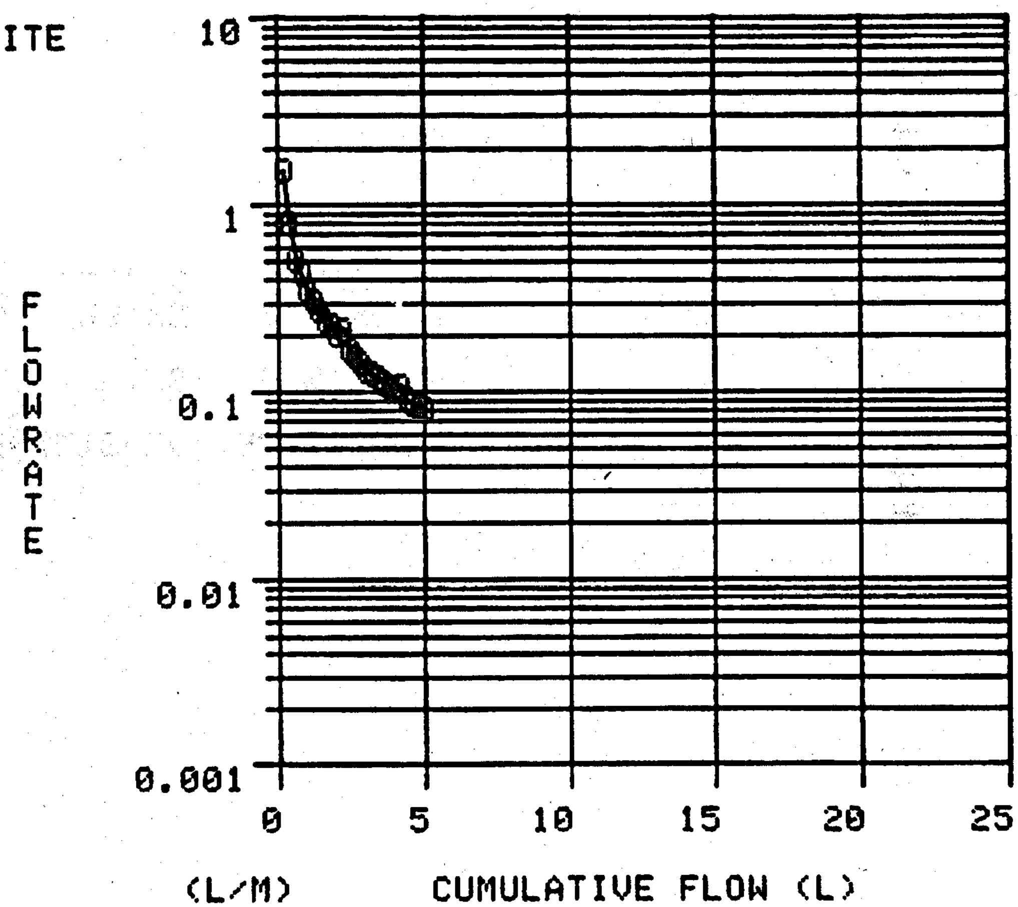
LITRES	MINS	L/MIN
0.500	0.55	0.909
1.000	1.12	0.877
1.500	2.13	0.495
2.000	2.98	0.588
2.500	3.85	0.575
3.000	4.83	0.510
3.500	5.98	0.435
4.000	7.27	0.388
4.500	8.72	0.345
5.000	10.33	0.311
5.500	12.05	0.291
6.000	13.85	0.278
6.500	15.75	0.263
7.000	17.82	0.242
7.500	19.52	0.294
8.000	21.08	0.321
8.500	22.75	0.299
9.000	24.38	0.307
9.500	26.18	0.278
10.000	28.75	0.195
10.300	30.37	0.185



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-7I
DATE: 13 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 1.22 VOL(L): 5.0

1UM PREFILTERED INJECTION SITE

LITRES	MINS	L/MIN
0.200	0.13	1.538
0.400	0.38	0.800
0.600	0.77	0.513
0.800	1.23	0.435
1.000	1.80	0.351
1.200	2.45	0.308
1.400	3.17	0.278
1.600	4.00	0.241
1.800	4.88	0.227
2.000	5.85	0.206
2.200	6.78	0.215
2.400	7.95	0.171
2.600	9.23	0.156
2.800	10.63	0.143
3.000	12.15	0.132
3.200	13.75	0.125
3.400	15.42	0.120
3.600	17.18	0.114
3.800	19.07	0.106
4.000	21.03	0.102
4.200	22.90	0.107
4.400	25.08	0.092
4.600	27.37	0.087
4.800	29.75	0.084



359

1UM PREFILTERED INJECTION SITE

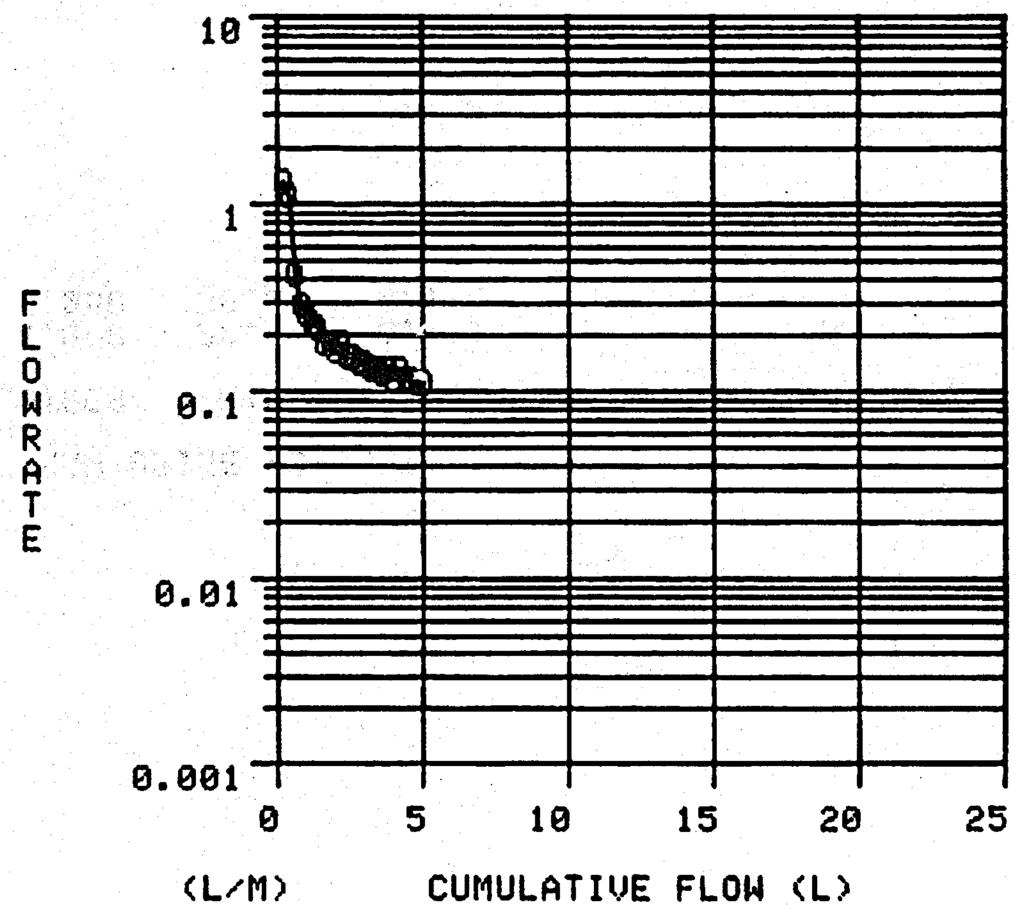
LITRES	MINS	L/MIN
4.800	29.75	0.084
5.000	32.18	0.082

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-12P

DATE: 8 JAN 79 PSIG: 40 FILTER: 1.0N SS(MG/L): 2.12 VOL(L): 5.0

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
0.200	0.15	1.333
0.400	0.33	1.111
0.600	0.80	0.426
0.800	1.48	0.294
1.000	2.25	0.260
1.200	3.10	0.235
1.400	4.00	0.222
1.600	5.10	0.182
1.800	6.20	0.182
2.000	7.40	0.167
2.200	8.50	0.182
2.400	9.80	0.154
2.600	11.10	0.154
2.800	12.50	0.143
3.000	13.90	0.143
3.200	15.40	0.133
3.400	16.90	0.133
3.600	18.50	0.125
3.800	20.00	0.133
4.000	21.70	0.118
4.200	23.20	0.133
4.400	24.90	0.118
4.600	26.60	0.118
4.800	28.40	0.111



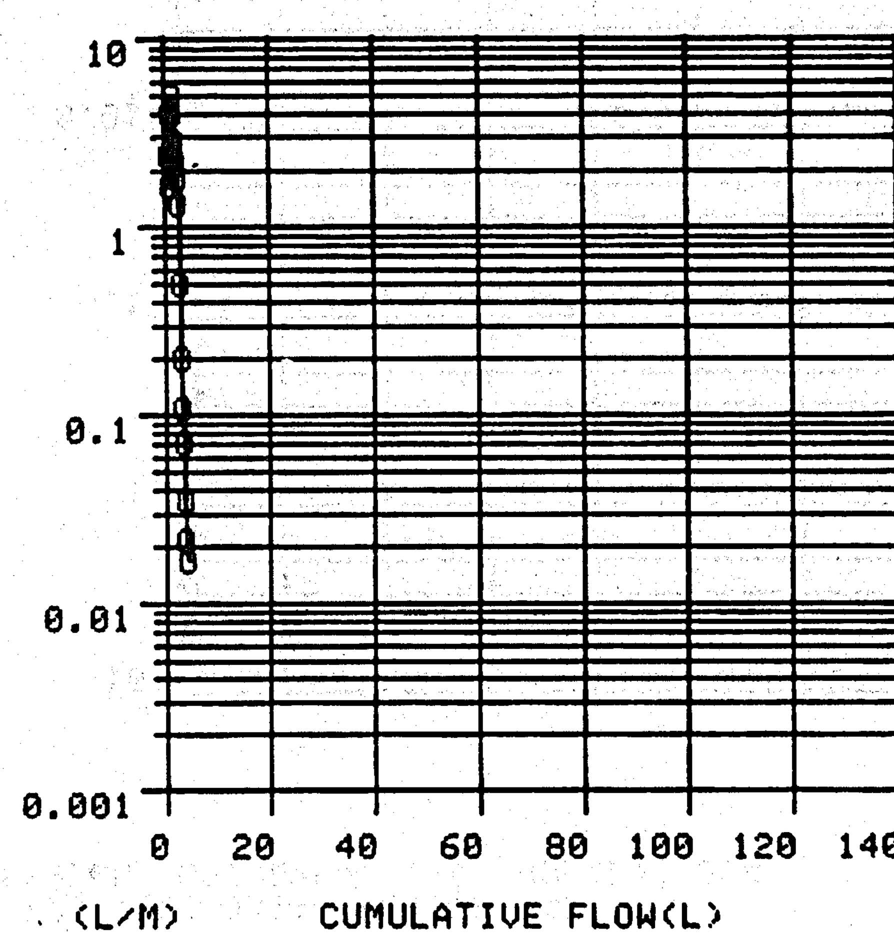
RAW BRINE PONDOUT

LITRES	MINS	L/MIN
4.800	28.40	0.111
5.000	30.20	0.111

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-13P
DATE: 9 JAN 79 PSIG: 7 FILTER:10.0N SS(MG/L): .55 VOL(L): 4.0

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
0.600	0.25	2.400
0.800	0.30	4.000
1.000	0.42	1.667
1.400	0.50	5.000
1.600	0.55	4.000
1.800	0.62	2.857
2.000	0.70	2.500
2.200	0.79	2.222
2.400	0.90	1.818
2.600	1.05	1.333
2.800	1.45	0.500
3.000	2.45	0.200
3.200	4.30	0.108
3.400	7.10	0.071
3.600	12.80	0.035
3.800	22.00	0.022
4.000	33.75	0.017

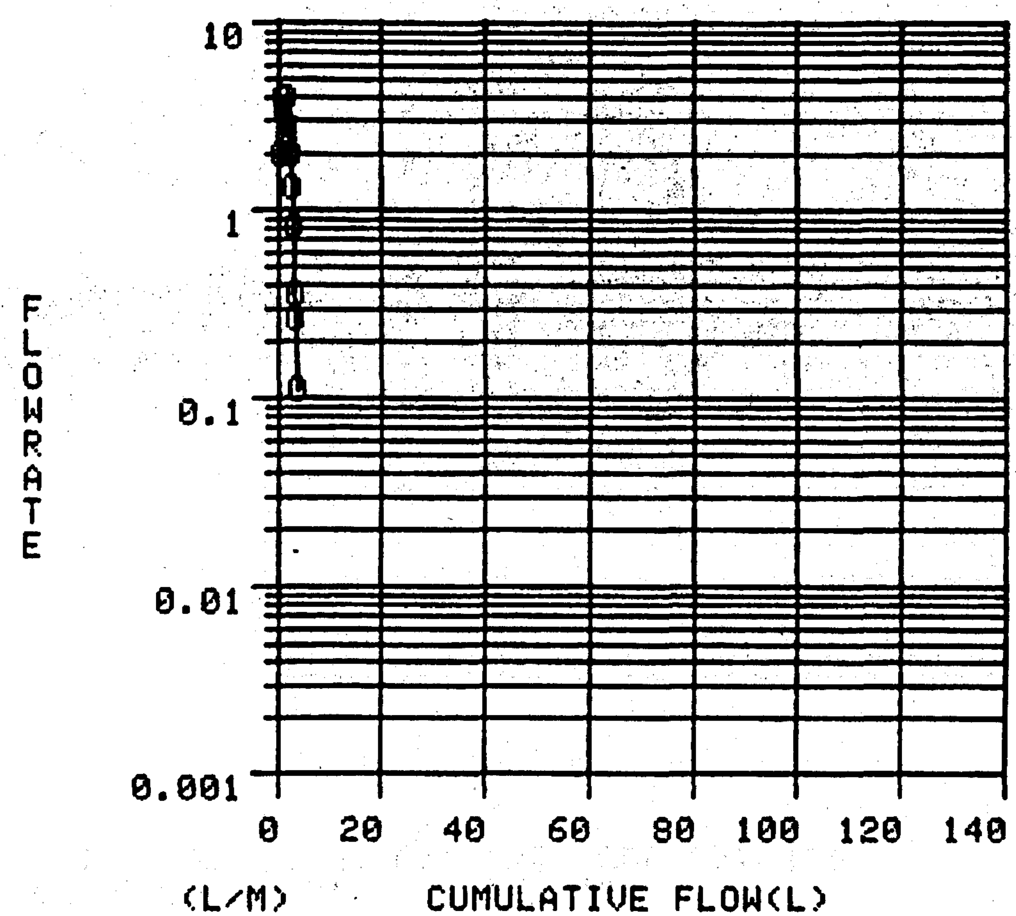


363

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-14P
DATE: 9 JAN 79 PSIG: 5 FILTER:10.0N SS(MG/L): .18 VOL(L): 3.4

RAW BRINE PONDOUT

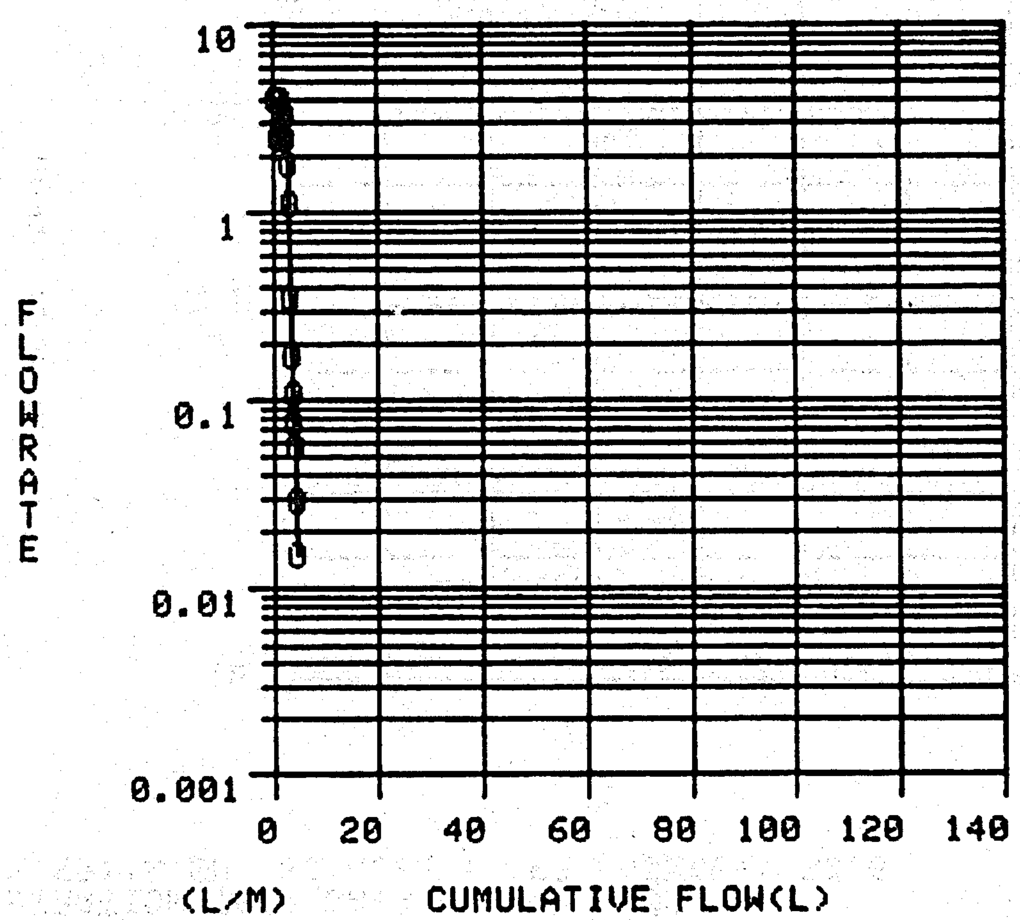
LITRES	MINS	L/MIN
0.200	0.10	2.000
0.400	0.20	2.000
0.600	0.25	4.000
0.800	0.31	3.333
1.000	0.37	3.333
1.200	0.45	2.500
1.400	0.50	4.000
1.600	0.55	4.000
1.800	0.63	2.500
2.000	0.70	2.857
2.200	0.80	2.000
2.400	0.90	2.000
2.600	1.05	1.333
2.800	1.29	0.833
3.000	1.85	0.357
3.200	2.60	0.267
3.400	4.40	0.111



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-23P
DATE: 12 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L): .48 VOL(L): 4.4

RAW BRINE PONDOUT

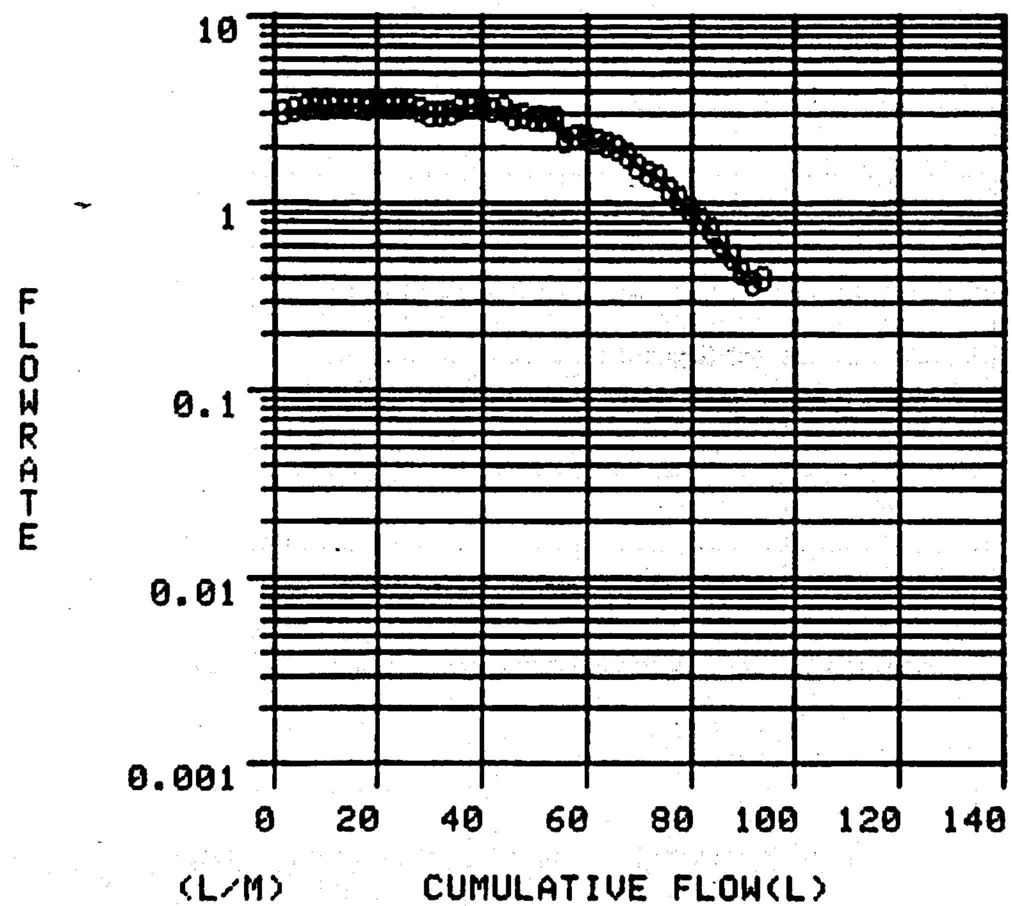
LITRES	MINS	L/MIN
0.200	0.05	4.000
0.400	0.10	4.000
0.600	0.15	4.000
0.800	0.20	4.000
1.000	0.28	2.500
1.200	0.35	2.857
1.400	0.40	4.000
1.600	0.45	4.000
1.800	0.51	3.333
2.000	0.59	2.500
2.200	0.65	3.333
2.400	0.71	3.333
2.600	0.79	2.500
2.800	0.90	1.818
3.000	1.08	1.111
3.200	1.65	0.351
3.400	2.80	0.174
3.600	4.65	0.108
3.800	7.30	0.075
4.000	10.80	0.057
4.200	17.70	0.029
4.400	30.90	0.015



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-15P
DATE: 9 JAN 79 PSIG: 7 FILTER:10.0N SS(MG/L): .02 VOL(L): 93.6

COL C: NO CHEMICAL FEED

LITRES	MINS	L/MIN
2.000	0.65	3.077
4.000	1.28	3.175
6.000	1.89	3.279
8.000	2.49	3.333
10.000	3.10	3.279
12.000	3.70	3.333
14.000	4.30	3.333
16.000	4.90	3.333
18.000	5.51	3.279
20.000	6.10	3.390
22.000	6.70	3.333
24.000	7.30	3.333
26.000	7.90	3.333
28.000	8.52	3.226
30.000	9.18	3.030
32.000	9.84	3.030
34.000	10.49	3.077
36.000	11.10	3.279
38.000	11.70	3.333
40.000	12.30	3.333
42.000	12.93	3.175
44.000	13.54	3.279
46.000	14.23	2.899
48.000	14.90	2.985



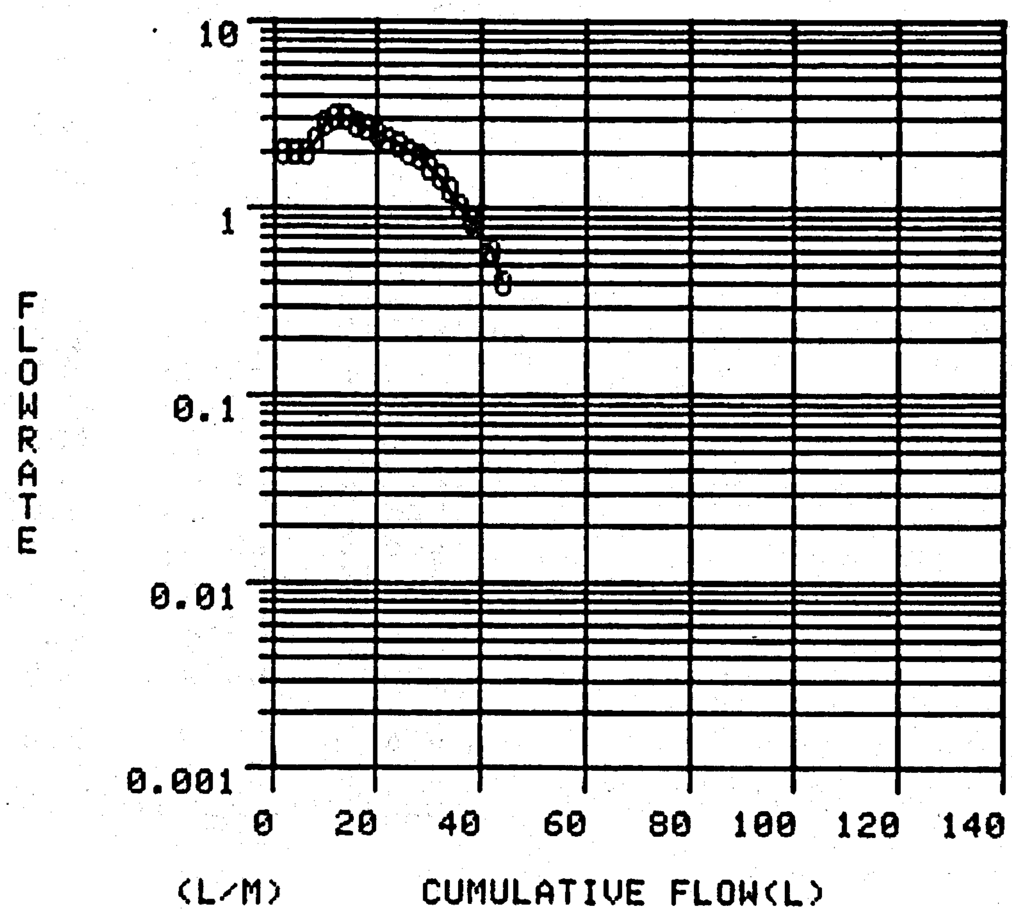
COL C: NO CHEMICAL FEED

LITRES	MINS	L/MIN
48.000	14.90	2.985
50.000	15.60	2.857
52.000	16.30	2.857
54.000	17.00	2.857
56.000	17.90	2.222
58.000	18.78	2.273
60.000	19.66	2.273
62.000	20.58	2.174
64.000	21.53	2.105
66.000	22.54	1.980
68.000	23.63	1.835
70.000	24.88	1.600
72.000	26.24	1.471
74.000	27.68	1.389
76.000	29.35	1.198
78.000	31.25	1.053
80.000	33.41	0.926
82.000	35.85	0.820
84.000	38.60	0.727
86.000	41.85	0.615
88.000	45.70	0.519
90.000	50.30	0.435
92.000	55.60	0.377
94.000	60.55	0.404

SPR MEMBRANE FILTRATION TEST DATA RUN:WH-30P
DATE: 14 JAN 79 PSIG: 7 FILTER:10.0N SS(MG/L): .002 VOL(L): 44.0

COL D: 6 PPM ALUM

LITRES	MINS	L/MIN
2.000	1.00	2.000
4.000	2.00	2.000
6.000	3.00	2.000
8.000	3.85	2.353
10.000	4.55	2.857
12.000	5.20	3.077
14.000	5.85	3.077
16.100	6.60	2.800
18.000	7.30	2.714
20.000	8.10	2.500
22.000	8.95	2.353
24.000	9.85	2.222
26.000	10.85	2.000
28.000	11.90	1.905
30.000	13.10	1.667
32.000	14.45	1.481
34.000	16.05	1.250
36.000	18.00	1.026
38.000	20.30	0.870
42.000	27.00	0.597
44.000	32.00	0.400

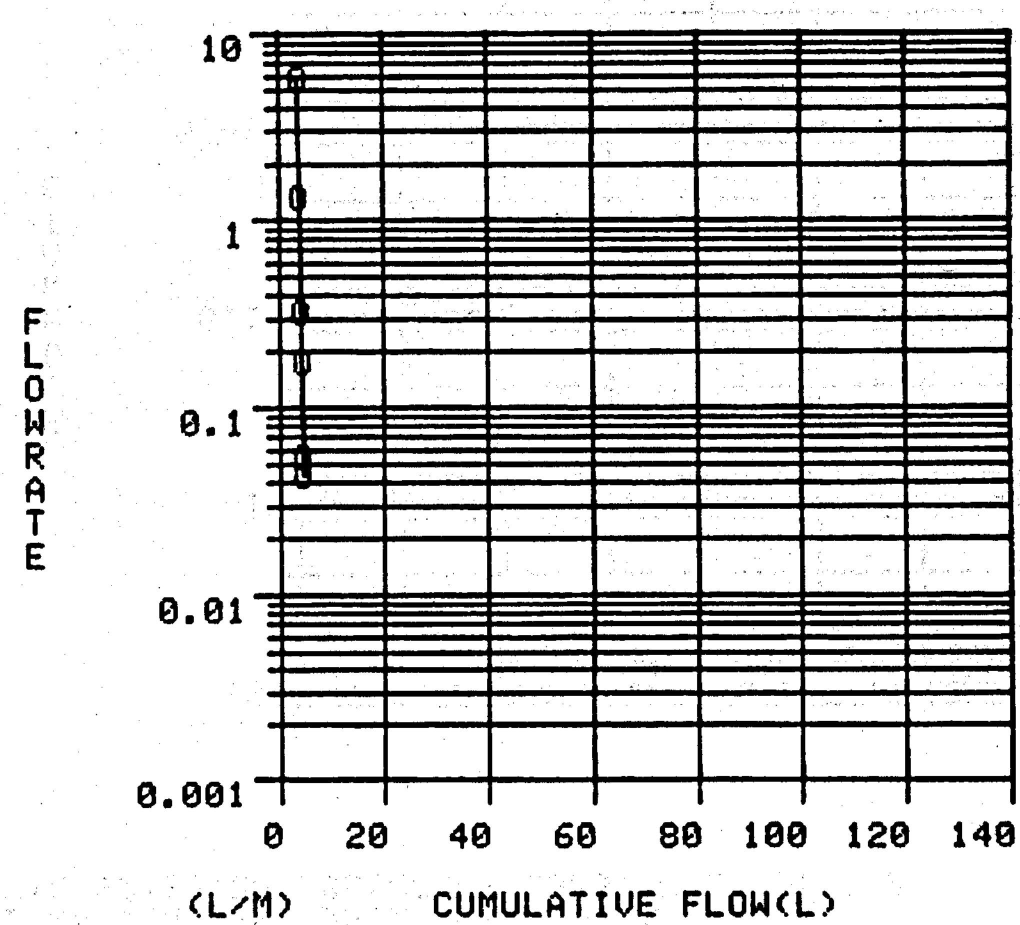


SPR MEMBRANE FILTRATION TEST DATA RUN:WH-4I

DATE: 12 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L): .66 VOL(L): 4.4

RAW BRINE: INJECTION PAD

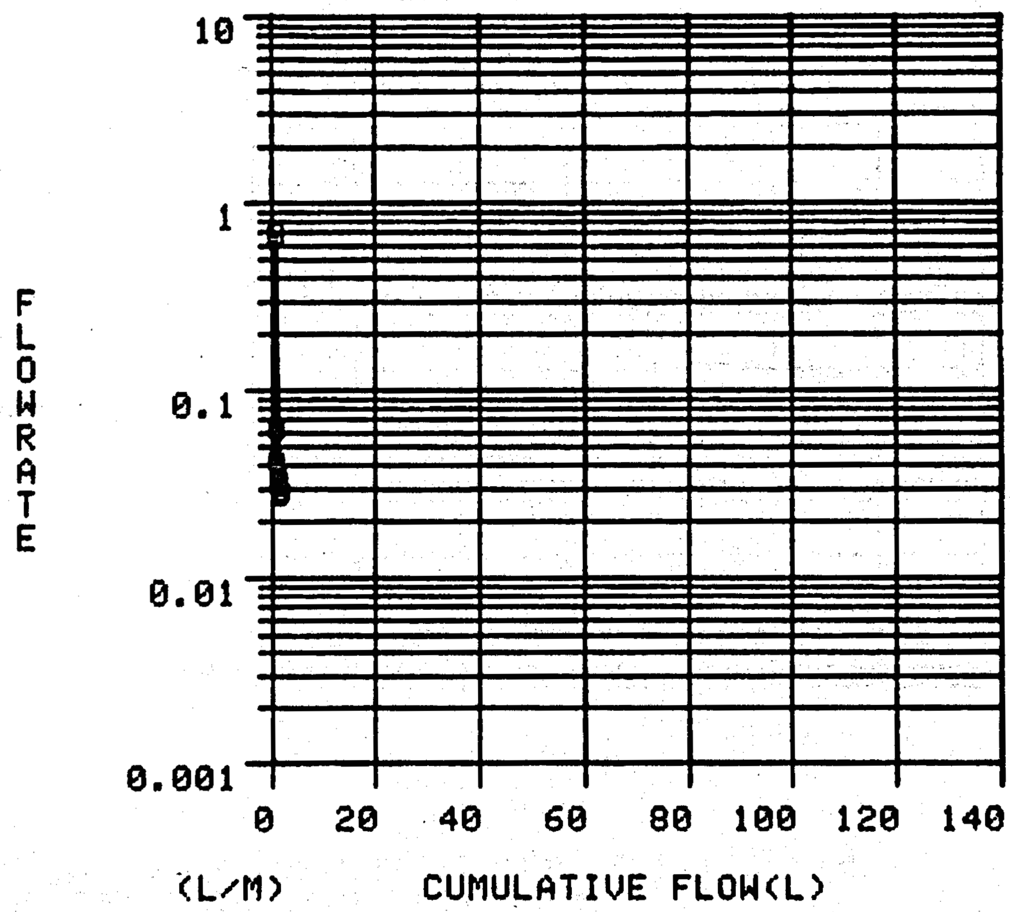
LITRES	MINS	L/MIN
3.600	0.62	5.806
3.800	0.77	1.333
4.000	1.38	0.328
4.200	2.52	0.175
4.300	4.32	0.056
4.400	6.60	0.044



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-6I
DATE: 13 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L):.556 VOL(L): 1.8

RAW BRINE: INJECTION PAD

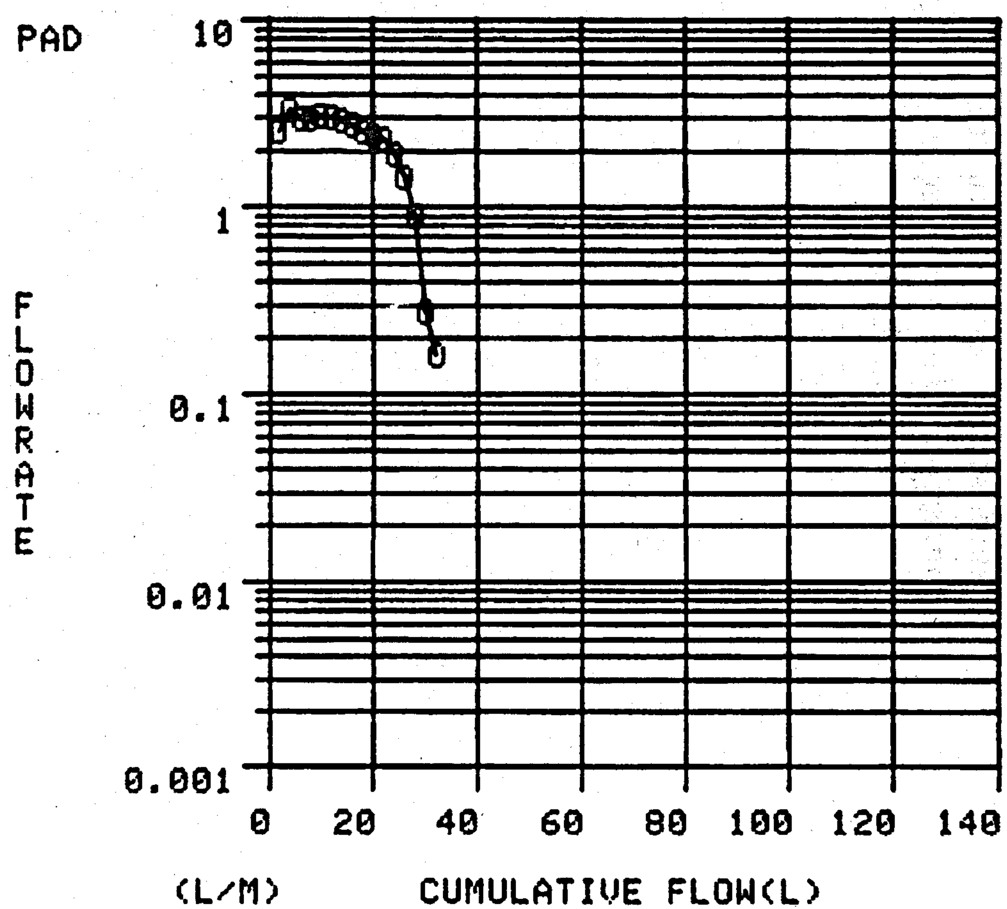
LITRES	MINS	L/MIN
0.800	1.15	0.696
0.900	2.72	0.064
1.000	5.08	0.042
1.100	7.85	0.036
1.200	10.68	0.035
1.300	13.82	0.032
1.400	16.90	0.032
1.500	20.25	0.030
1.600	23.72	0.029
1.700	27.20	0.029
1.800	30.72	0.028



SPR MEMBRANE FILTRATION TEST DATA RUN:WH-5I
DATE: 13 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L): .06 VOL(L): 32.0

1UM PREFILTERED BRINE: INJ. PAD

LITRES	MINS	L/MIN
2.000	0.78	2.564
4.000	1.38	3.333
6.000	2.05	2.985
8.000	2.72	2.985
10.000	3.37	3.077
12.000	4.03	3.030
14.000	4.72	2.899
16.000	5.45	2.740
18.000	6.23	2.564
20.000	7.05	2.439
22.000	7.90	2.353
24.000	8.93	1.942
26.000	10.30	1.460
28.000	12.52	0.901
30.000	19.72	0.278
32.000	32.05	0.162



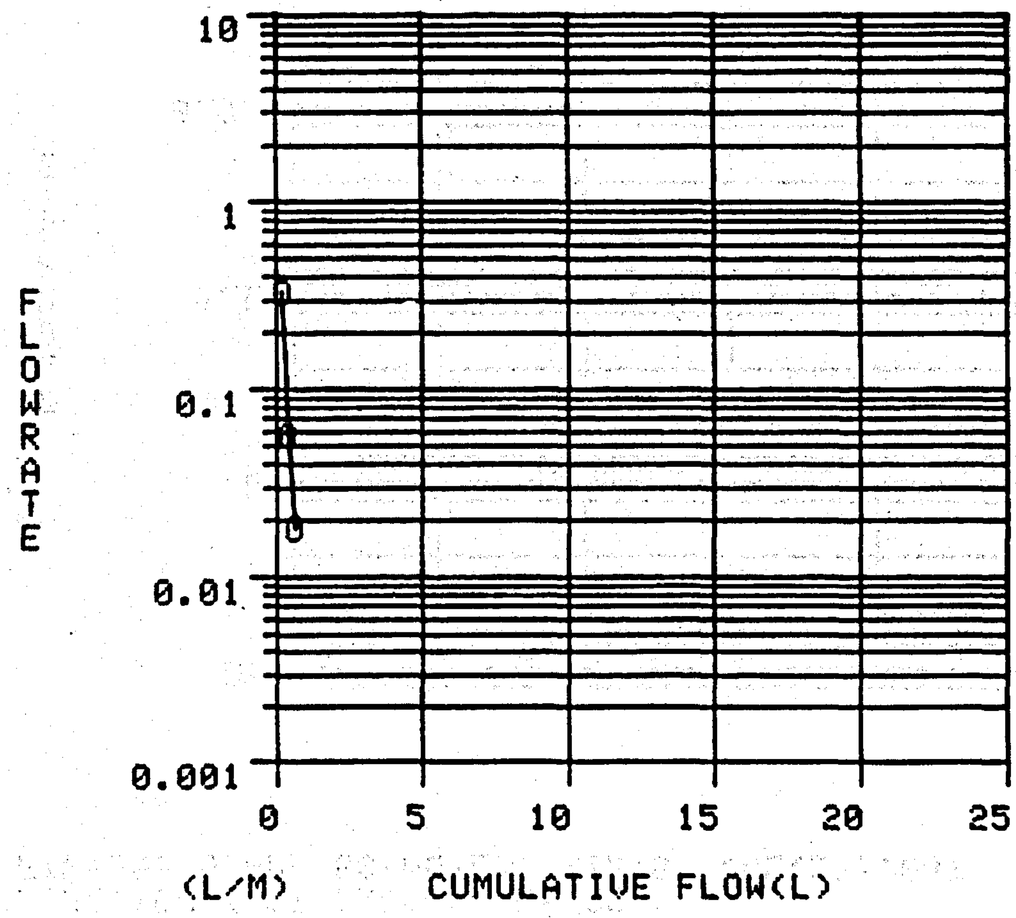
APPENDIX X

EXPERIMENTAL DATA FROM THE LLL FILTER INJECTION TESTS PERFORMED AT BAYOU CHOCTAW

SPR MEMBRAE FILTRATION TEST DATA RUN:1C
DATE:26 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): -- VOL(L):0.60

COL A: NO CHEMICAL FEED

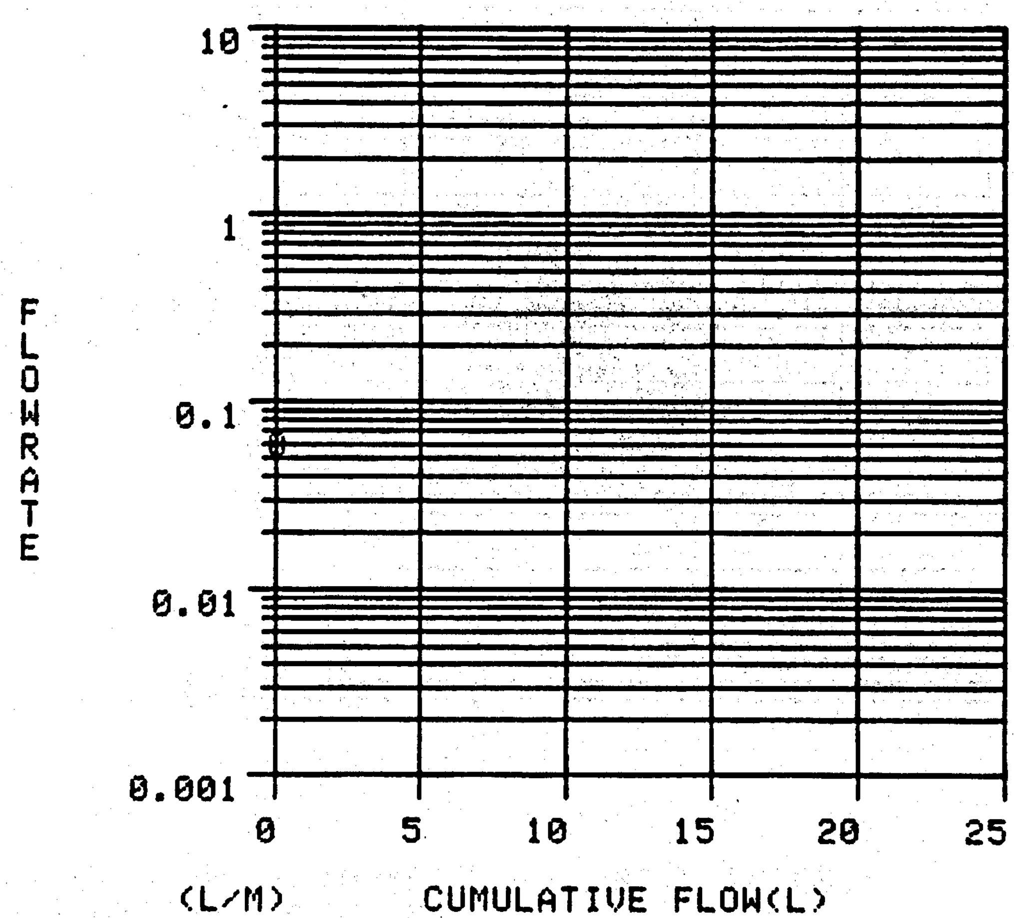
LITRES	MINS	L/MIN
0.200	0.60	0.333
0.400	4.10	0.057
0.600	15.00	0.018



SPR MEMBRANE FILTRATION TEST DATA RUN: 2C
DATE: 26 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 112.8 VOL(L):.047

RAW CAVERN LAKE WATER

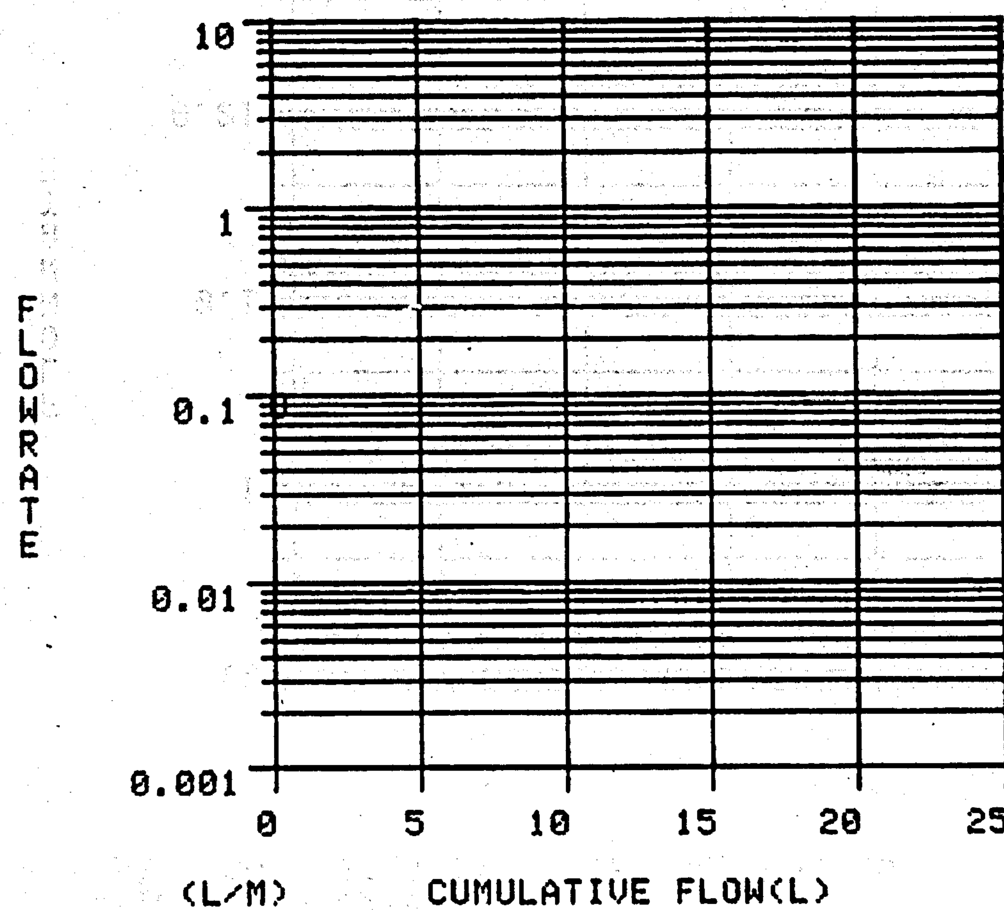
LITRES	MINS	L/MIN
0.047	0.80	0.059



SPR MEMBRANE FILTRATION TEST DATA RUN: 3C
DATE: 27 JAN 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 11.11 VOL(L):.18

RAW BRINE: INJECTION PAD

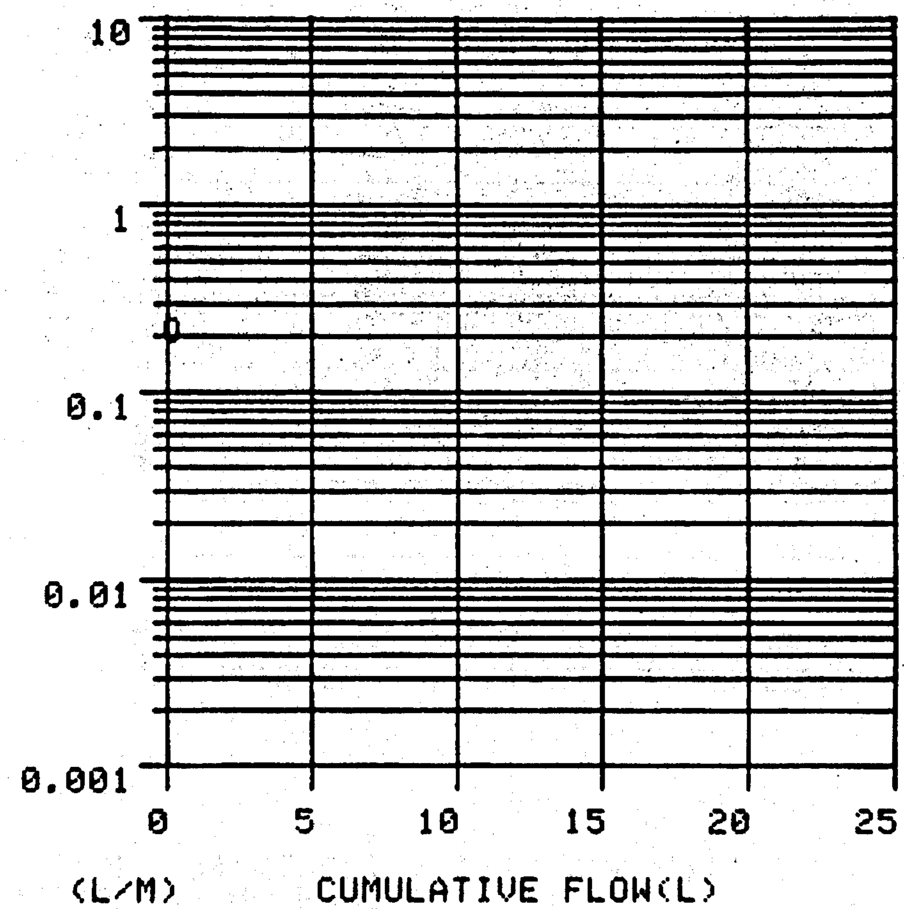
LITRES	MINS	L/MIN
0.180	2.00	0.090



SPR MEMBRANE FILTRATION TEST DATA RUN: 4C
DATE: 27 JAN 79 PSIG: 50 FILTER:1.0N SS(MG/L): 6.67 VOL(L):.18

RAW BRINE: INJECTION PAD

LITRES	MINS	L/MIN
0.180	0.83	0.217

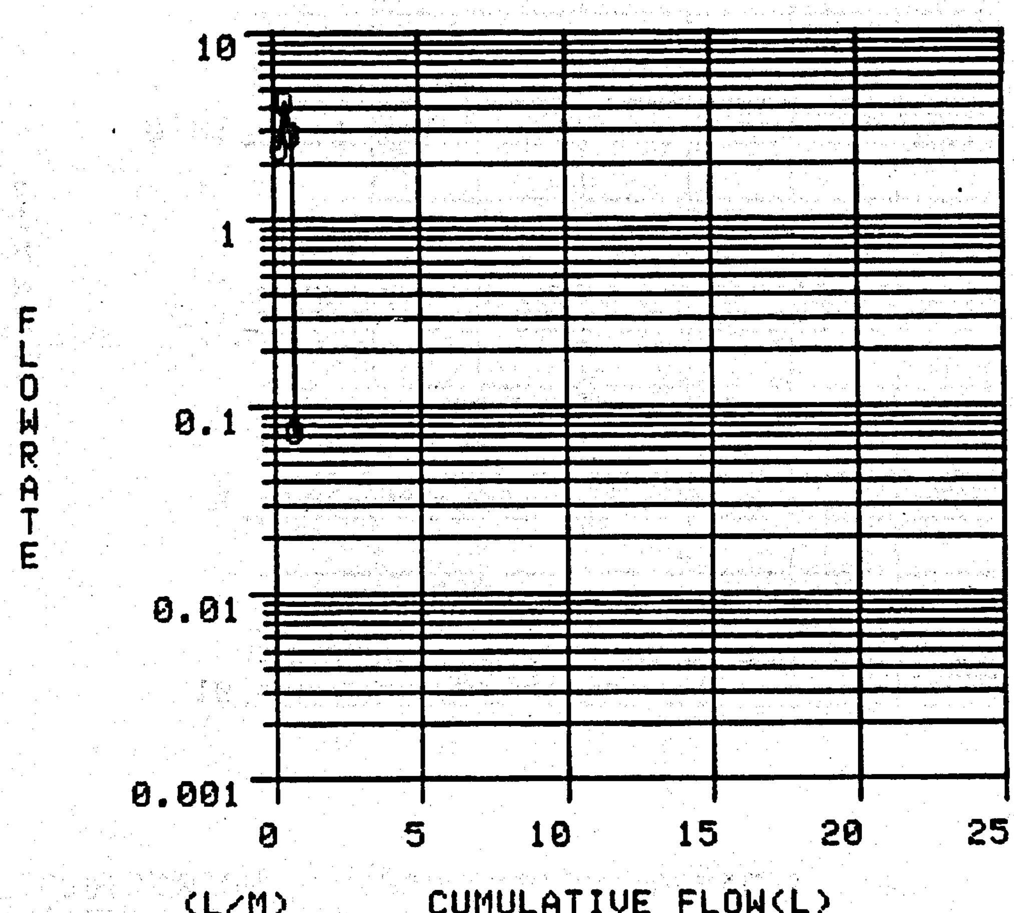


SPR MEMBRANE FILTRATION TEST DATA RUN: 6C

DATE: 27 JAN 79 PSIG: 50 FILTER: 5.0N SS(MG/L):.91 VOL(L): .66

RAW BRINE: INJECTION PAD

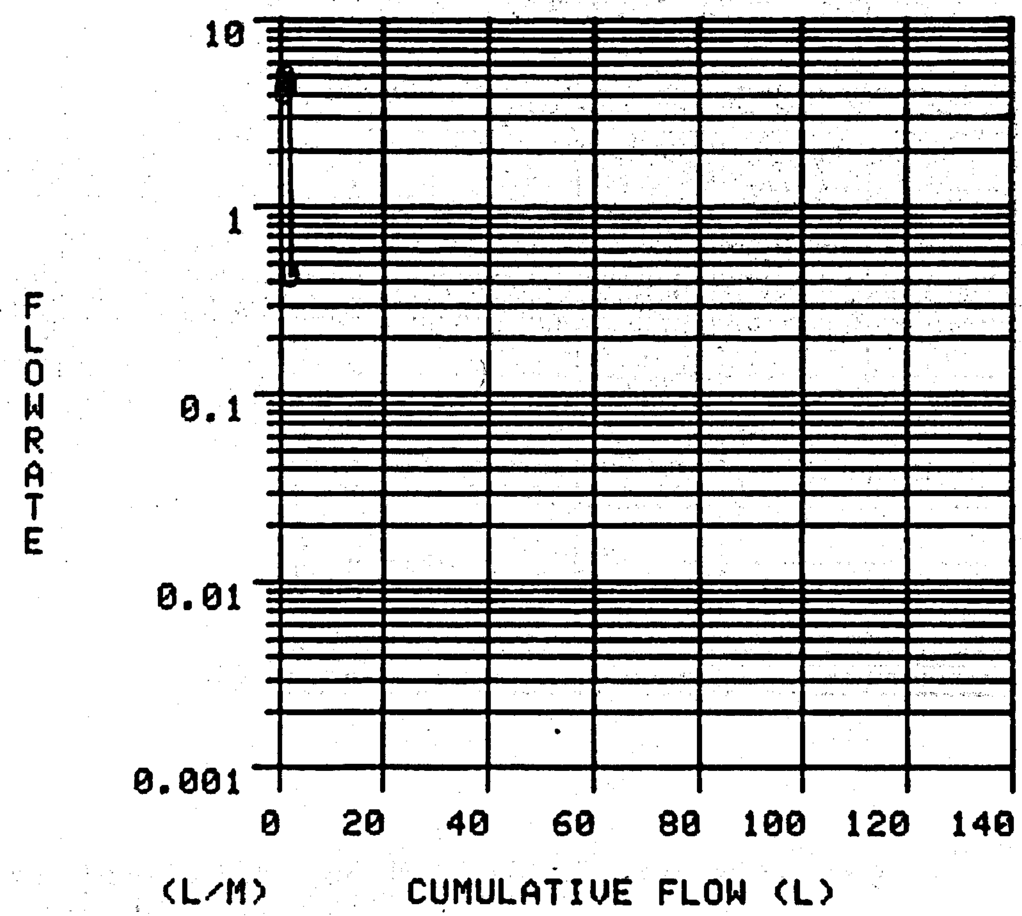
LITRES	MINS	L/MIN
0.200	0.08	2.410
0.400	0.13	4.255
0.600	0.20	2.857
0.660	1.00	0.075



SPR MEMBRANE FILTRATION TEST DATA RUN:8C
DATE: 27 JAN 79 PSIG: 15 FILTER:10.0N SS(MG/L):0.53 VOL(L): 1.88

RAW BRINE: INJECTION PAD

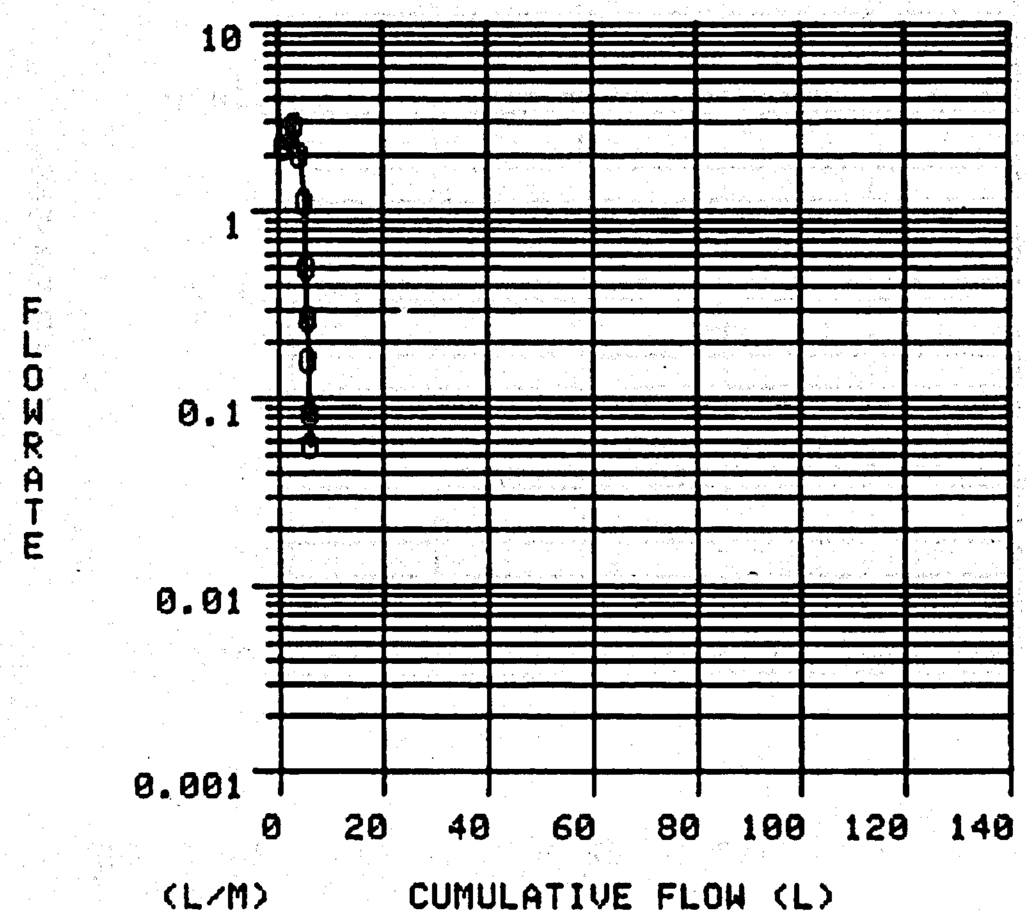
LITRES	MINS	L/MIN
0.500	0.12	4.167
1.000	0.22	5.000
1.500	0.33	4.545
1.880	1.20	0.437



SPR MEMBRANE FILTRATION TEST DATA RUN:11C
DATE: 28 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L): .068 VOL(L): 5.9

COL A: NO CHEMICAL FEED

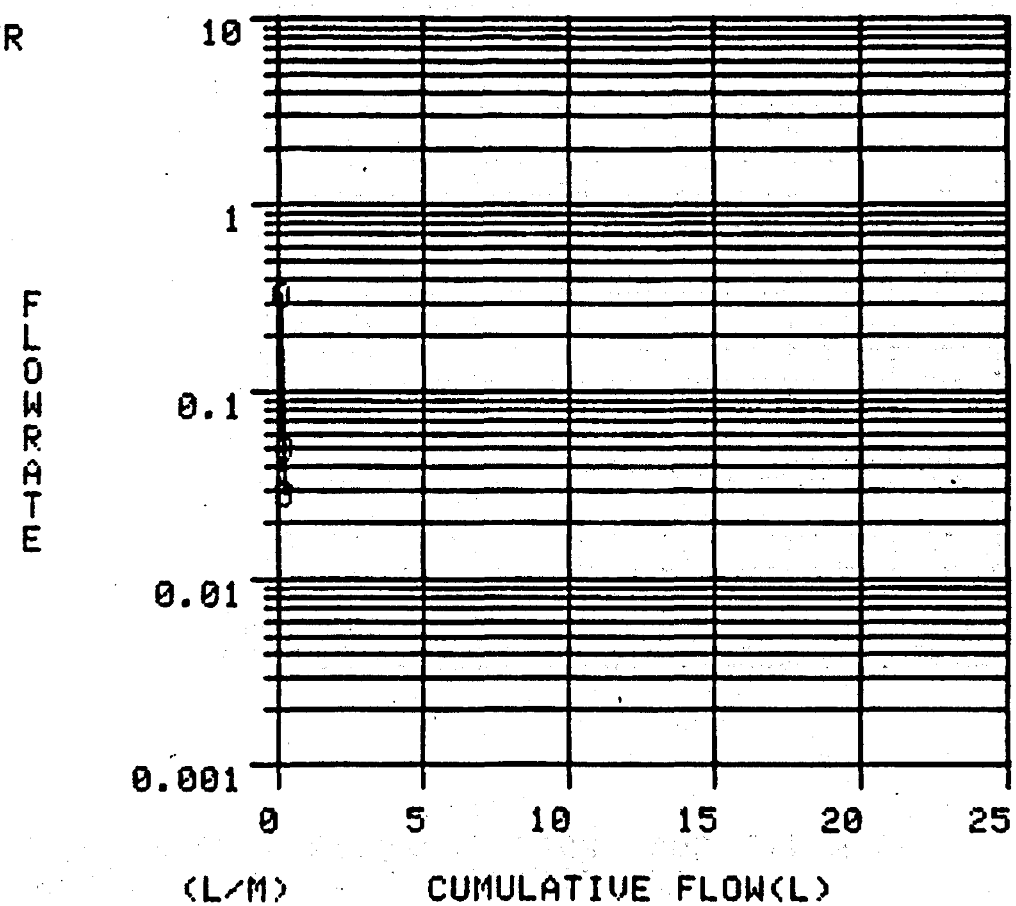
LITRES	MINS	L/MIN
1.000	0.45	2.222
2.000	0.85	2.500
3.000	1.20	2.857
4.000	1.70	2.000
5.000	2.60	1.111
5.200	3.00	0.500
5.400	3.75	0.267
5.600	5.00	0.160
5.800	7.40	0.083
5.890	9.00	0.056



SPR MEMBRANE FILTRATION TEST DATA RUN: 12C
DATE: 28 JAN 79 PSIG:50 FILTER: 0.4N SS(MG/L): 6.82 VOL(L): .22

90% RAW BRINE+10% LAKE WATER

LITRES	MINS	L/MIN
0.100	0.30	0.333
0.200	2.30	0.050
0.220	3.00	0.029

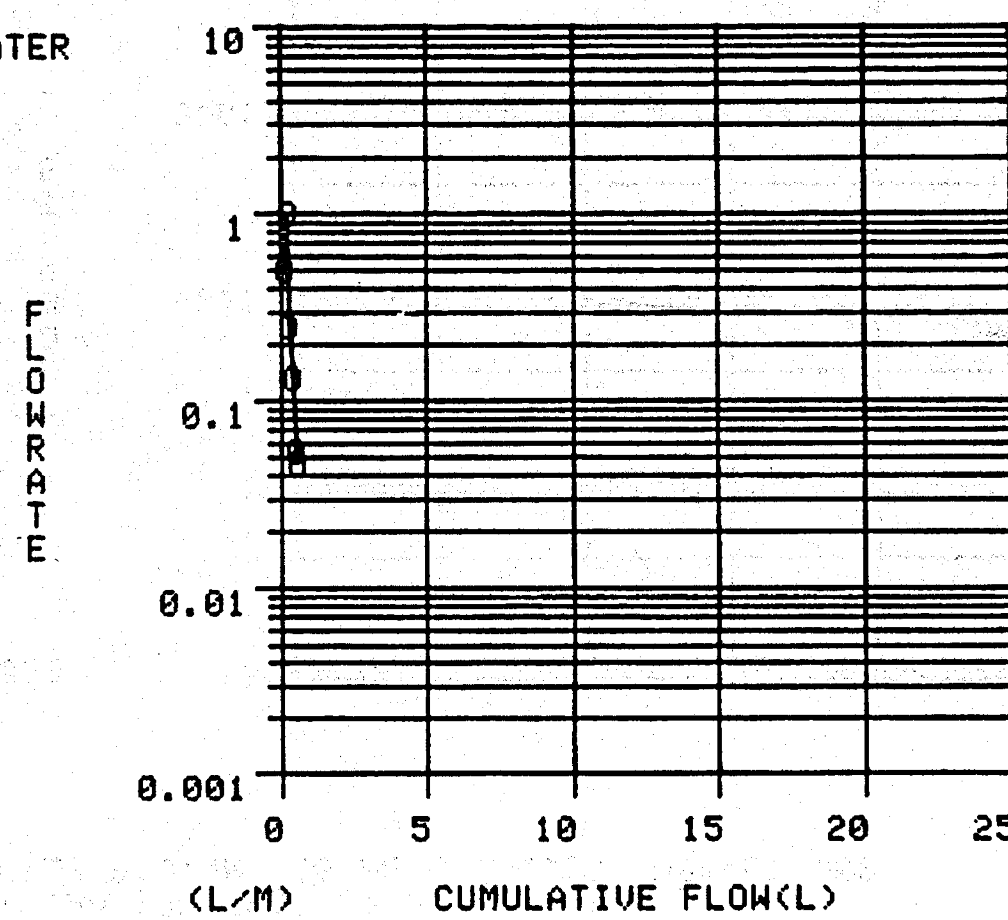


SPR MEMBRANE FILTRATION TEST DATA RUN: 13C

DATE: 28 JAN 79 PSIG:50 FILTER:.45M SS(MG/L): 6.82 VOL(L):.58

COL A:90% BRINE+10% LAKE WATER

LITRES	MINS	L/MIN
0.100	0.20	0.500
0.200	0.30	1.000
0.300	0.70	0.250
0.400	1.45	0.133
0.500	3.30	0.054
0.580	5.00	0.047

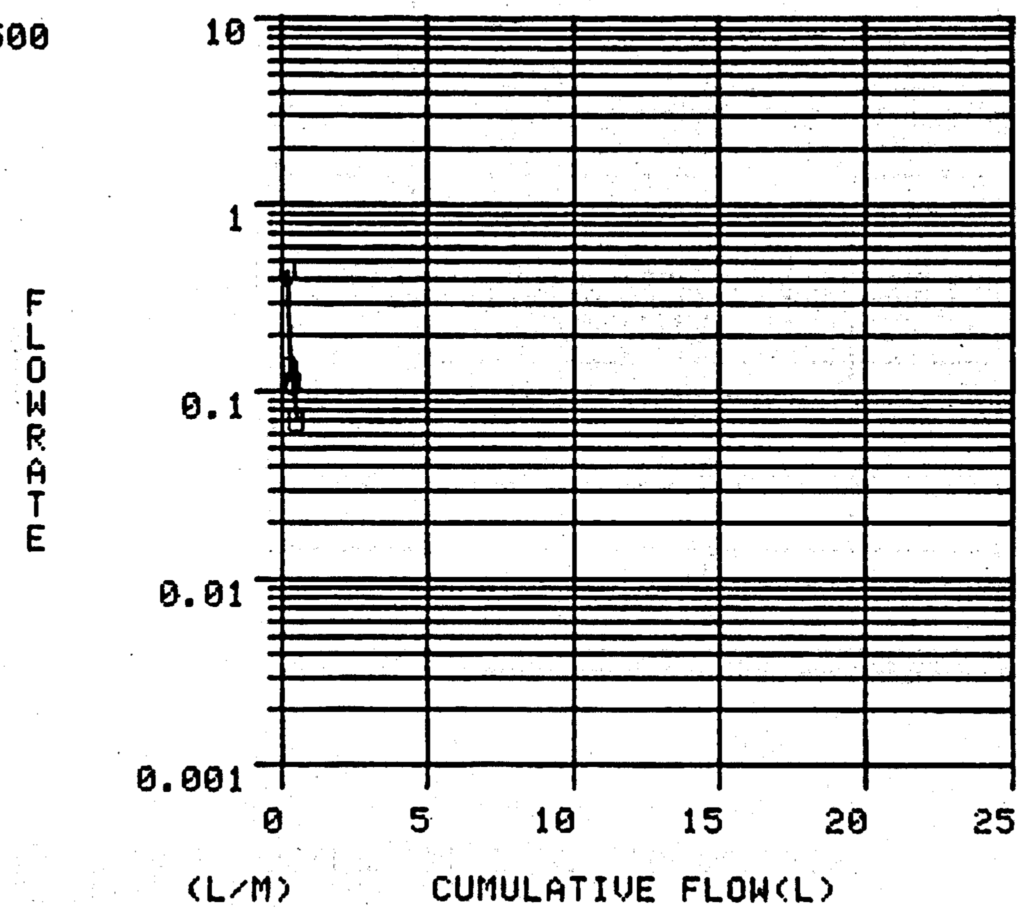


381

SPR MEMBRANE FILTRATION TEST DATA RUN: 14C
DATE: 29 JAN 79 PSIG:50 FILTER:0.4N SS(MG/L): 1.15 VOL(L):.52

COL B:10 PPM ALUM+.1 PPM 4500

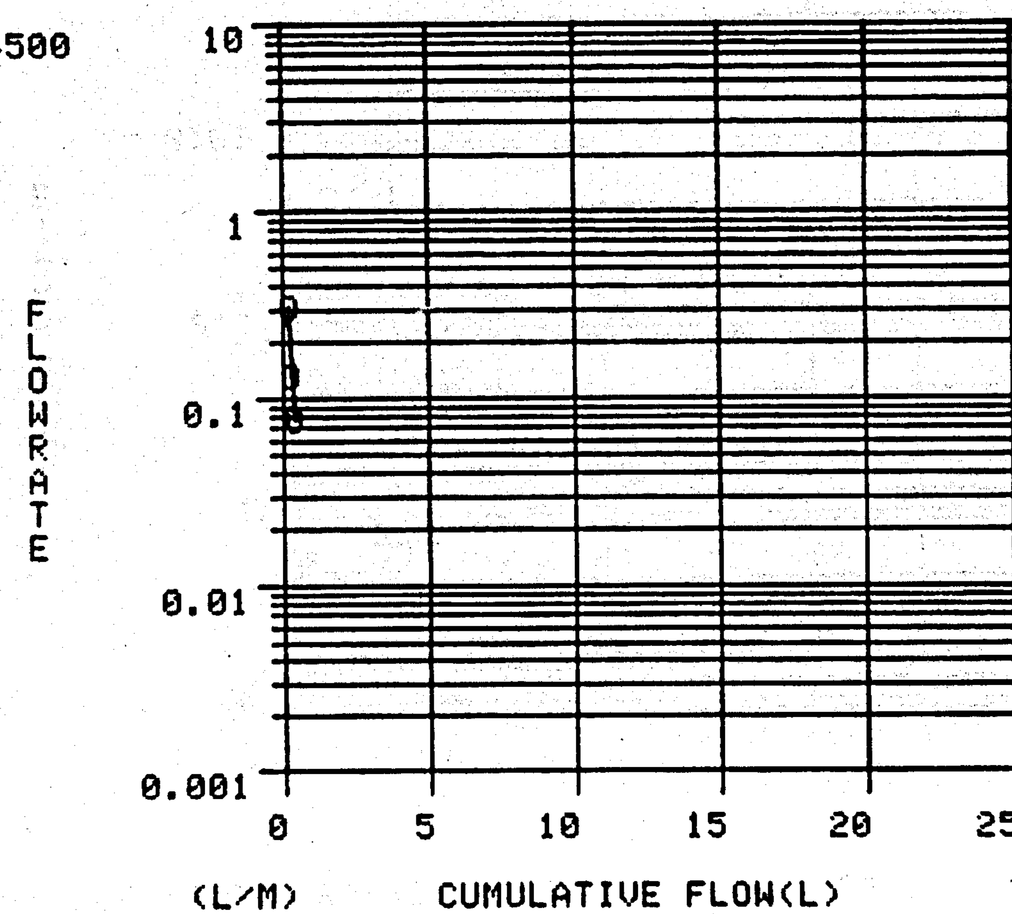
LITRES	MINS	L/MIN
0.200	0.45	0.444
0.300	1.20	0.133
0.400	2.10	0.111
0.520	3.80	0.071



SPR MEMBRANE FILTRATION TEST DATA RUN: 16C
DATE: 29 JAN 79 PSIG: 50 FILTER:0.4N SS(MG/L): 1.0 VOL(L):.4

COL 8:10 PPM ALUM +.1 PPM 4500

LITRES	MINS	L/MIN
0.200	0.65	0.308
0.300	1.40	0.133
0.400	2.70	0.077

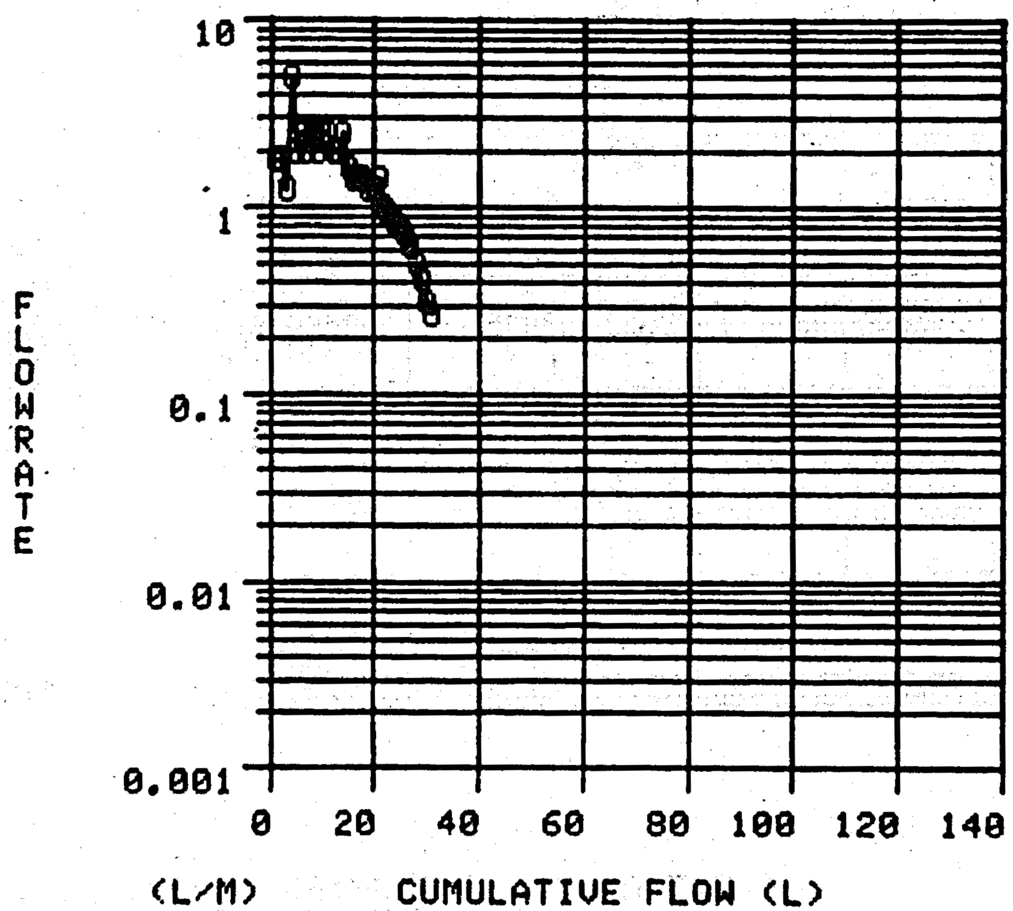


383

SPR MEMBRANE FILTRATION TEST DATA RUN:17C
DATE: 29 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L):.013 VOL(L): 31

COL B: 10 PPM ALUM+.1 4500

LITRES	MINS	L/MIN
1.000	0.55	1.818
2.000	1.10	1.818
3.000	1.90	1.250
4.000	2.10	5.000
5.000	2.60	2.000
6.000	3.00	2.500
7.000	3.50	2.000
8.000	3.90	2.500
9.000	4.40	2.000
10.000	4.80	2.500
11.000	5.20	2.500
12.000	5.70	2.000
13.000	6.20	2.000
14.000	6.60	2.500
15.000	7.20	1.667
16.000	7.90	1.429
17.000	8.60	1.429
18.000	9.30	1.429
19.000	10.10	1.250
20.000	10.90	1.250
21.000	11.60	1.429
22.000	12.60	1.000
23.000	13.70	0.909
24.000	14.90	0.833



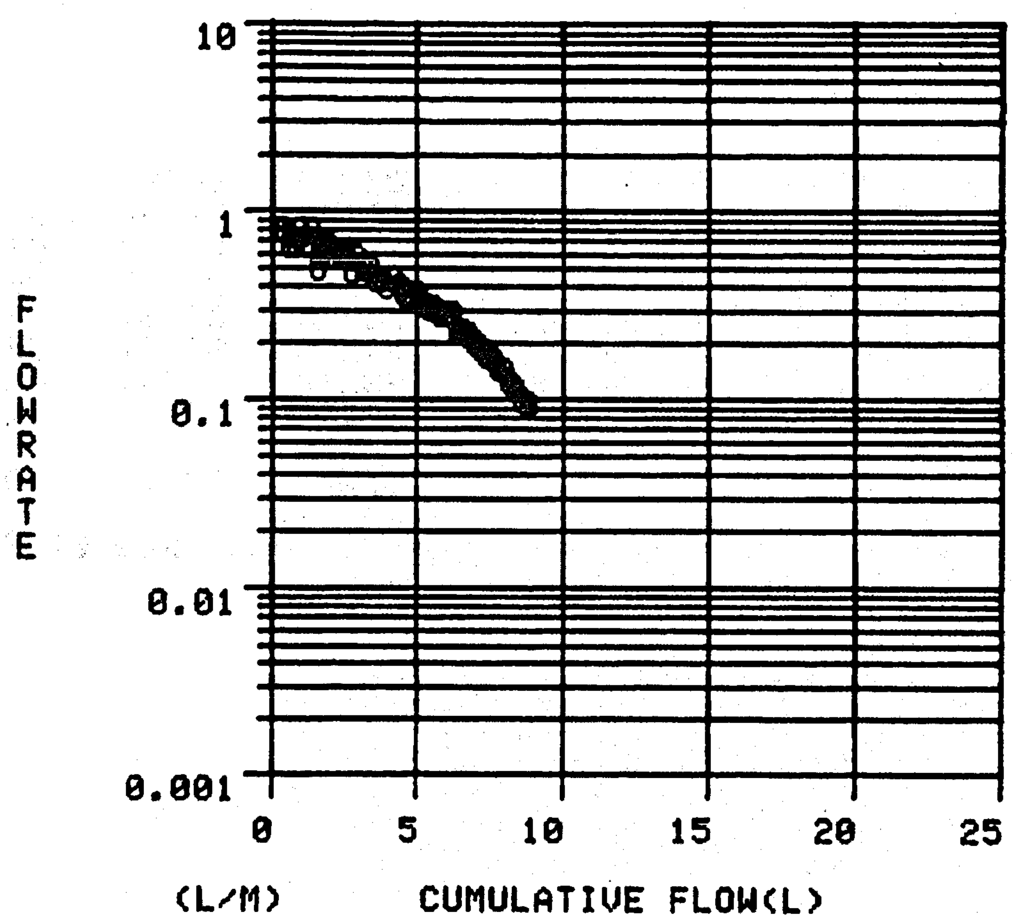
COL B: 10 PPM ALUM+.1 4500

LITRES	MINS	L/MIN
24.000	14.90	0.833
25.000	16.20	0.769
26.000	17.60	0.714
27.000	19.20	0.625
28.000	21.20	0.500
29.000	23.60	0.417
30.000	26.80	0.313
31.000	30.50	0.270

SPR MEMBRANE FILTRATION TEST DATA RUN:18C
DATE: 29 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L): 1.2 VOL(L):8.8

ULTRAFILTERED WEAK BRINE

LITRES	MINS	L/MIN
0.200	0.25	0.800
0.400	0.50	0.800
0.600	0.80	0.667
0.800	1.10	0.667
1.000	1.35	0.800
1.200	1.65	0.667
1.400	1.90	0.800
1.600	2.30	0.500
1.800	2.60	0.667
2.000	2.90	0.667
2.200	3.25	0.571
2.400	3.60	0.571
2.600	3.94	0.588
2.800	4.35	0.488
3.000	4.70	0.571
3.200	5.10	0.500
3.400	5.50	0.500
3.600	5.95	0.444
3.800	6.40	0.444
4.000	6.90	0.400
4.200	7.35	0.444
4.400	7.85	0.400
4.600	8.40	0.364
4.800	8.95	0.364



ULTRAFILTERED WEAK BRINE

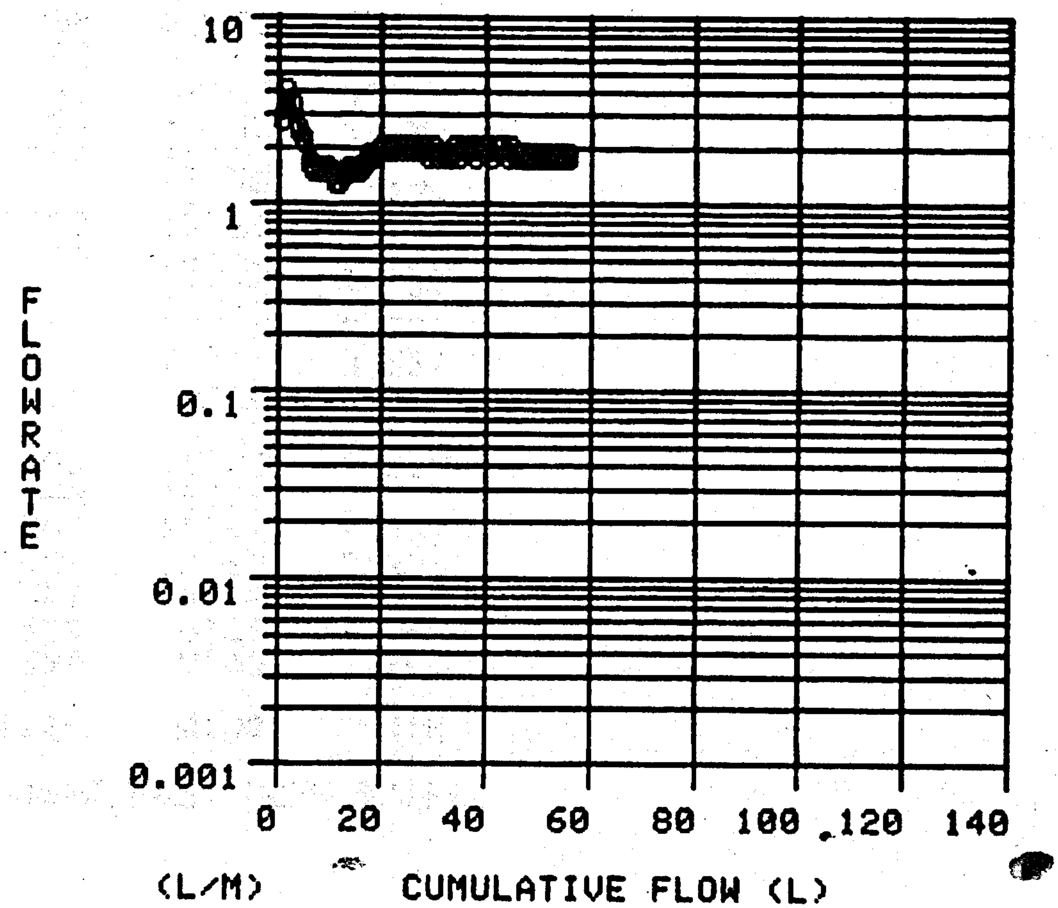
LITRES	MINS	L/MIN
4.800	8.95	0.364
5.000	9.50	0.364
5.200	10.10	0.333
5.400	10.75	0.308
5.600	11.40	0.308
5.800	12.10	0.286
6.000	12.80	0.286
6.200	13.50	0.286
6.400	14.35	0.235
6.600	15.20	0.235
6.800	16.10	0.222
7.000	17.10	0.200
7.200	18.15	0.190
7.400	19.30	0.174
7.600	20.50	0.167
7.800	21.85	0.148
8.000	23.25	0.143
8.200	24.85	0.125
8.400	26.60	0.114
8.600	28.60	0.100
8.800	30.70	0.095

SPR MEMBRANE FILTRATION TEST DATA RUN:19C

DATE: 29 JAN 79 PSIG: 20 FILTER: 8.0M SS(MG/L): .54 VOL(L): 56.0

ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
1.000	0.35	2.857
2.000	0.60	4.000
3.000	0.90	3.333
4.000	1.30	2.500
5.000	1.75	2.222
6.000	2.35	1.667
7.000	3.00	1.538
8.000	3.65	1.538
9.000	4.30	1.538
10.000	4.95	1.538
11.000	5.70	1.333
12.000	6.45	1.333
13.000	7.15	1.429
14.000	7.80	1.538
15.000	8.45	1.538
16.000	9.10	1.538
17.000	9.70	1.667
18.000	10.25	1.818
19.000	10.80	1.818
20.000	11.30	2.000
21.000	11.80	2.000
22.000	12.30	2.000
23.000	12.80	2.000
24.000	13.30	2.000



ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
24.000	13.30	2.000
25.000	13.80	2.000
26.000	14.30	2.000
27.000	14.80	2.000
28.000	15.30	2.000
29.000	15.85	1.818
30.000	16.35	2.000
31.000	16.90	1.818
32.000	17.45	1.818
33.000	18.00	1.818
34.000	18.50	2.000
35.000	19.05	1.818
36.000	19.55	2.000
37.000	20.05	2.030
38.000	20.60	1.818
39.000	21.10	2.000
40.000	21.60	2.000
41.000	22.15	1.818
42.000	22.65	2.000
43.000	23.15	2.000
44.000	23.70	1.818
45.000	24.20	2.000
46.000	24.75	1.818
47.000	25.30	1.818
48.000	25.85	1.818
49.000	26.40	1.818
50.000	26.95	1.818
51.000	27.50	1.818
52.000	28.05	1.818
53.000	28.60	1.818
54.000	29.15	1.818

ULTRAFILTERED BRINE

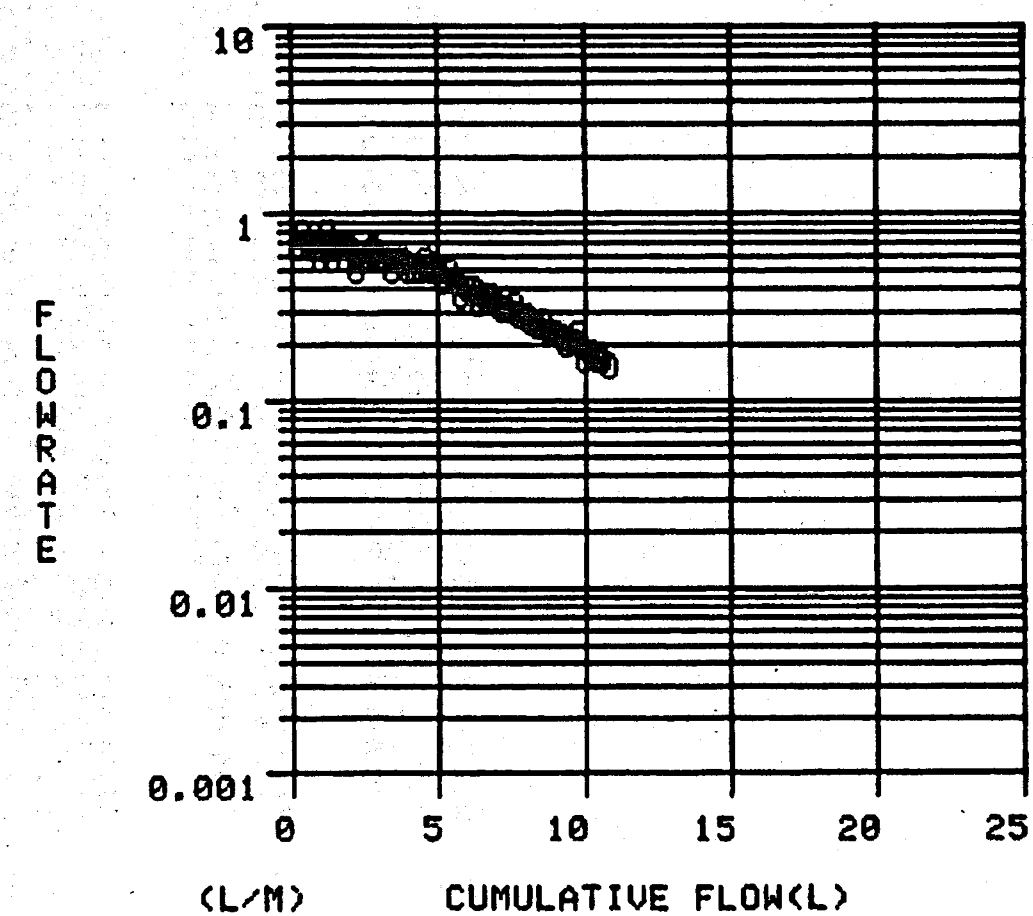
LITRES	MINS	L/MIN
54.000	29.15	1.818
55.000	29.70	1.818
56.000	30.25	1.818

SPR MEMBRANE FILTRATION TEST DATA RUN:20C

DATE: 30 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .24 VOL(L):10.8

ULTRAFILTERED WEAK BRINE

LITRES	MINS	L/MIN
0.200	0.30	0.667
0.400	0.55	0.800
0.600	0.85	0.667
0.800	1.15	0.667
1.000	1.50	0.571
1.200	1.75	0.800
1.400	2.10	0.571
1.600	2.40	0.667
1.800	2.70	0.667
2.000	3.00	0.667
2.200	3.40	0.500
2.400	3.75	0.571
2.600	4.10	0.571
2.800	4.40	0.667
3.000	4.75	0.571
3.200	5.10	0.571
3.400	5.50	0.500
3.600	5.85	0.571
3.800	6.20	0.571
4.000	6.60	0.500
4.200	7.00	0.500
4.400	7.40	0.500
4.600	7.75	0.571
4.800	8.15	0.500



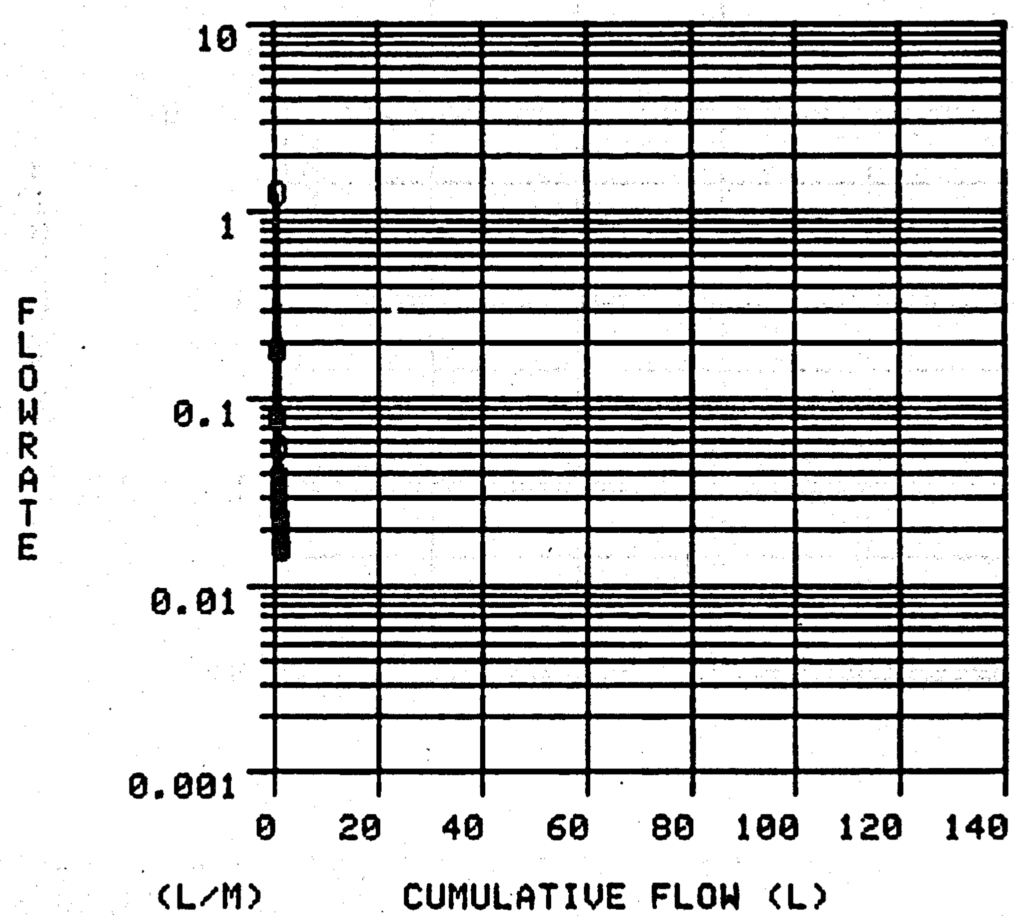
ULTRAFILTERED WEAK BRINE

LITRES	MINS	L/MIN
4.800	8.15	0.500
5.000	8.55	0.500
5.200	9.00	0.444
5.400	9.40	0.500
5.600	9.85	0.444
5.800	10.40	0.364
6.000	10.90	0.400
6.200	11.40	0.400
6.400	12.00	0.333
6.600	12.55	0.364
6.800	13.10	0.364
7.000	13.70	0.333
7.200	14.35	0.308
7.400	15.00	0.308
7.600	15.60	0.333
7.800	16.30	0.286
8.000	17.00	0.286
8.200	17.75	0.267
8.400	18.55	0.250
8.600	19.30	0.267
8.800	20.15	0.235
9.000	21.00	0.235
9.200	21.90	0.222
9.400	22.90	0.200
9.600	23.85	0.211
9.800	24.70	0.235
10.000	25.90	0.167
10.200	27.00	0.182
10.400	28.20	0.167
10.600	29.40	0.167
10.800	30.70	0.154

SPR MEMBRANE FILTRATION TEST DATA   RUN:25C
DATE: 30 JAN 79   PSIG: 50   FILTER: 8.0M   SS(MG/L): 23.9   VOL(L):1.4

RAW WEAK BRINE

LITRES	MINS	L/MIN
0.500	0.40	1.250
0.600	0.95	0.182
0.700	2.20	0.080
0.800	4.00	0.056
0.850	5.50	0.033
0.900	6.80	0.038
0.950	8.40	0.031
1.000	10.10	0.029
1.050	12.00	0.026
1.100	14.20	0.023
1.150	16.40	0.023
1.200	19.00	0.019
1.250	21.60	0.019
1.300	24.40	0.018
1.350	27.40	0.017
1.400	30.50	0.016

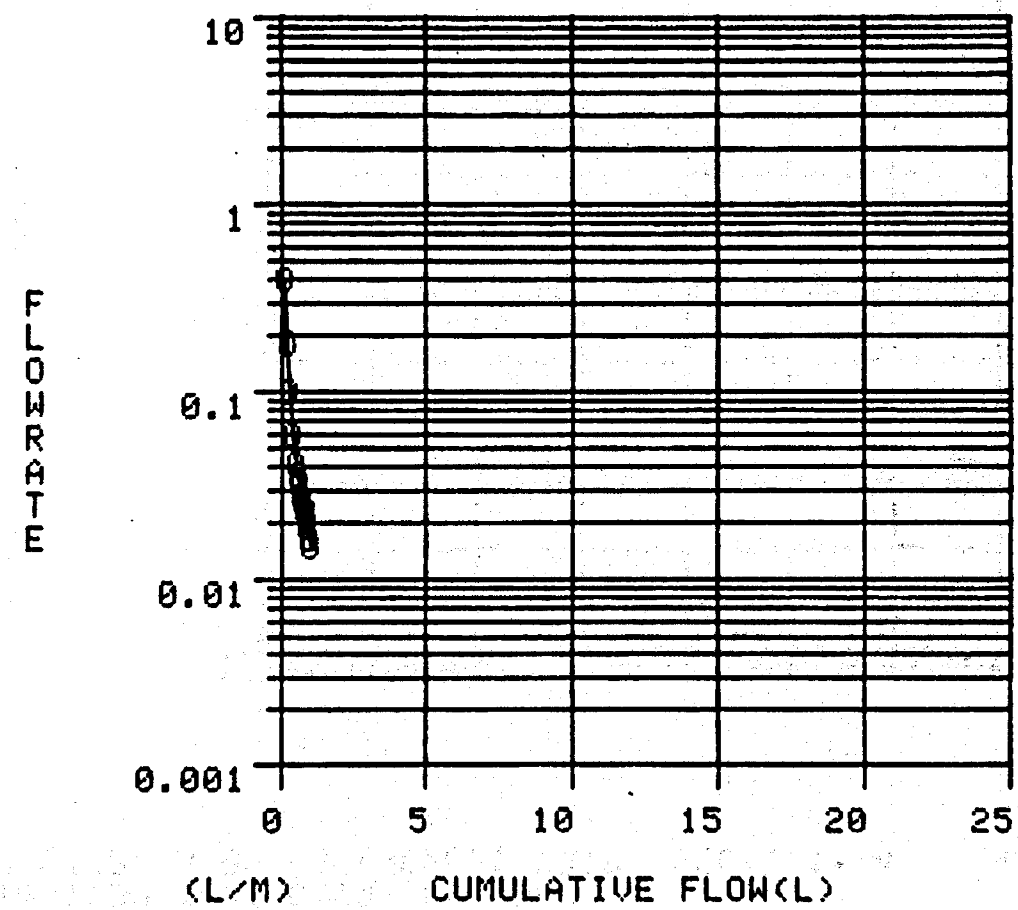


393

SPR MEMBRANE FILTRATION TEST DATA RUN: 26CJ
DATE: 1 JAN 79 PSIG:50 FILTER: 0.45M SS(MG/L): 20.92 VOL(L): 1.0

RAW WEAK BRINE PONDOUT

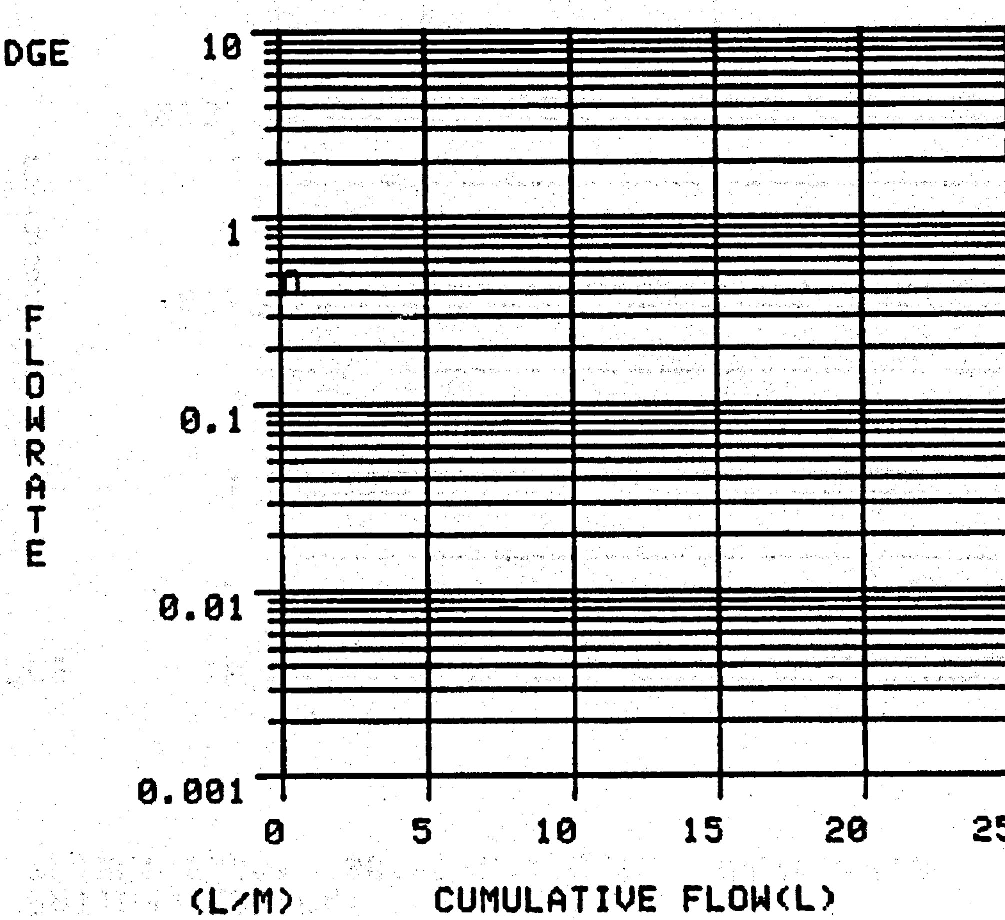
LITRES	MINS	L/MIN
0.100	0.25	0.400
0.200	0.80	0.182
0.300	1.80	0.100
0.400	3.50	0.059
0.500	5.90	0.042
0.550	7.30	0.036
0.600	8.80	0.033
0.650	10.60	0.028
0.700	12.50	0.026
0.750	14.60	0.024
0.800	16.70	0.024
0.850	19.20	0.020
0.900	21.80	0.019
0.950	24.80	0.017
1.000	28.10	0.015



SPR MEMBRANE FILTRATION TEST DATA RUN:26C
DATE: 31 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L):-- VOL(L):.384

WEAK BRINE: 5UM CUNO CARTRIDGE

LITRES	MINS	L/MIN
0.384	0.84	0.457

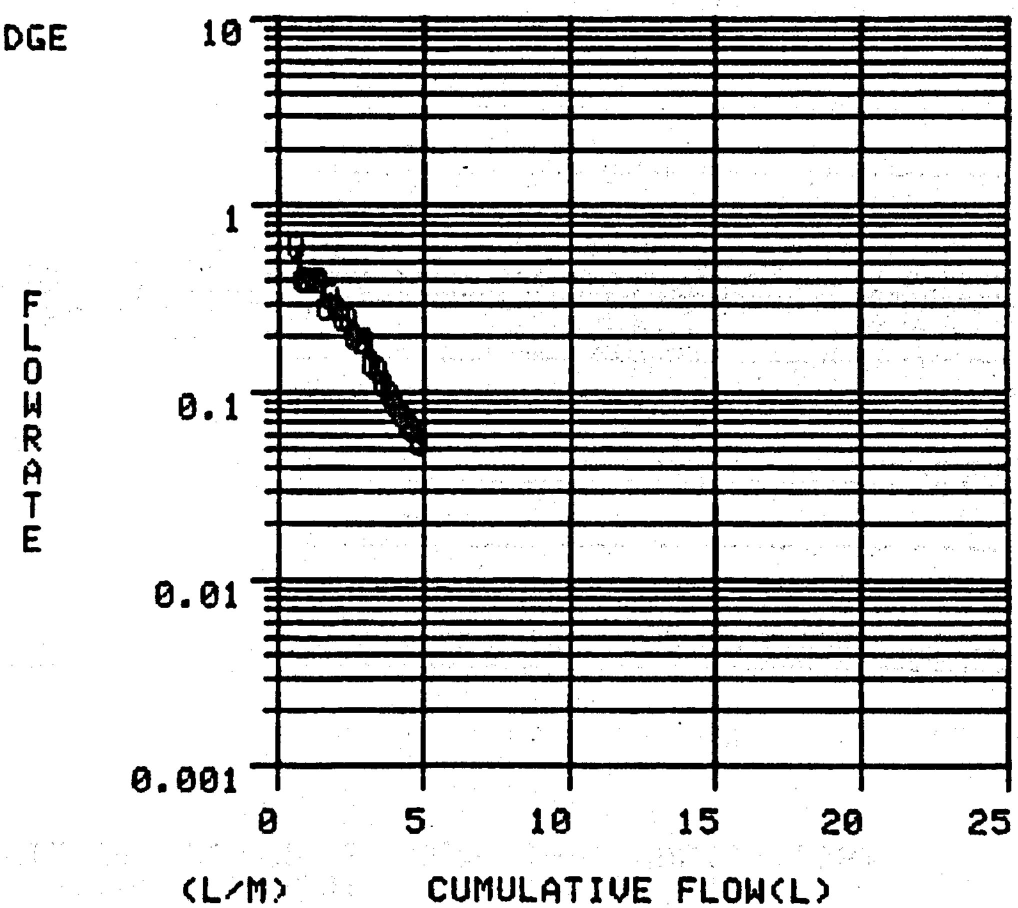


SPR MEMBRANE FILTRATION TEST DATA RUN:26C-L

DATE: 31 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L): 0.62 VOL(L):4.8

WEAK BRINE: 1UM CUNO CARTRIDGE

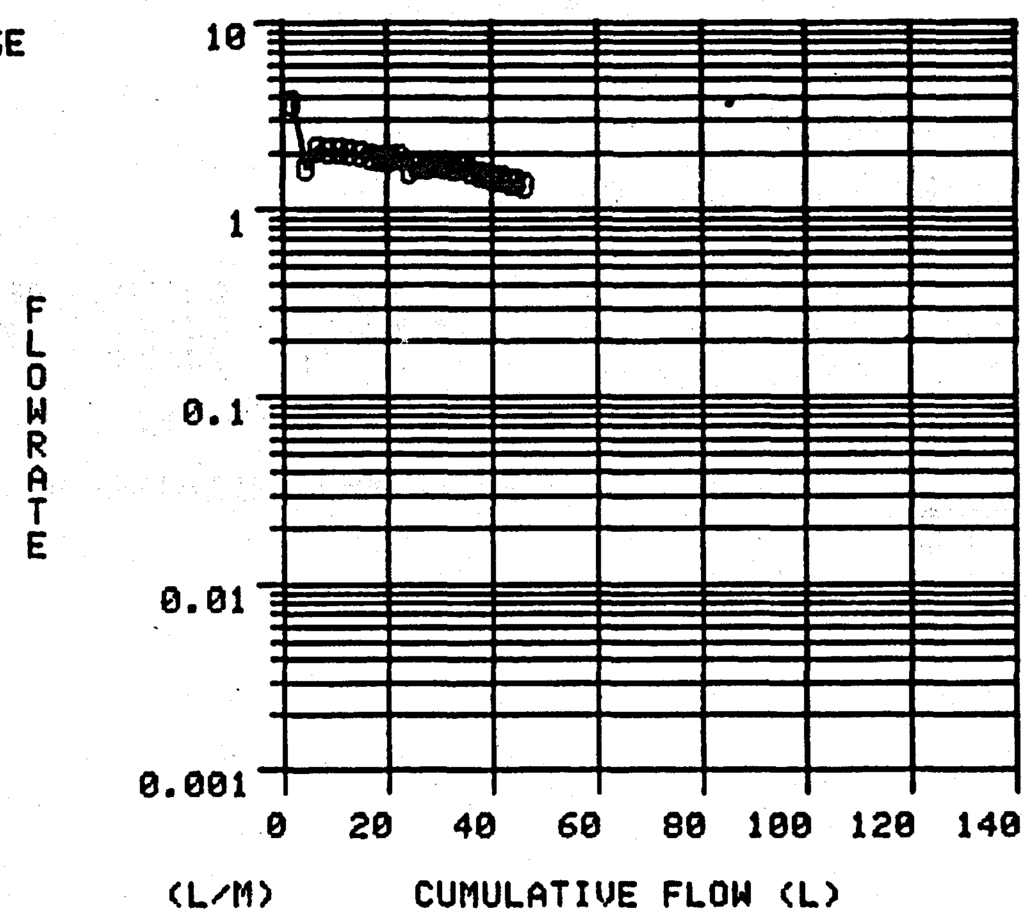
LITRES	MINS	L/MIN
0.600	1.00	0.600
0.800	1.50	0.400
1.000	2.00	0.400
1.200	2.50	0.400
1.400	3.00	0.400
1.600	3.70	0.286
1.800	4.30	0.333
2.000	5.00	0.286
2.200	5.80	0.250
2.400	6.60	0.250
2.600	7.60	0.200
2.800	8.65	0.190
3.000	9.70	0.190
3.200	11.10	0.143
3.400	12.60	0.133
3.600	14.40	0.111
3.800	16.45	0.098
4.000	18.70	0.089
4.200	21.30	0.077
4.400	24.20	0.069
4.600	27.30	0.065
4.800	31.00	0.054



SPR MEMBRANE FILTRATION TEST DATA RUN:27C
DATE: 31 JAN 79 PSIG: 14 FILTER: 8.0M SS(MG/L): .14 VOL(L): 53.8

CUNO 1UM PREFILTER CARTRIDGE

LITRES	MINS	L/MIN
1.858	0.50	3.716
4.413	2.00	1.703
6.558	3.00	2.145
8.653	4.00	2.095
10.735	5.00	2.082
12.778	6.00	2.043
14.759	7.00	1.981
16.695	8.00	1.936
18.591	9.00	1.896
20.483	10.00	1.892
22.392	11.00	1.909
24.039	12.00	1.647
25.779	13.00	1.740
27.513	14.00	1.734
29.258	15.00	1.745
30.971	16.00	1.713
32.653	17.00	1.682
34.373	18.00	1.720
35.999	19.00	1.626
37.585	20.00	1.586
39.123	21.00	1.538
40.620	22.00	1.497
42.102	23.00	1.482
43.512	24.00	1.410



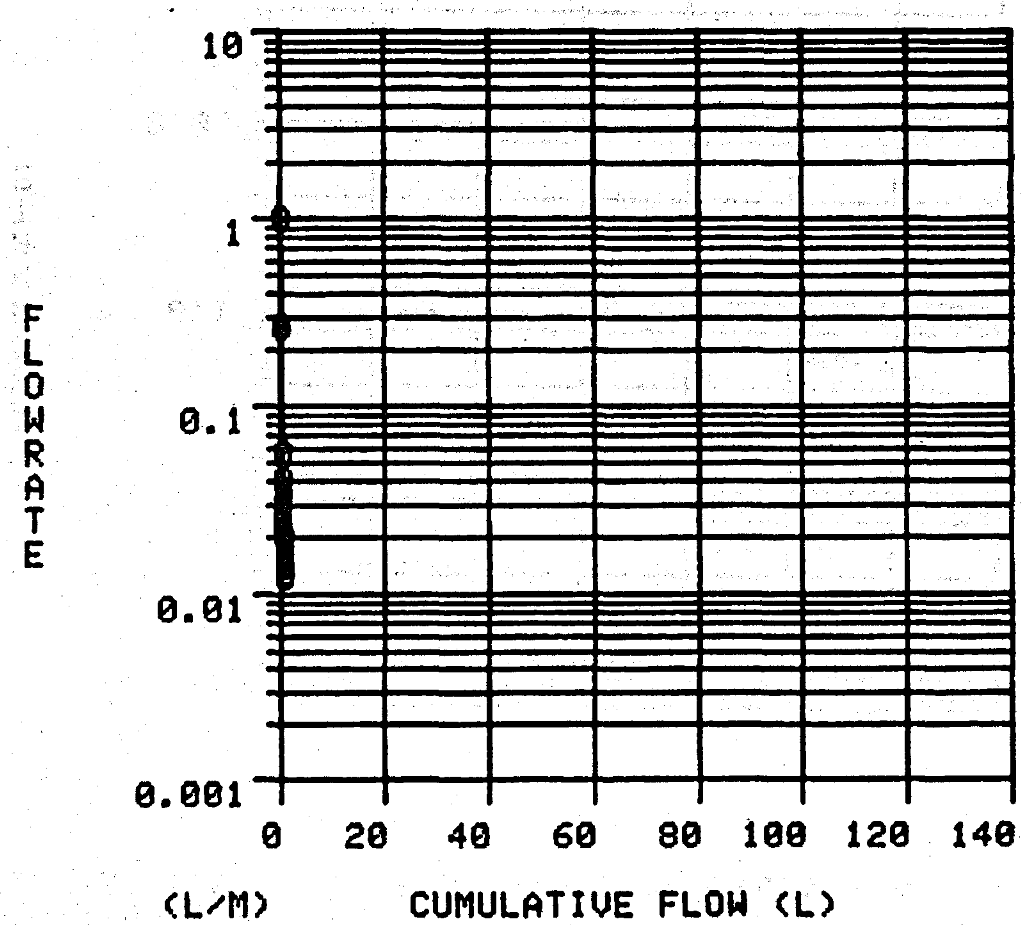
CUNO 1UM PREFILTER CARTRIDGE

LITRES	MINS	L/MIN
43.512	24.00	1.410
44.928	25.00	1.416
46.288	26.00	1.360

SPR MEMBRANE FILTRATION TEST DATA RUN:27CJ
DATE: 30 JAN 79 PSIG: 12 FILTER: 8.0M SS(MG/L): 23.46 VOL(L): 1.05

RAW WEAK BRINE PONDOUT

LITRES	MINS	L/MIN
0.200	0.20	1.000
0.400	0.95	0.267
0.500	2.70	0.057
0.550	3.90	0.042
0.600	5.40	0.033
0.650	7.20	0.028
0.700	9.20	0.025
0.750	11.60	0.021
0.800	14.10	0.020
0.850	17.10	0.017
0.900	20.10	0.017
0.950	23.50	0.015
1.000	27.30	0.013
1.050	31.30	0.013

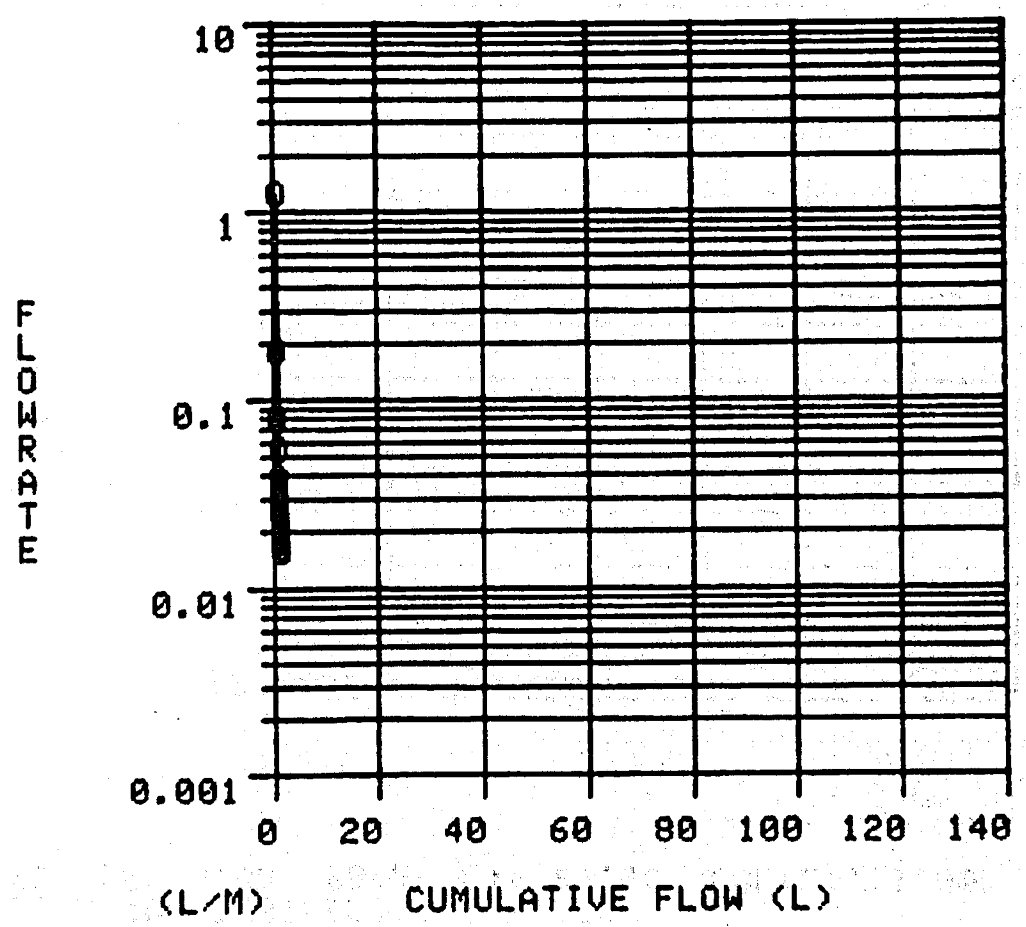


399

SPR MEMBRANE FILTRATION TEST DATA RUN:25C
DATE: 30 JAN 79 PSIG: 50 FILTER: 8.0M SS(MG/L): 23.9 VOL(L): 1.4

RAW WEAK BRINE PONDOUT

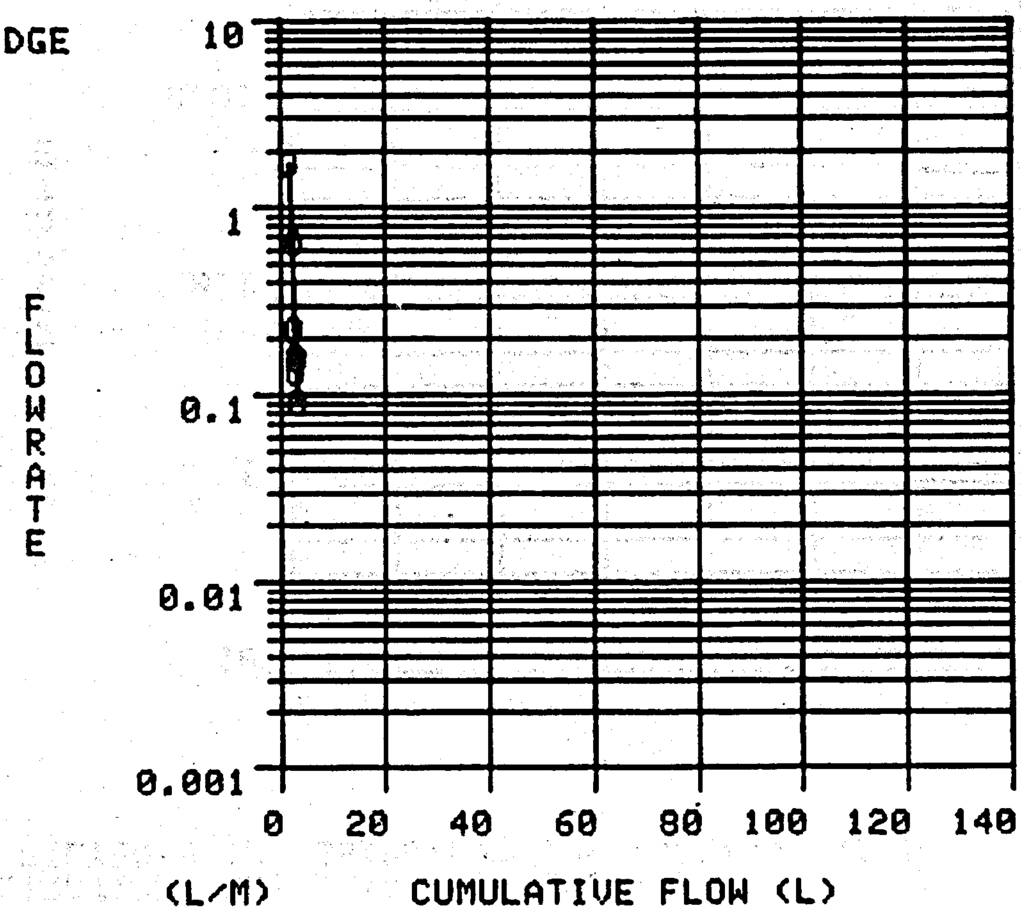
LITRES	MINS	L/MIN
0.500	0.40	1.250
0.600	0.95	0.182
0.700	2.20	0.080
0.800	4.00	0.056
0.850	5.50	0.033
0.900	6.80	0.038
0.950	8.40	0.031
1.000	10.10	0.029
1.050	12.00	0.026
1.100	14.20	0.023
1.150	16.40	0.023
1.200	19.00	0.019
1.250	21.60	0.019
1.300	24.40	0.018
1.350	27.40	0.017
1.400	30.50	0.016



SPR MEMBRANE FILTRATION TEST DATA RUN:29C
DATE: 31 JAN 79 PSIG:14 FILTER: 8.0M SS(MG/L): 2.28 VOL(L): 3.2

CUNO 5UM PREFILTERED CARTRIDGE

LITRES	MINS	L/MIN
1.712	1.00	1.712
2.357	2.00	0.645
2.581	3.00	0.224
2.742	4.00	0.161
2.875	5.00	0.133
3.000	5.80	0.156
3.200	8.00	0.091

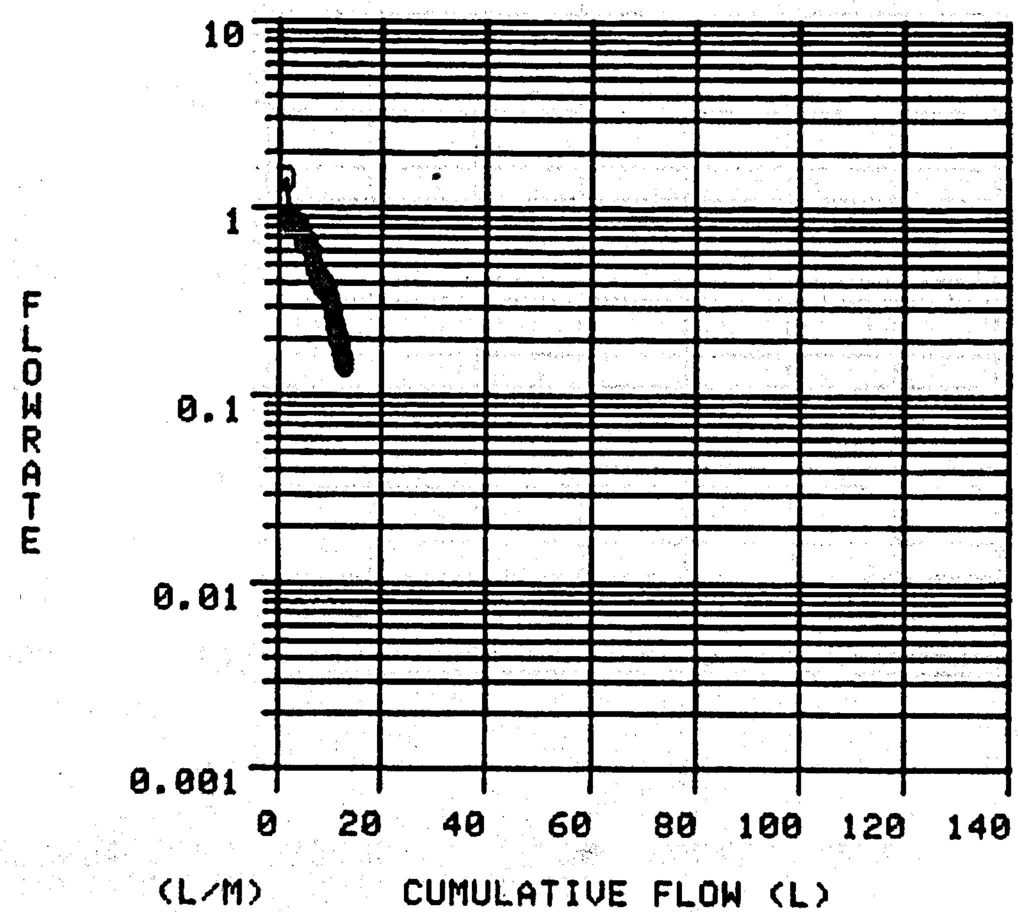


SPR MEMBRANE FILTRATION TEST DATA RUN:29C-2

DATE: 31 JAN 79 PSIG: 14 FILTER:8.0M SS(MG/L): .29 VOL(L): 12.9

COL D: 4 PPM 3340

LITRES	MINS	L/MIN
1.428	1.00	1.428
2.298	2.00	0.870
3.115	3.00	0.817
3.918	4.00	0.803
4.628	5.00	0.710
5.296	6.00	0.668
5.943	7.00	0.647
6.516	8.00	0.573
7.012	9.00	0.496
7.460	10.00	0.448
7.875	11.00	0.415
8.266	12.00	0.391
8.668	13.00	0.402
9.057	14.00	0.389
9.422	15.00	0.365
9.769	16.00	0.347
10.091	17.00	0.322
10.379	18.00	0.288
10.647	19.00	0.268
10.899	20.00	0.252
11.137	21.00	0.238
11.359	22.00	0.222
11.570	23.00	0.211
11.770	24.00	0.200



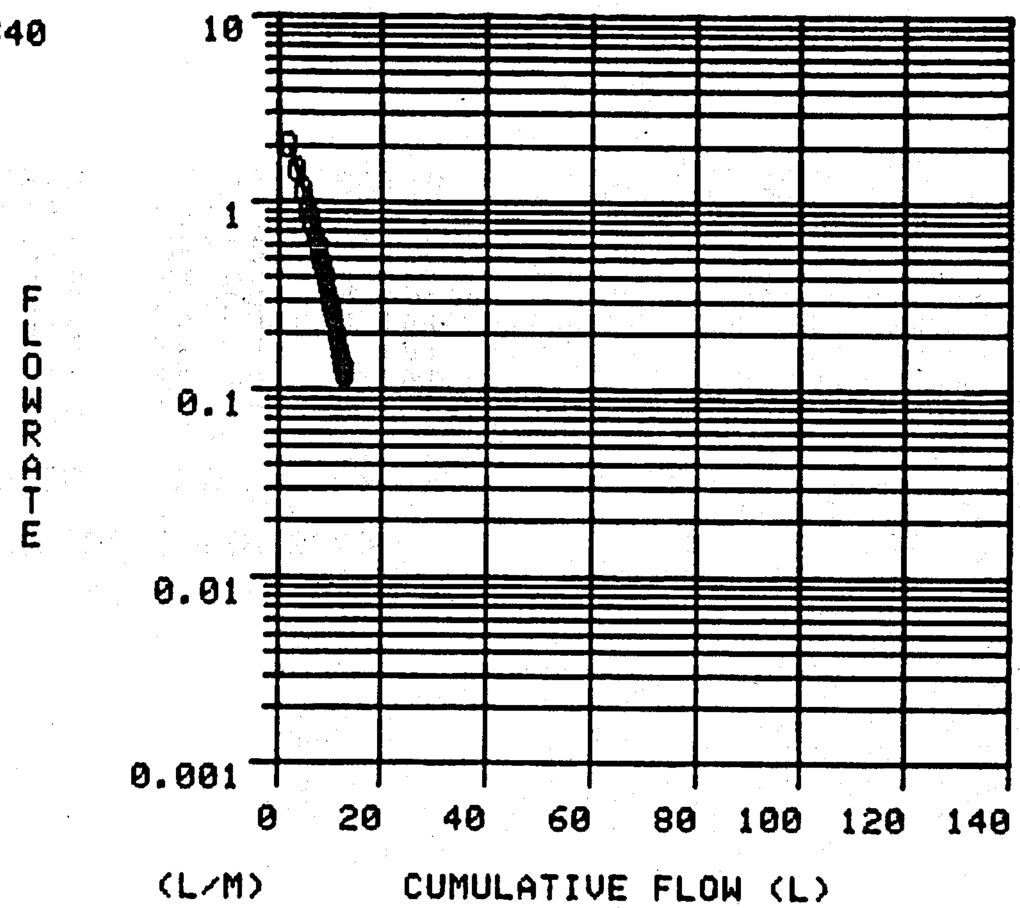
COL D: 4 PPM 3340

LITRES	MINS	L/MIN
11.770	24.00	0.290
11.961	25.00	0.191
12.142	26.00	0.181
12.315	27.00	0.173
12.483	28.00	0.168
12.642	29.00	0.159
12.797	30.00	0.155
12.945	31.00	0.148

SPR MEMBRANE FILTRATION TEST DATA RUN:31C
DATE: 31 JAN 79 PSIG: 16 FILTER:8.0M SS(MG/L): .33 VOL(L): 12.96

COL D: WEAK BRINE 2.5PPM 3340

LITRES	MINS	L/MIN
2.020	1.00	2.020
3.528	2.00	1.508
4.695	3.00	1.167
5.635	4.00	0.940
6.402	5.00	0.767
7.052	6.00	0.650
7.632	7.00	0.580
8.128	8.00	0.496
8.578	9.00	0.450
8.977	10.00	0.399
9.345	11.00	0.368
9.663	12.00	0.318
9.956	13.00	0.293
10.231	14.00	0.275
10.487	15.00	0.256
10.728	16.00	0.241
10.945	17.00	0.217
11.147	18.00	0.202
11.340	19.00	0.193
11.522	20.00	0.182
11.696	21.00	0.174
11.862	22.00	0.166
12.020	23.00	0.158
12.172	24.00	0.152



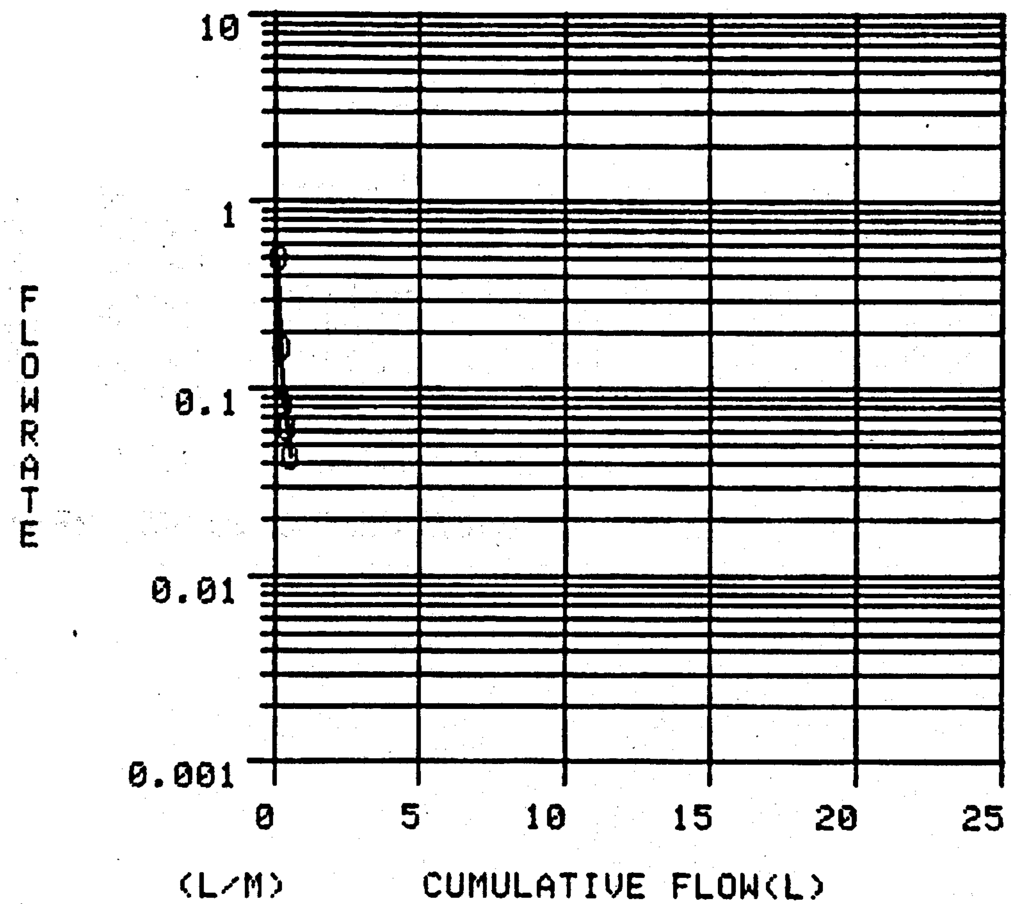
COL D: WEAK BRINE 2.5PPM 3340

LITRES	MINS	L/MIN
12.172	24.00	0.152
12.315	25.00	0.143
12.454	26.00	0.139
12.588	27.00	0.134
12.713	28.00	0.125
12.842	29.00	0.129
12.964	30.00	0.122

SPR MEMBRANE FILTRATION TEST DATA RUN: 32C
DATE: 1 FEB 79 PSIG: 50 FILTER:0.4N SS(MG/L):18.6 VOL(L): .5

RAW WEAK BRINE PONDOUT

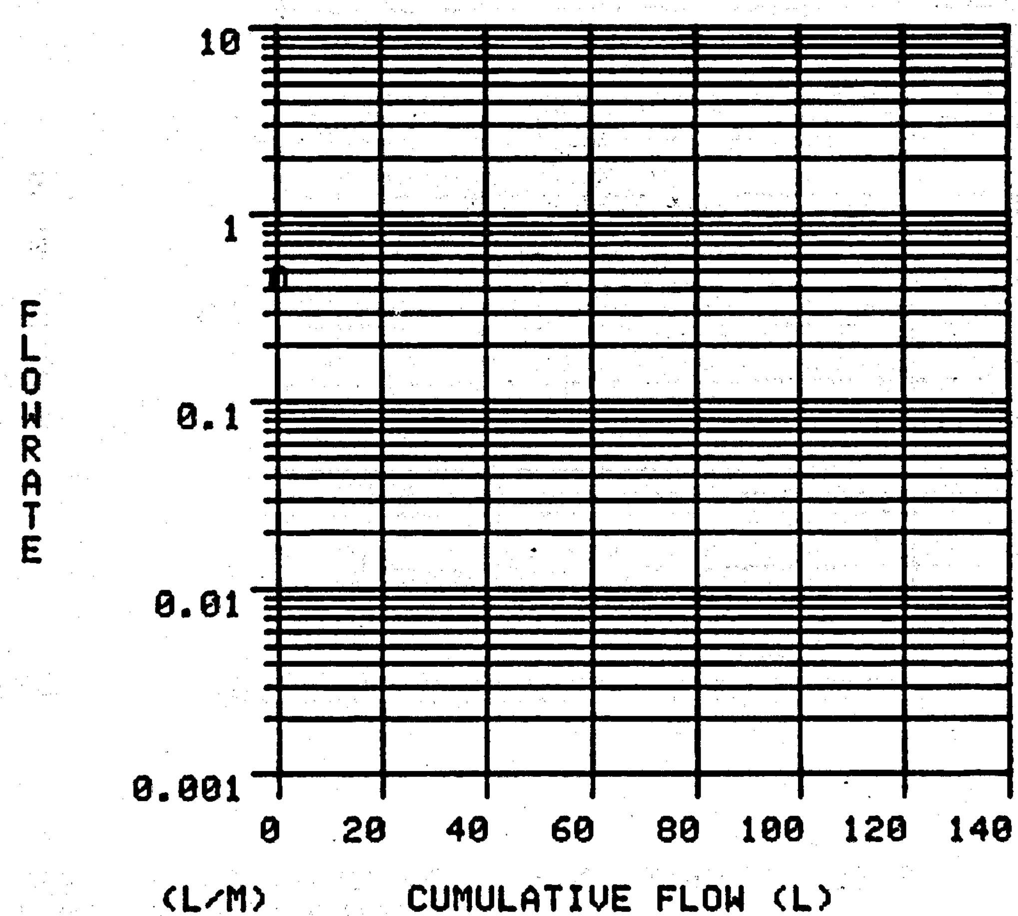
LITRES	MINS	L/MIN
0.100	0.20	0.500
0.200	0.80	0.167
0.300	2.00	0.083
0.400	3.60	0.063
0.500	5.90	0.043



SPR MEMBRANE FILTRATION TEST DATA RUN:33C
DATE: 1 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L): 2.19 VOL(L): .32

RAW WEAK BRINE PONDOUT

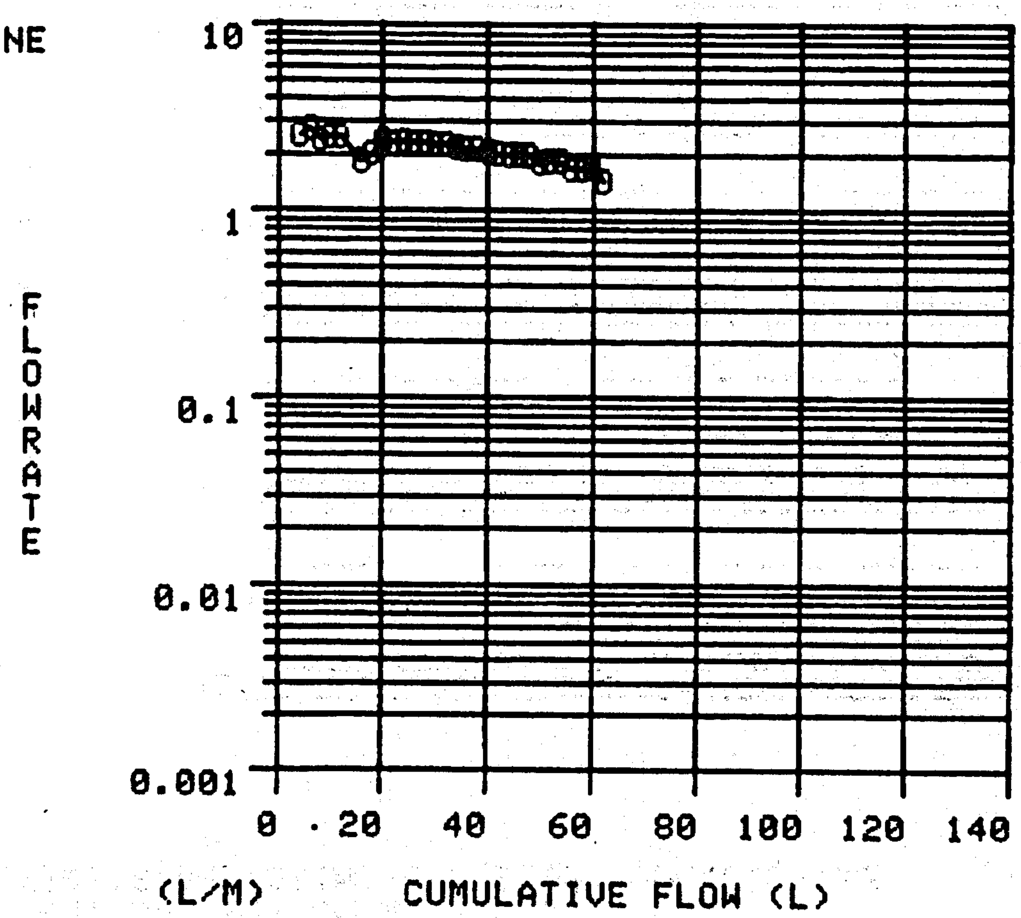
LITRES	MINS	L/MIN
0.320	0.70	0.457



SPR MEMBRANE FILTRATION TEST DATA RUN:36CJ
DATE: 2 FEB 79 PSIG: 8 FILTER:10.0N SS(MG/L): .008 VOL(L): 63.6

COL D: PREFILTERED WEAK BRINE

LITRES	MINS	L/MIN
4.000	1.57	2.548
6.000	2.30	2.740
8.000	3.13	2.410
10.000	3.93	2.500
12.000	4.72	2.532
16.000	6.16	1.869
18.000	7.15	2.020
20.000	7.98	2.410
22.000	8.83	2.353
24.000	9.67	2.381
26.000	10.52	2.353
28.000	11.38	2.326
30.000	12.25	2.299
32.000	13.13	2.273
34.000	14.03	2.222
36.000	14.95	2.174
38.000	15.88	2.151
40.000	16.83	2.105
42.000	17.82	2.020
44.000	18.82	2.000
46.000	19.83	1.980
48.000	20.83	2.000
50.000	21.93	1.818
52.000	23.00	1.869



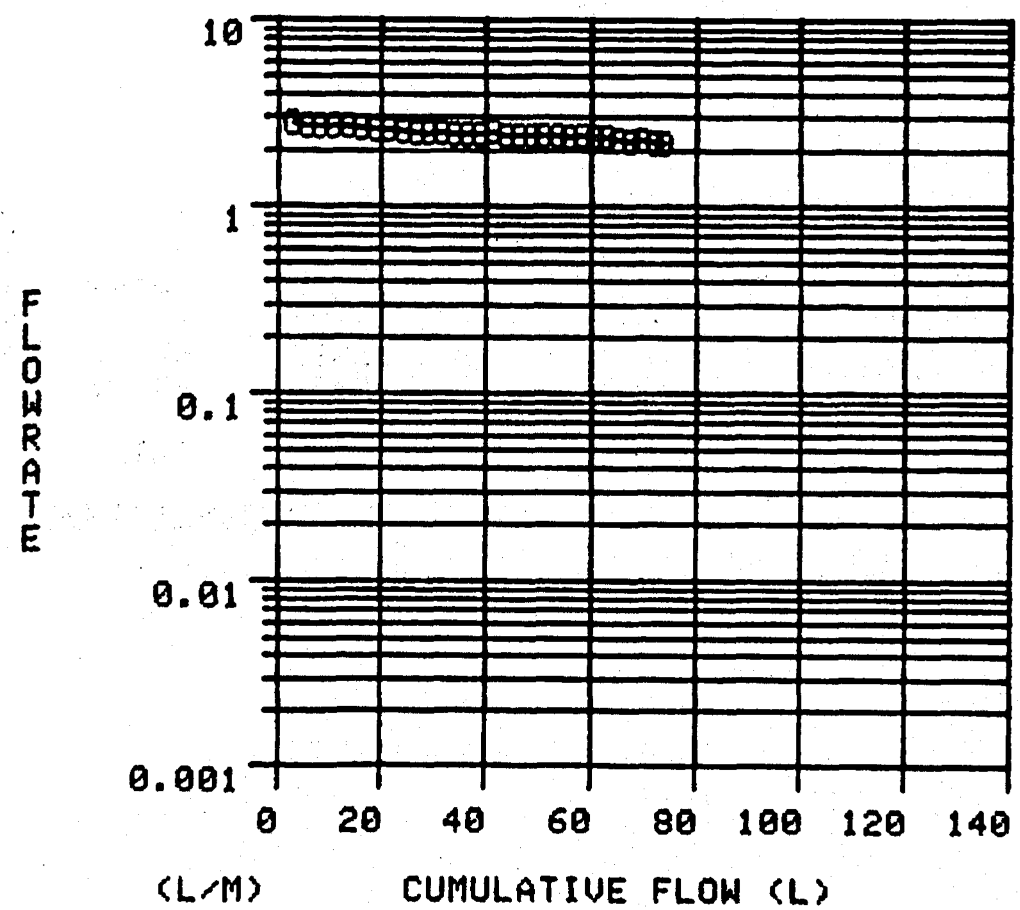
COL D: PREFILTERED WEAK BRINE

LITRES	MINS	L/MIN
52.000	23.00	1.869
54.000	24.08	1.852
56.000	25.27	1.681
58.000	26.45	1.695
60.000	27.60	1.739
62.000	28.97	1.460

SPR MEMBRANE FILTRATION TEST DATA RUN:37C
DATE: 1 FEB 79 PSIG: 8 FILTER:10.0N SS(MG/L): .007 VOL(L): 74.4

COL A: CHLOROX + 2PPM 3340

LITRES	MINS	L/MIN
2.797	1.00	2.797
5.487	2.00	2.690
8.189	3.00	2.702
10.898	4.00	2.709
13.585	5.00	2.687
16.228	6.00	2.643
18.835	7.00	2.607
21.439	8.00	2.604
23.998	9.00	2.559
26.523	10.00	2.525
29.012	11.00	2.489
31.505	12.00	2.493
33.989	13.00	2.484
36.462	14.00	2.473
38.932	15.00	2.470
41.468	16.00	2.536
43.878	17.00	2.410
46.313	18.00	2.435
48.737	19.00	2.424
51.147	20.00	2.410
53.562	21.00	2.415
55.953	22.00	2.391
58.377	23.00	2.424
60.738	24.00	2.361



COL A: CHLOROX + 2PPM 3340

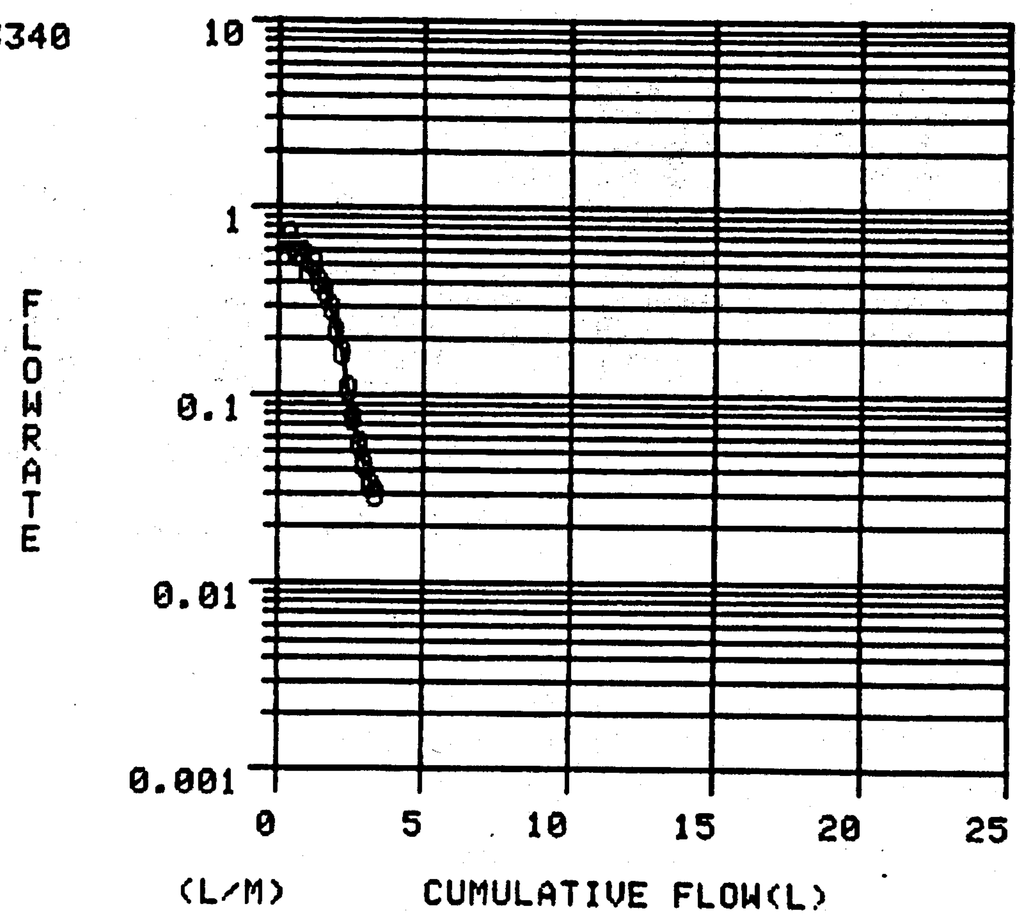
LITRES	MINS	L/MIN
60.738	24.00	2.361
63.098	25.00	2.360
65.377	26.00	2.279
67.639	27.00	2.262
69.928	28.00	2.289
72.153	29.00	2.225
74.358	30.00	2.205

SPR MEMBRANE FILTRATION TEST DATA RUN:38C

DATE: 1 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .33 VOL(L): 3.35

COL A:5 PPM CLOROX+ 2 PPM 3340

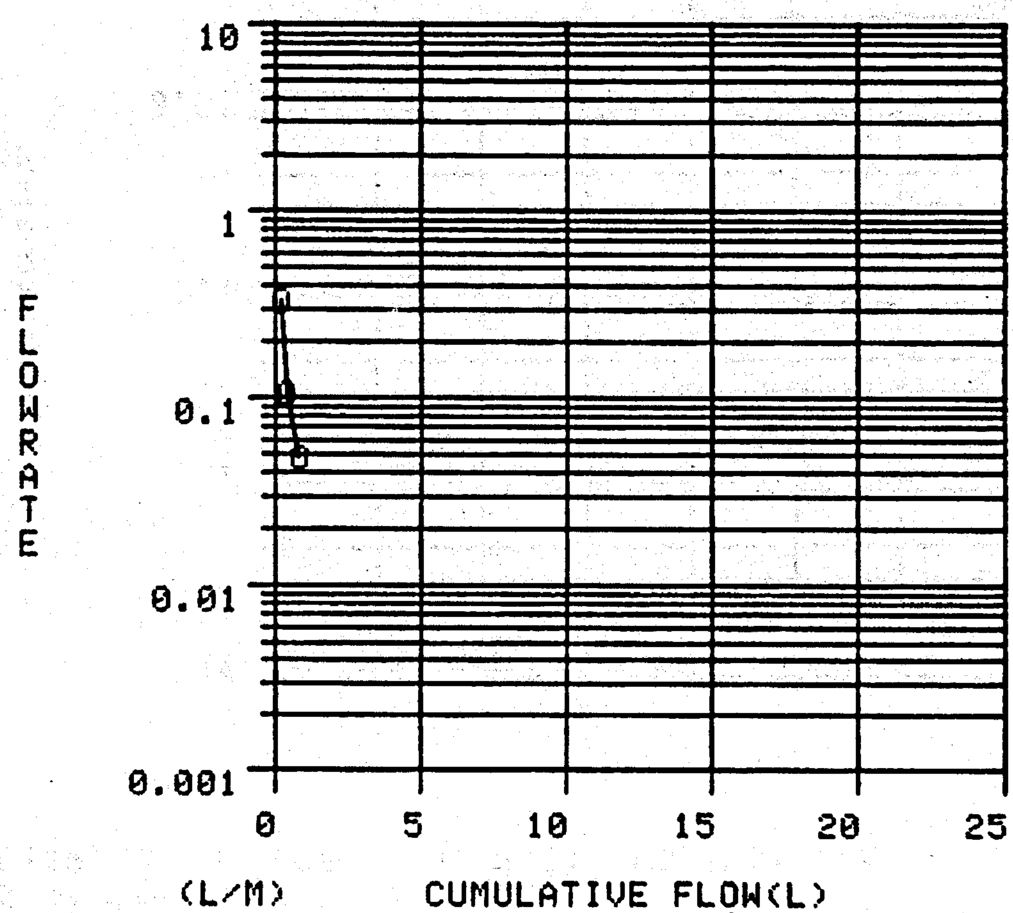
LITRES	MINS	L/MIN
0.200	0.35	0.571
0.400	0.63	0.714
0.600	0.98	0.571
0.800	1.33	0.571
1.000	1.77	0.455
1.200	2.17	0.500
1.400	2.67	0.400
1.600	3.23	0.357
1.800	3.92	0.290
2.000	4.83	0.220
2.200	6.02	0.168
2.400	7.87	0.108
2.600	10.53	0.075
2.800	14.17	0.055
3.000	18.90	0.042
3.200	24.93	0.033
3.350	30.00	0.030



SPR MEMBRANE FILTRATION TEST DATA RUN: 41C
DATE: 2 FEB 79 PSIG: 50 FILTER: .45M SS(MG/L): 23.62 VOL(L):.05

RAW WEAK BRINE PONDOUT

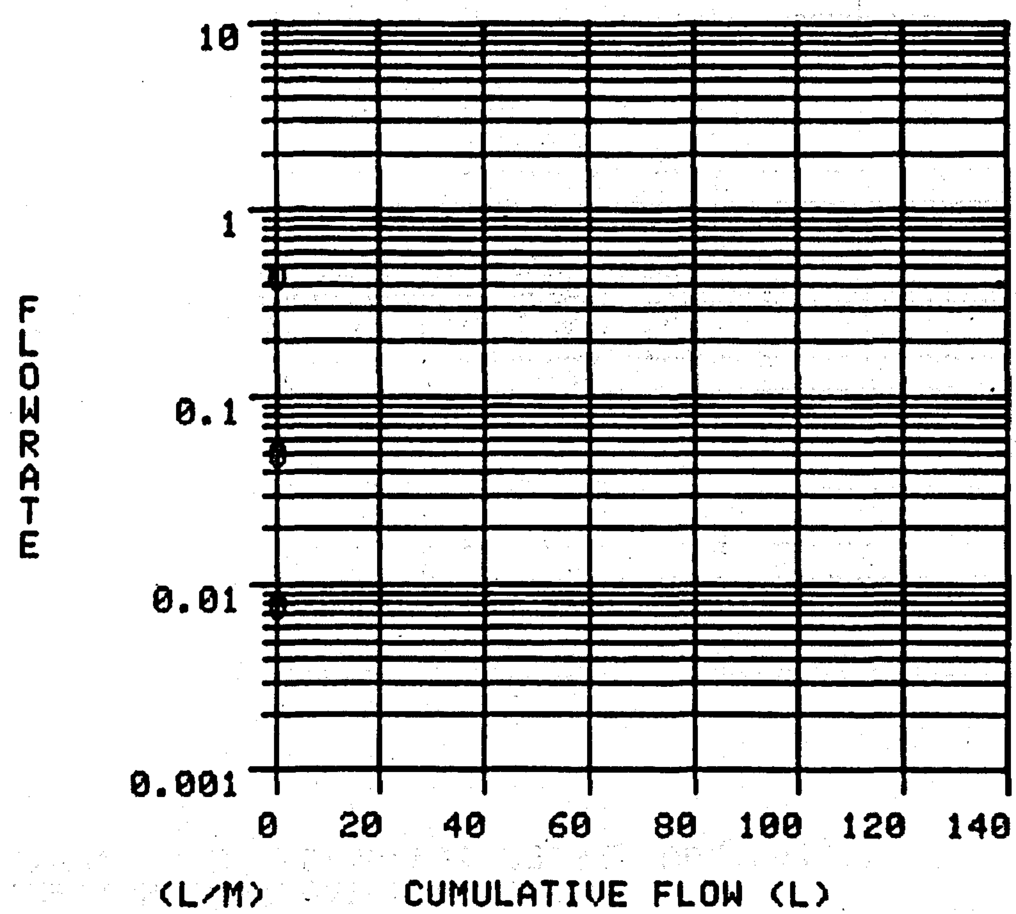
LITRES	MINS	L/MIN
0.200	0.60	0.333
0.400	2.50	0.105
0.800	10.80	0.048



SPR MEMBRANE FILTRATION TEST DATA RUN:42C
DATE: 2 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L): 7.31 VOL(L): .26

RAW WEAK BRINE PONDOUT

LITRES	MINS	L/MIN
0.220	0.50	0.440
0.240	0.90	0.050
0.260	3.50	0.008

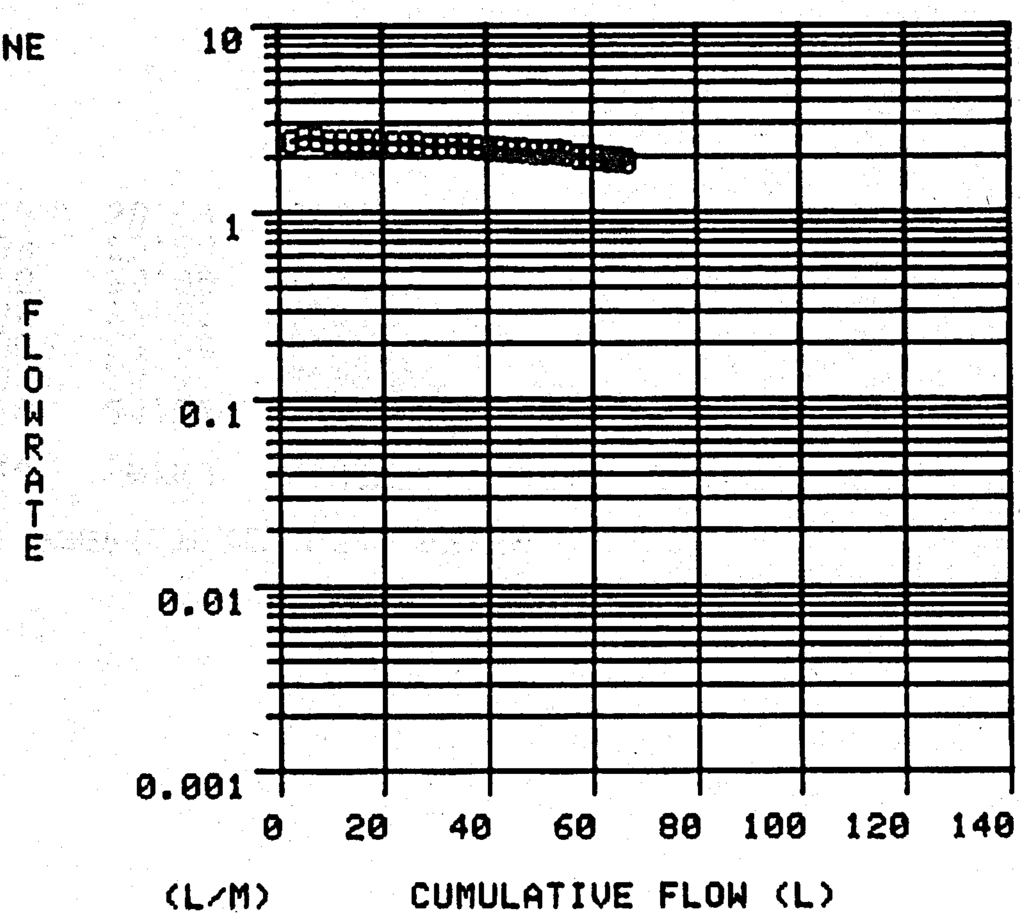


414

SPR MEMBRANE FILTRATION TEST DATA RUN:48C
DATE: 2 FEB 79 PSIG: 8 FILTER:10.0N SS(MG/L): .01 VOL(L): 67.1

COL D: PREFILTERED WEAK BRINE

LITRES	MINS	L/MIN
2.423	1.00	2.423
5.003	2.00	2.580
7.513	3.00	2.510
9.935	4.00	2.422
12.358	5.00	2.423
14.758	6.00	2.400
17.163	7.00	2.405
19.563	8.00	2.400
21.938	9.00	2.375
24.305	10.00	2.367
26.685	11.00	2.380
28.988	12.00	2.303
31.283	13.00	2.295
33.595	14.00	2.312
35.888	15.00	2.293
38.138	16.00	2.250
40.365	17.00	2.227
42.573	18.00	2.208
44.752	19.00	2.179
46.932	20.00	2.180
49.052	21.00	2.120
51.165	22.00	2.113
53.282	23.00	2.117
55.378	24.00	2.096



COL D: PREFILTERED WEAK BRINE

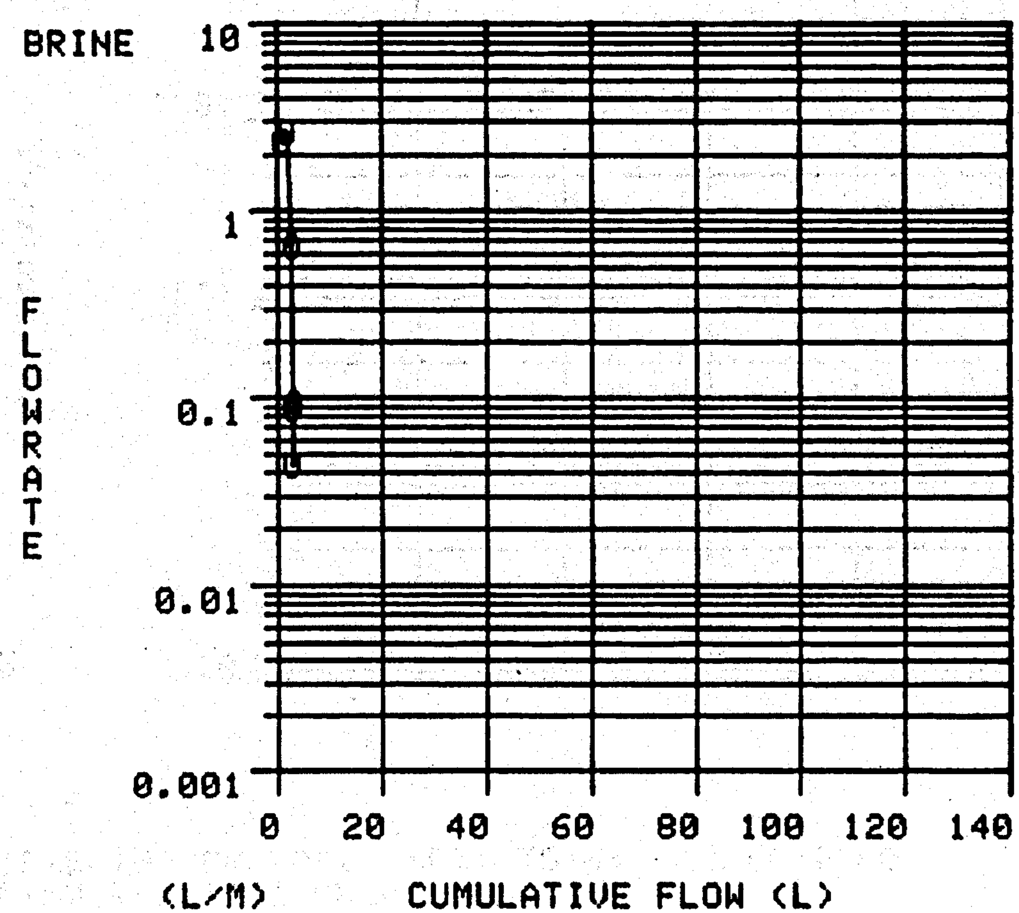
LITRES	MINS	L/MIN
55.378	24.00	2.096
57.385	25.00	2.007
59.383	26.00	1.998
61.338	27.00	1.955
63.275	28.00	1.937
65.189	29.00	1.914
67.068	30.00	1.879

SPR MEMBRANE FILTRATION TEST DATA RUN:56C

DATE: 3 FEB 79 PSIG: 10 FILTER:10.0N SS(MG/L): .24 VOL(L): 2.97

10% FILTRATE LAKE + 90% RAW BRINE

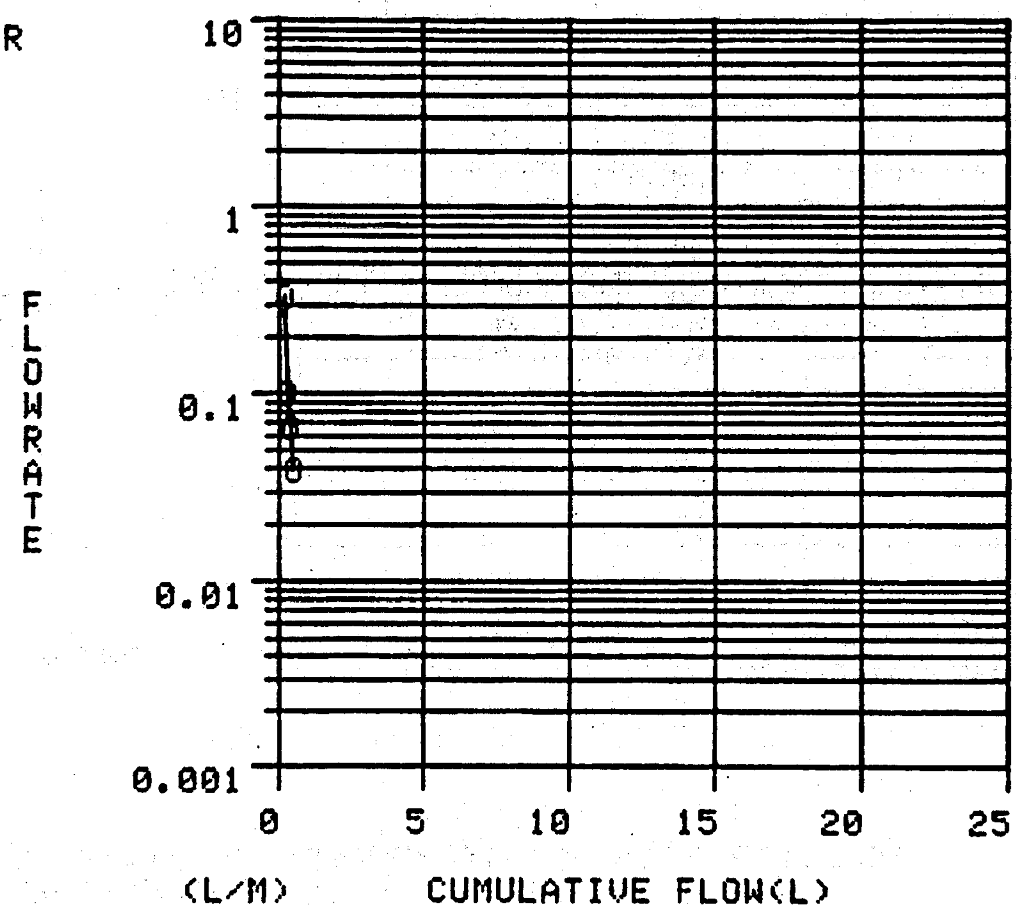
LITRES	MINS	L/MIN
1.000	0.42	2.381
2.000	0.80	2.632
2.700	1.87	0.654
2.800	3.00	0.088
2.900	5.25	0.044
2.970	6.00	0.093



SPR MEMBRANE FILTRATION TEST DATA RUN: 53C
DATE: 3 FEB 79 PSIG: 50 FILTER:0.45M SS(MG/L): 10.44 VOL(L):.46

90% RAW BRINE+10% LAKE WATER

LITRES	MINS	L/MIN
0.200	0.60	0.333
0.300	1.60	0.100
0.400	3.10	0.067
0.475	5.00	0.039



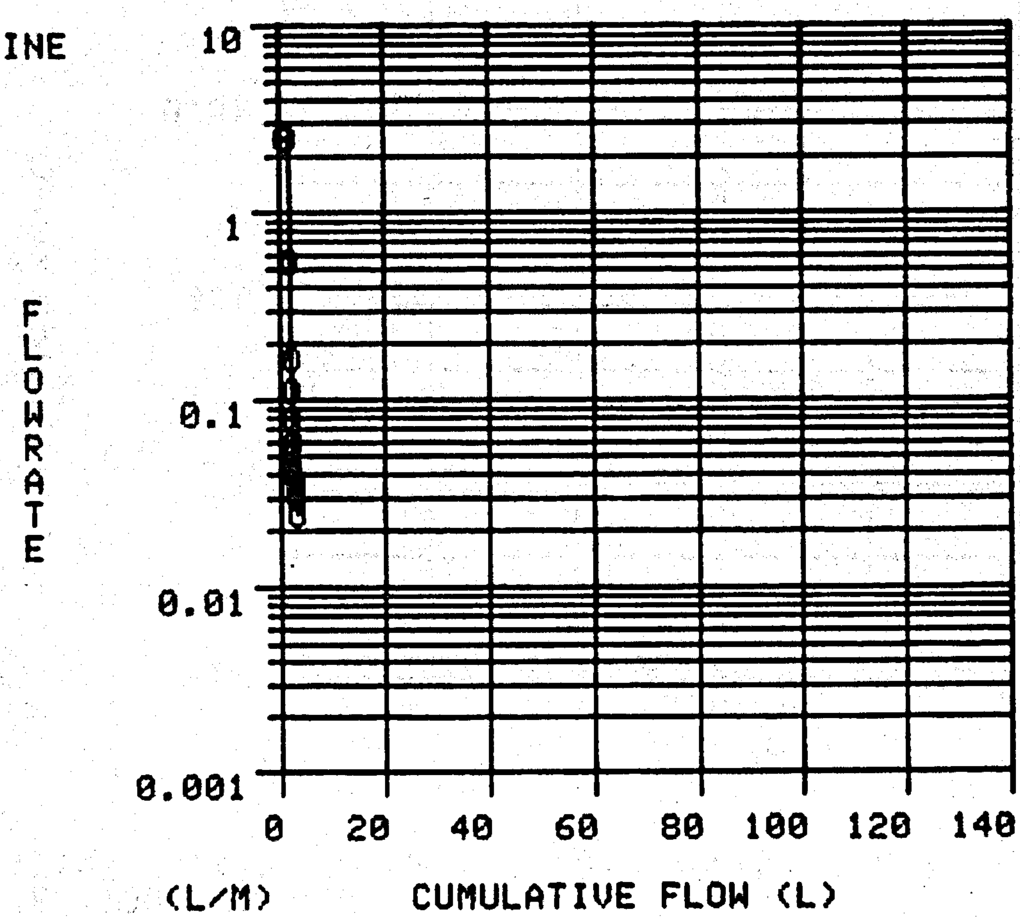
418

SPR MEMBRANE FILTRATION TEST DATA RUN:54C

DATE: 3 FEB 79 PSIG: 8 FILTER:10.0N SS(MG/L): .25 VOL(L): 3.21

10% LAKE WATER + 90% RAW BRINE

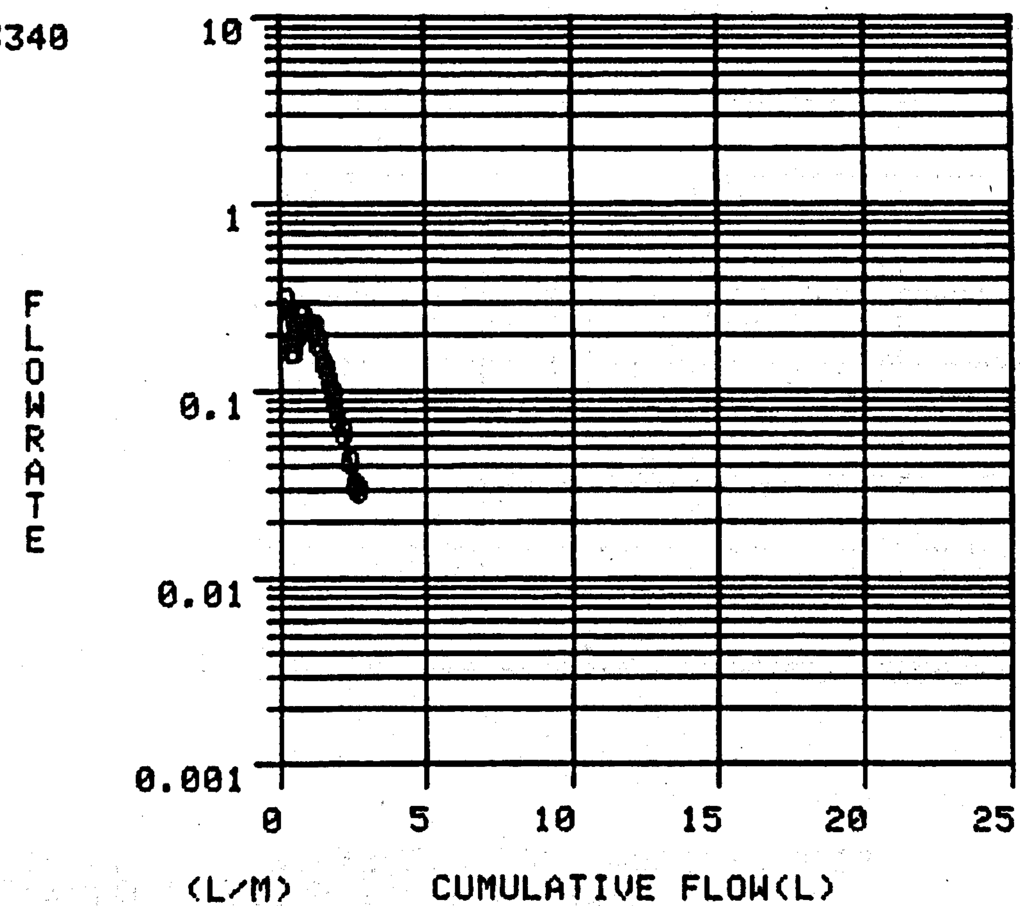
LITRES	MINS	L/MIN
0.500	0.20	2.500
1.000	0.40	2.500
1.500	0.60	2.500
2.000	1.50	0.556
2.100	2.10	0.167
2.200	3.00	0.111
2.300	4.30	0.077
2.400	6.00	0.059
2.500	8.30	0.043
2.600	10.80	0.040
2.700	13.50	0.037
2.800	16.40	0.034
2.900	19.50	0.032
3.000	22.80	0.030
3.100	25.50	0.037
3.211	30.00	0.025



SPR MEMBRANE FILTRATION TEST DATA RUN:58C
DATE: 3 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .50 VOL(L): 2.095

COL C:.3 PPM 507C + 2 PPM 3340

LITRES	MINS	L/MIN
0.200	0.65	0.308
0.300	1.10	0.222
0.400	1.70	0.167
0.500	2.30	0.167
0.600	2.80	0.200
0.700	3.20	0.250
0.800	3.60	0.250
0.900	4.05	0.222
1.000	4.50	0.222
1.100	4.95	0.222
1.200	5.40	0.222
1.300	5.95	0.182
1.400	6.50	0.182
1.500	7.20	0.143
1.600	7.95	0.133
1.700	8.85	0.111
1.800	9.87	0.098
1.900	11.00	0.088
2.000	12.40	0.071
2.200	15.70	0.061
2.400	20.45	0.042
2.600	26.80	0.031
2.695	30.00	0.030

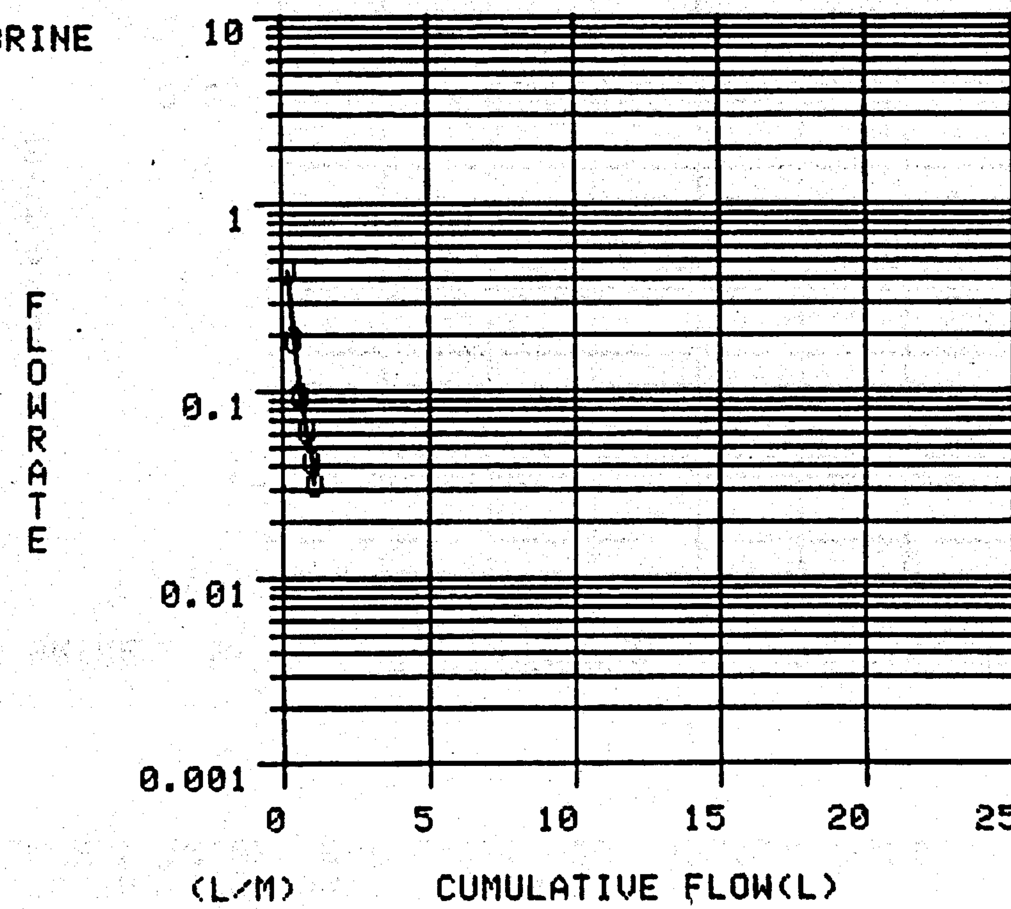


SPR MEMBRANE FILTRATION TEST DATA RUN: 59C

DATE: 3 FEB 79 PSIG: 50 FILTER:0.45M SS(MG/L): 5.76 VOL(L):1.1

10% FILTRATE LAKE+90% RAW BRINE

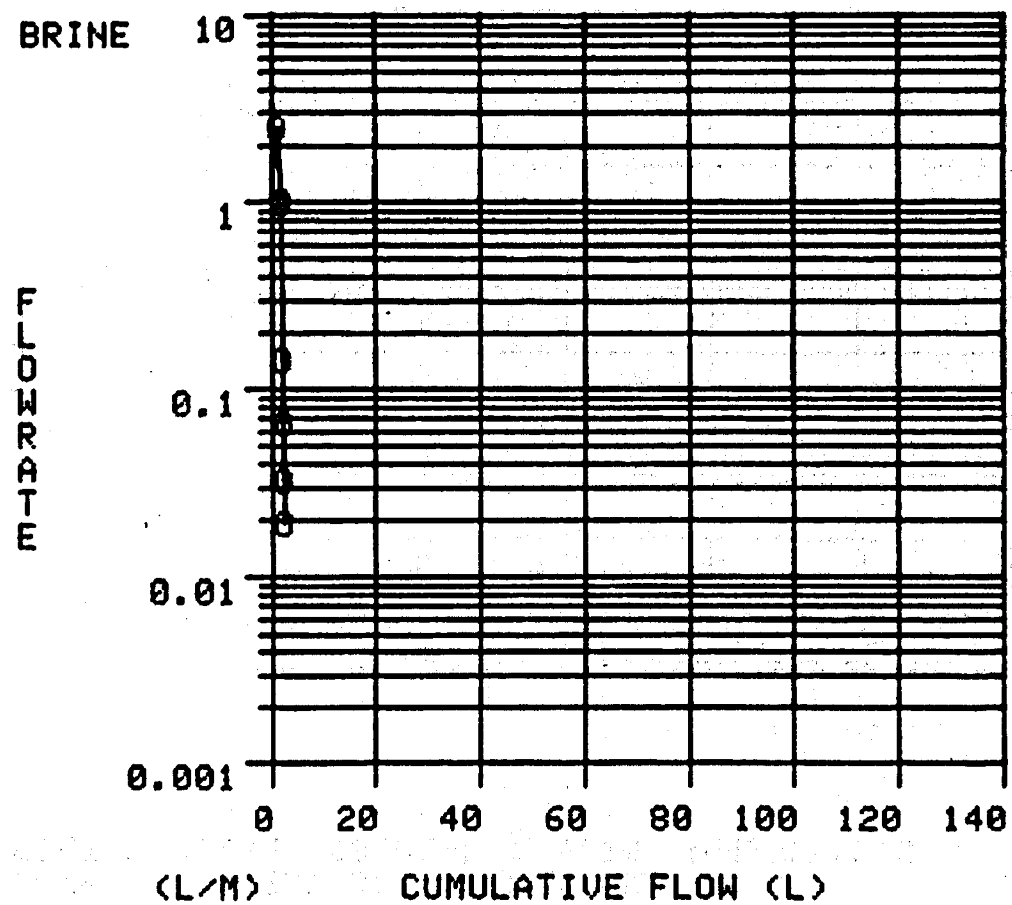
LITRES	MINS	L/MIN
0.200	0.45	0.444
0.400	1.50	0.190
0.600	3.60	0.095
0.800	6.80	0.063
1.000	11.50	0.043
1.100	14.60	0.032



SPR MEMBRANE FILTRATION TEST DATA RUN:60C
DATE: 3 FEB 79 PSIG: 10 FILTER: 10.0N SS(MG/L): .36 VOL(L): 2.26

10% FILTRATE LAKE + 90% RAW BRINE

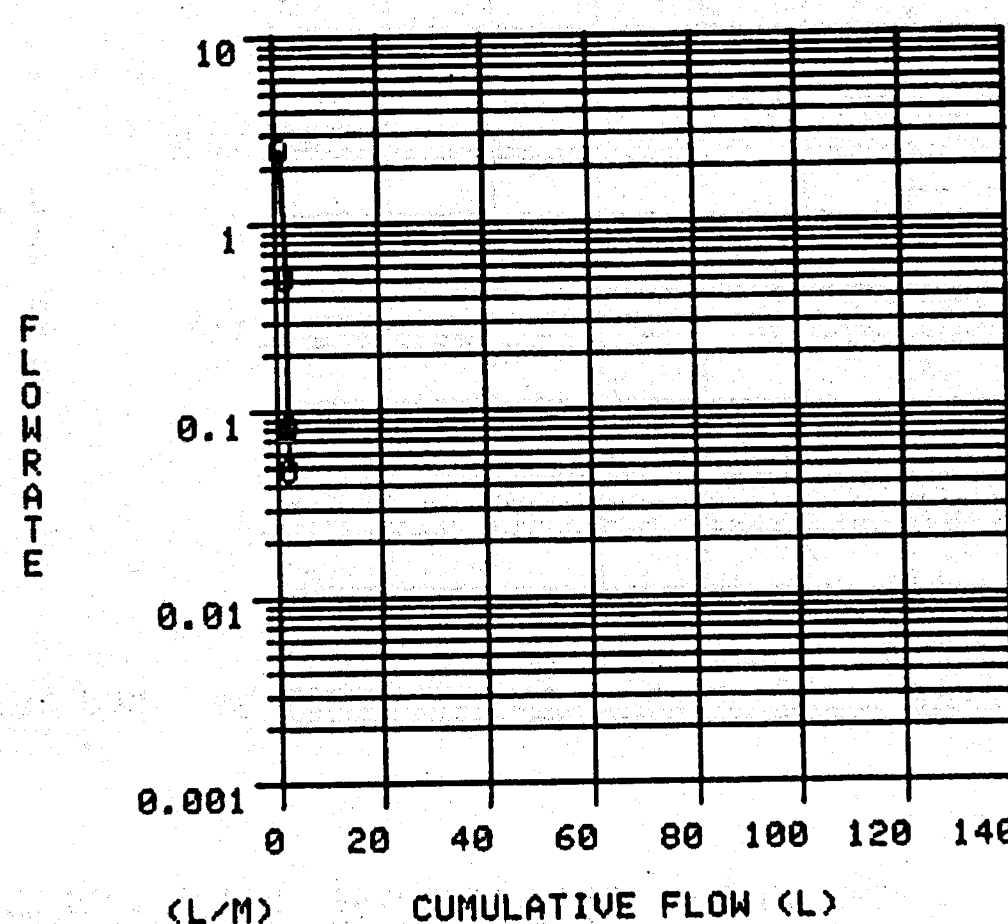
LITRES	MINS	L/MIN
1.000	0.40	2.500
1.800	1.20	1.000
2.000	2.60	0.143
2.100	4.10	0.067
2.200	7.15	0.033
2.255	10.00	0.019



SPR MEMBRANE FILTRATION TEST DATA RUN:61C
DATE: 3 FEB 79 PSIG: 10 FILTER:10.0N SS(MG/L): .35 VOL(L): 2.3

90% BRINE+ 10% SETTLED LAKE

LITRES	MINS	L/MIN
1.000	0.40	2.500
2.000	2.30	0.526
2.100	3.50	0.083
2.200	5.53	0.049

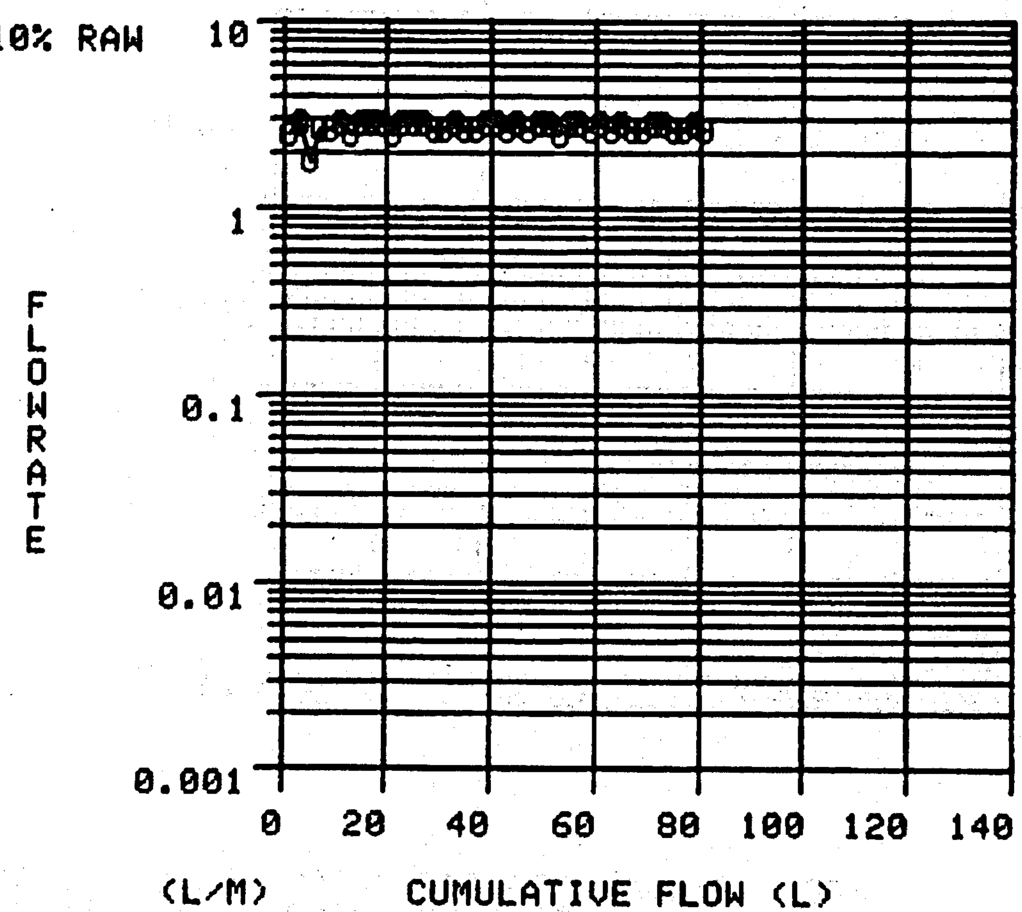


SPR MEMBRANE FILTRATION TEST DATA RUN:64C

DATE: 3 FEB 79 PSIG: 10 FILTER: 10.0N SS(MG/L): .01 VOL(L): 81

1UM CUNO PREFILTER: 90% + 10% RAW

LITRES	MINS	L/MIN
1.000	0.40	2.500
3.000	1.10	2.857
5.000	2.20	1.818
7.000	2.95	2.667
9.000	3.70	2.667
11.000	4.40	2.857
13.000	5.20	2.500
15.000	5.90	2.857
17.000	6.60	2.857
19.000	7.30	2.857
21.000	8.10	2.500
23.000	8.80	2.857
25.000	9.50	2.857
27.000	10.20	2.857
29.000	10.95	2.667
31.000	11.70	2.667
33.000	12.40	2.857
35.000	13.15	2.667
37.000	13.90	2.667
39.000	14.60	2.857
41.000	15.30	2.857
43.000	16.05	2.667
45.000	16.75	2.857
47.000	17.50	2.667



1UM CUNO PREFILTER: 90% + 10% RAW

LITRES	MINS	L/MIN
47.000	17.50	2.667
49.000	18.20	2.857
51.000	18.90	2.857
53.000	19.70	2.500
55.000	20.40	2.857
57.000	21.10	2.857
59.000	21.85	2.667
61.000	22.55	2.857
63.000	23.30	2.667
65.000	24.00	2.857
67.000	24.75	2.667
69.000	25.50	2.667
71.000	26.20	2.857
73.000	26.90	2.857
75.000	27.65	2.667
77.000	28.40	2.667
79.000	29.10	2.857
81.000	29.85	2.667

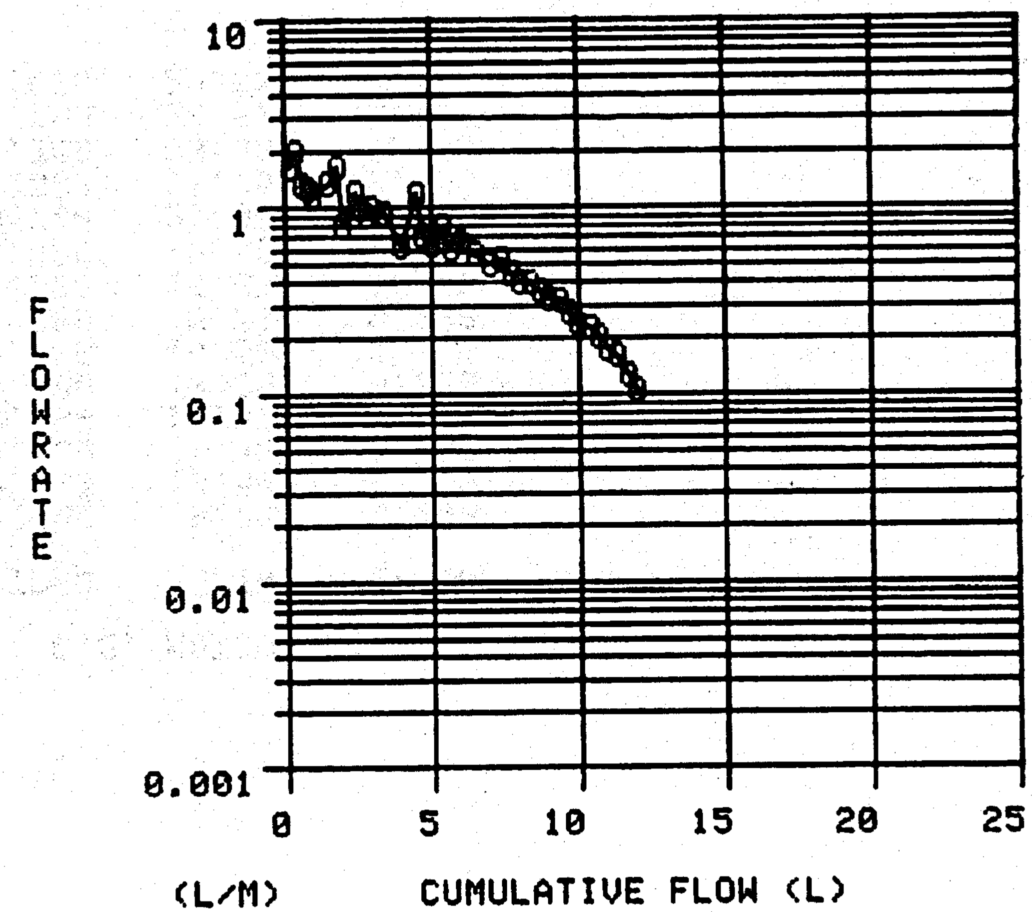
APPENDIX XI

EXPERIMENTAL DATA FROM THE VENDOR FILTER INJECTION TESTS PERFORMED AT BAYOU CHOCTAW

SPR MEMBRANE FILTRATION TEST DATA RUN:M1
DATE: 29 JAN 79 PSIG:50 FILTER:0.45M SS(MG/L):.23 VOL(L): 12

C.E. NATCO--M1

LITRES	MINS	L/MIN
0.200	0.12	1.667
0.400	0.22	2.000
0.600	0.37	1.333
0.800	0.53	1.250
1.000	0.70	1.176
1.500	1.07	1.351
1.800	1.25	1.667
2.000	1.50	0.800
2.400	1.83	1.212
2.600	2.03	1.000
2.800	2.25	0.909
3.000	2.45	1.000
3.400	2.88	0.930
4.000	3.83	0.632
4.500	4.25	1.190
4.700	4.53	0.714
5.000	5.00	0.638
5.400	5.50	0.800
5.700	6.00	0.600
6.000	6.45	0.667
6.500	7.33	0.568
7.000	8.33	0.500
7.400	9.08	0.533
7.700	9.75	0.448



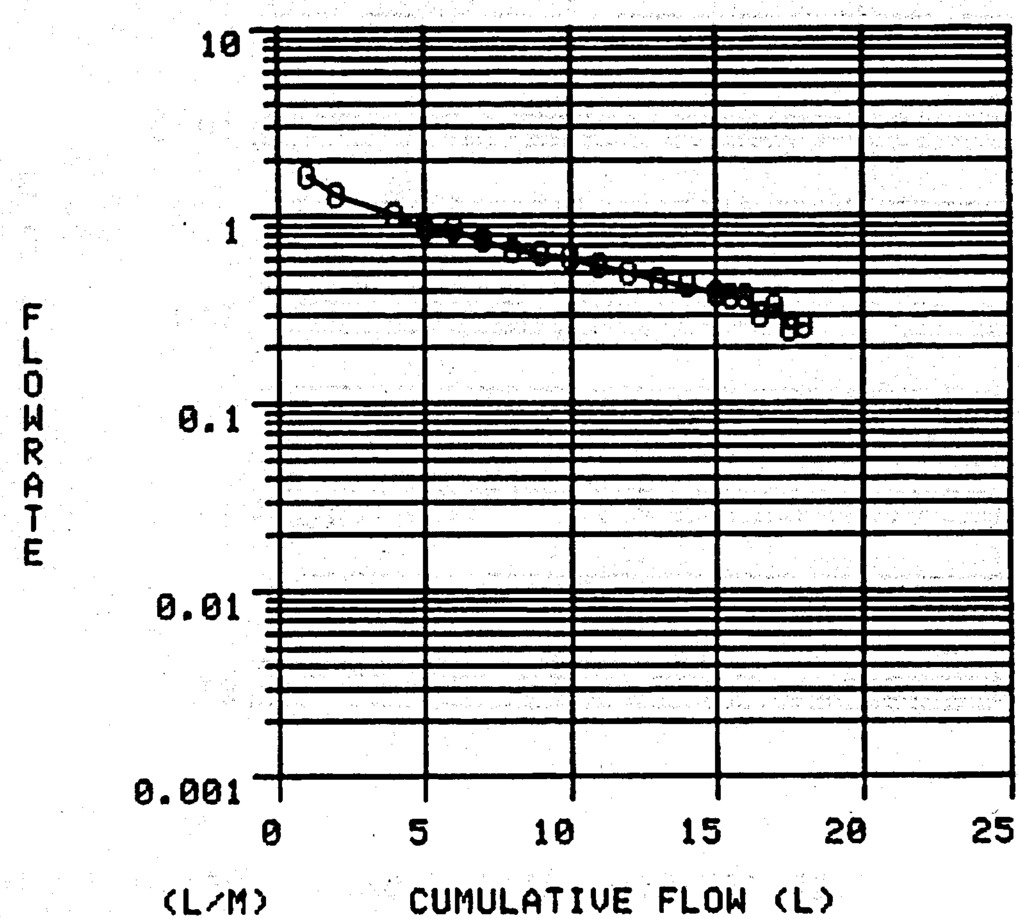
C.E. NATCO--M1

LITRES	MINS	L/MIN
7.700	9.75	0.448
8.000	10.50	0.400
8.400	11.50	0.400
8.700	12.33	0.361
9.000	13.25	0.326
9.400	14.50	0.320
9.700	15.58	0.278
10.000	16.83	0.240
10.400	18.58	0.229
10.700	20.05	0.204
11.000	21.75	0.176
11.300	23.58	0.164
11.700	26.67	0.129
12.000	29.50	0.106

SPR MEMBRANE FILTRATION TEST DATA RUN:29
DATE: 29 JAN 79 PSIG:50 FILTER:0.45M SS(MG/L):.20 VOL(L): 18

C.E. NATCO--29

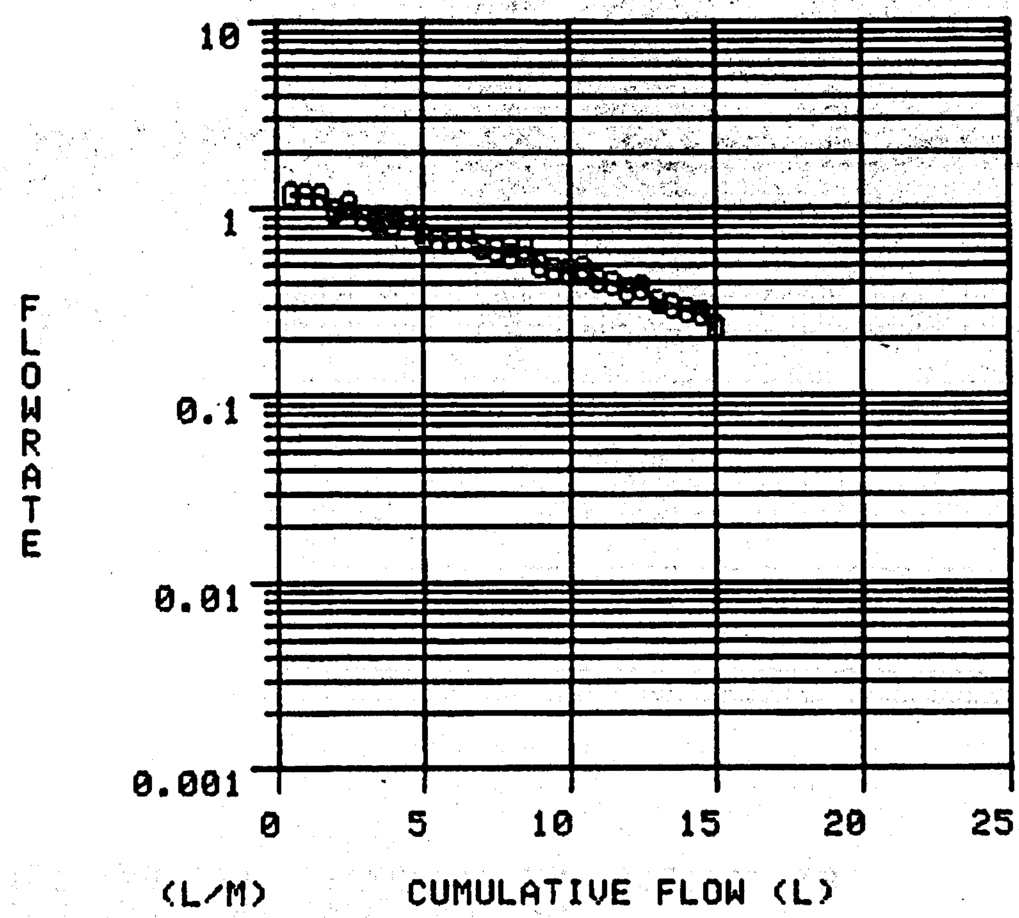
LITRES	MINS	L/MIN
1.000	0.60	1.667
2.000	1.37	1.299
4.000	3.33	1.020
5.000	4.50	0.855
6.000	5.67	0.855
7.000	7.00	0.752
8.000	8.50	0.667
9.000	10.08	0.633
10.000	11.75	0.599
11.000	13.58	0.546
12.000	15.58	0.500
13.000	17.75	0.461
14.000	20.08	0.429
15.000	22.67	0.386
15.500	24.00	0.376
16.000	25.33	0.376
16.500	27.00	0.299
17.000	28.50	0.333
17.500	30.50	0.250
18.000	32.42	0.260



SPR MEMBRANE FILTRATION TEST DATA RUN:34
DATE: 29 JAN 79 PSIG:50 FILTER:0.45M SS(MG/L):.17 VOL(L): 15.2

C.E. NATCO--34

LITRES	MINS	L/MIN
0.500	0.42	1.190
1.000	0.85	1.163
1.500	1.28	1.163
2.000	1.80	0.962
2.500	2.27	1.064
3.000	2.83	0.893
3.500	3.42	0.847
4.000	4.02	0.833
4.500	4.58	0.893
5.000	5.27	0.725
5.500	6.00	0.685
6.000	6.73	0.685
6.500	7.45	0.694
7.000	8.25	0.625
7.500	9.08	0.602
8.000	9.97	0.562
8.500	10.78	0.617
9.000	11.78	0.500
9.500	12.83	0.476
10.000	13.90	0.467
10.500	14.93	0.485
11.000	16.12	0.420
11.500	17.37	0.400
12.000	18.73	0.368



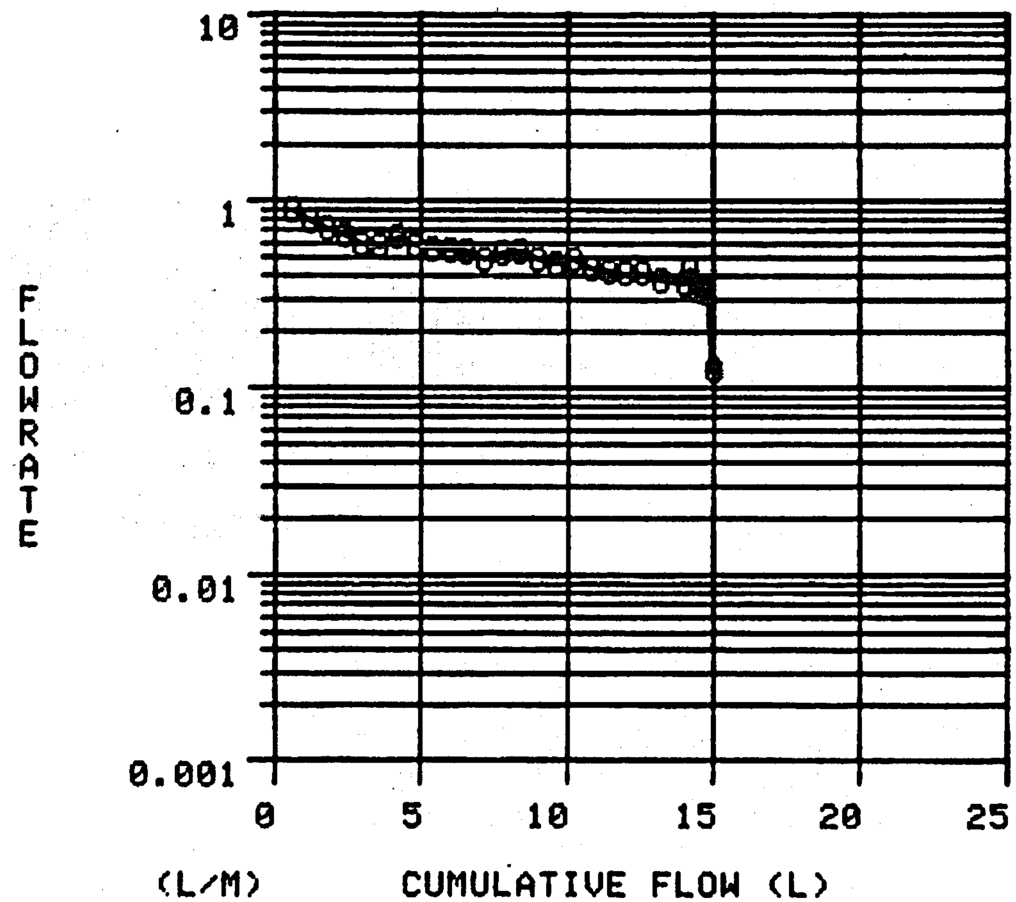
C.E. NATCO--34

LITRES	MINS	L/MIN
12.000	18.73	0.368
12.500	20.05	0.379
13.000	21.60	0.323
13.500	23.25	0.303
14.000	25.00	0.286
14.500	26.80	0.278
15.000	28.95	0.233

SPR MEMBRANE FILTRATION TEST DATA RUN:39U-40D
DATE: 30 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .16 VOL(L): 15

C.E.NATCO--39U-40D

LITRES	MINS	L/MIN
0.600	0.67	0.896
1.200	1.43	0.789
1.800	2.27	0.714
2.400	3.17	0.667
3.000	4.18	0.594
3.600	5.22	0.577
4.200	6.15	0.645
4.800	7.18	0.583
5.400	8.25	0.561
6.000	9.33	0.556
6.600	10.43	0.545
7.200	11.65	0.492
7.800	12.78	0.531
8.400	13.88	0.545
9.000	15.10	0.492
9.600	16.38	0.469
10.200	17.60	0.492
10.800	18.97	0.438
11.400	20.38	0.426
12.000	21.83	0.414
12.600	23.28	0.414
13.200	24.87	0.377
14.000	27.07	0.364
14.200	27.53	0.435



432

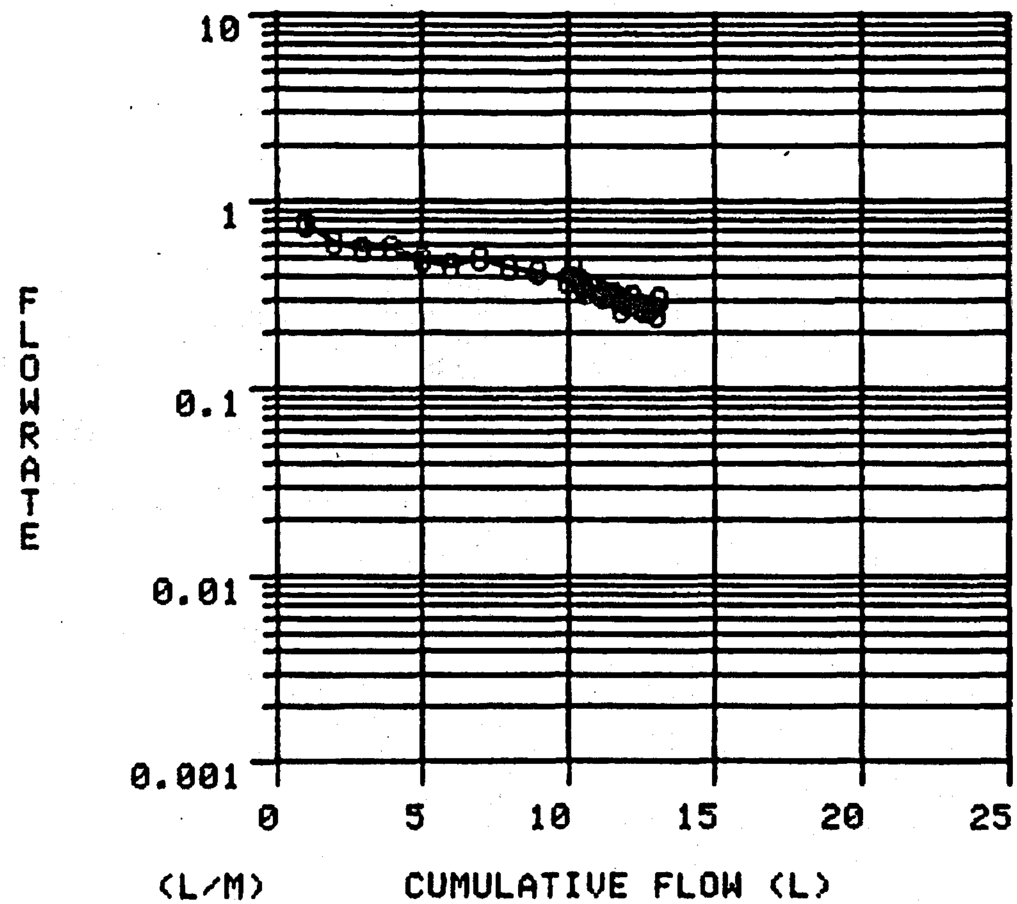
C.E.NATCO--39U-40D

LITRES	MINS	L/MIN
14.200	27.53	0.435
14.400	28.12	0.339
14.600	28.72	0.333
14.800	29.33	0.328
15.000	30.93	0.125

SPR MEMBRANE FILTRATION TEST DATA RUN:51U-52D
DATE: 31 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .16 VOL(L): 13.1

C.E. NATCO--51U-52D

LITRES	MINS	L/MIN
1.000	1.32	0.758
2.000	2.98	0.602
3.000	4.75	0.565
4.000	6.50	0.571
5.000	8.52	0.495
6.000	10.70	0.459
7.000	12.70	0.500
8.000	14.93	0.448
9.000	17.30	0.422
10.000	19.93	0.380
10.200	20.38	0.444
10.400	20.92	0.370
10.600	21.52	0.333
10.800	22.10	0.345
11.000	22.68	0.345
11.200	23.32	0.313
11.400	23.95	0.317
11.600	24.57	0.323
11.800	25.32	0.267
12.000	26.00	0.294
12.200	26.65	0.308
12.400	27.38	0.274
12.600	28.13	0.267
12.800	28.87	0.270



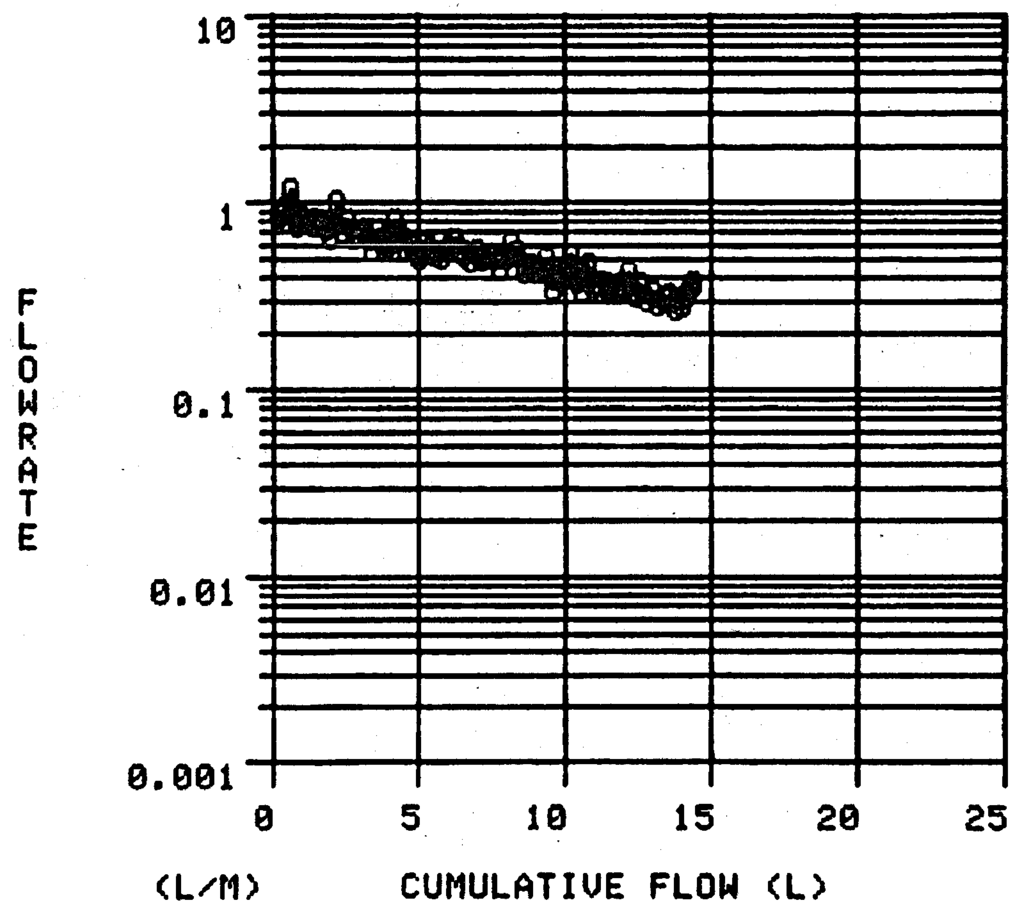
C.E. NATCO--51U-52D

LITRES	MINS	L/MIN
12.800	28.87	0.270
13.000	29.67	0.250
13.100	30.00	0.303

SPR MEMBRANE FILTRATION TEST DATA RUN:42U-43D
DATE: 31 JAN 79 PSIG: 50 FILTER:0.45M SS(MG/L): .15 VOL(L): 14.4

C.E. NATCO--42U-43D

LITRES	MINS	L/MIN
0.200	0.23	0.870
0.400	0.45	0.909
0.600	0.62	1.176
0.800	0.88	0.769
1.000	1.12	0.833
1.200	1.37	0.800
1.400	1.63	0.769
1.600	1.88	0.800
1.800	2.15	0.741
2.000	2.45	0.667
2.200	2.65	1.000
2.400	2.93	0.714
2.600	3.18	0.800
2.800	3.48	0.667
3.000	3.77	0.690
3.200	4.05	0.714
3.400	4.40	0.571
3.600	4.68	0.714
3.800	5.00	0.625
4.000	5.33	0.606
4.200	5.58	0.800
4.400	5.88	0.667
4.600	6.23	0.571
4.800	6.57	0.588



C.E. NATCO--42U-43D

LITRES	MINS	L/MIN
4.800	6.57	0.588
5.000	6.95	0.526
5.200	7.28	0.606
5.400	7.63	0.571
5.600	8.00	0.541
5.800	8.38	0.526
6.000	8.73	0.571
6.200	9.05	0.625
6.400	9.40	0.571
6.600	9.77	0.541
6.800	10.17	0.500
7.000	10.53	0.556
7.200	10.92	0.513
7.400	11.30	0.526
7.600	11.68	0.526
7.800	12.12	0.455
8.000	12.50	0.526
8.200	12.83	0.606
8.400	13.20	0.541
8.600	13.65	0.444
8.800	14.08	0.465
9.000	14.53	0.444
9.200	14.98	0.444
9.400	15.38	0.500
9.600	15.95	0.351
9.800	16.45	0.400
10.000	16.92	0.426
10.200	17.30	0.526
10.400	17.82	0.385
10.600	18.40	0.345
10.800	18.83	0.465

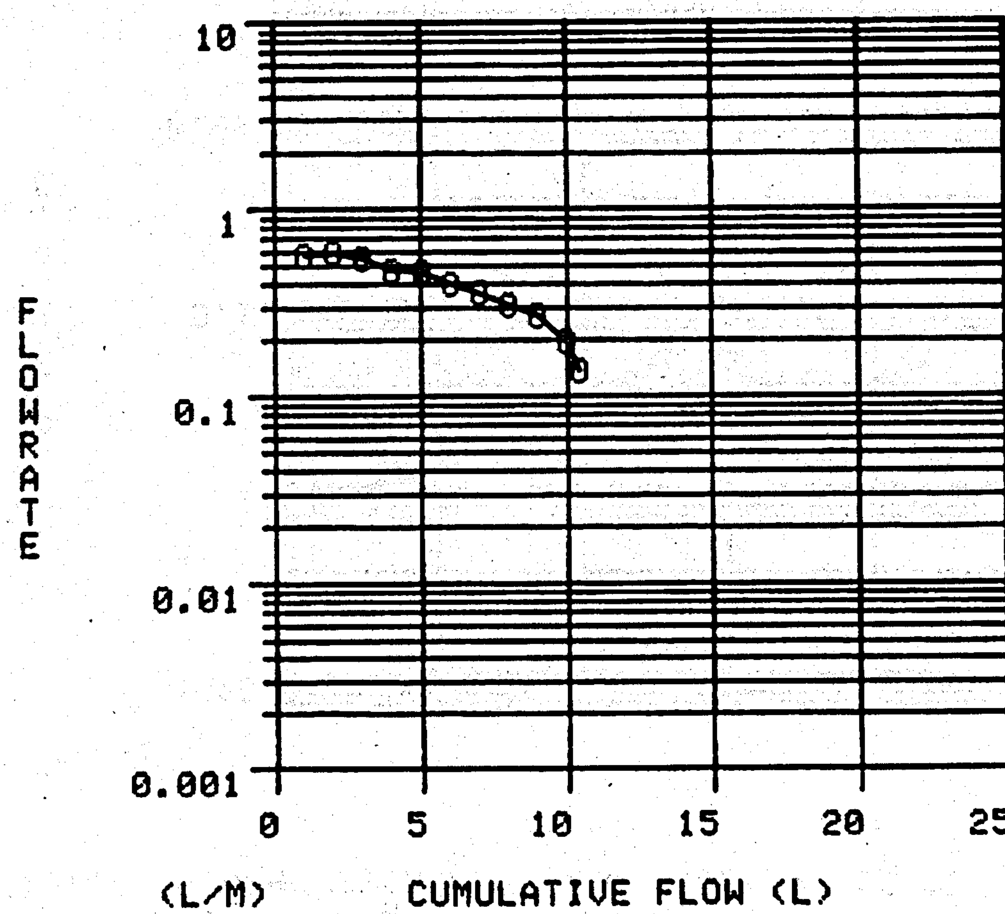
C.E. NATCO--42U-43D

LITRES	MINS	L/MIN
10.800	18.83	0.465
11.000	19.38	0.364
11.200	19.92	0.370
11.400	20.47	0.364
11.600	21.03	0.357
11.800	21.60	0.351
12.000	22.15	0.364
12.200	22.62	0.426
12.400	23.23	0.328
12.600	23.78	0.364
12.800	24.43	0.308
13.000	25.03	0.333
13.200	25.72	0.290
13.400	26.37	0.308
13.600	27.00	0.317
13.800	27.72	0.278
14.000	28.42	0.286
14.200	29.03	0.328
14.400	29.57	0.370

SPR MEMBRANE FILTRATION TEST DATA RUN:55U-56D
DATE: 31 JAN 79 PSIG: 50 FILTER:0.45M SS(MG/L): .16 VOL(L): 10.4

C.E. NATCO--55U-56D

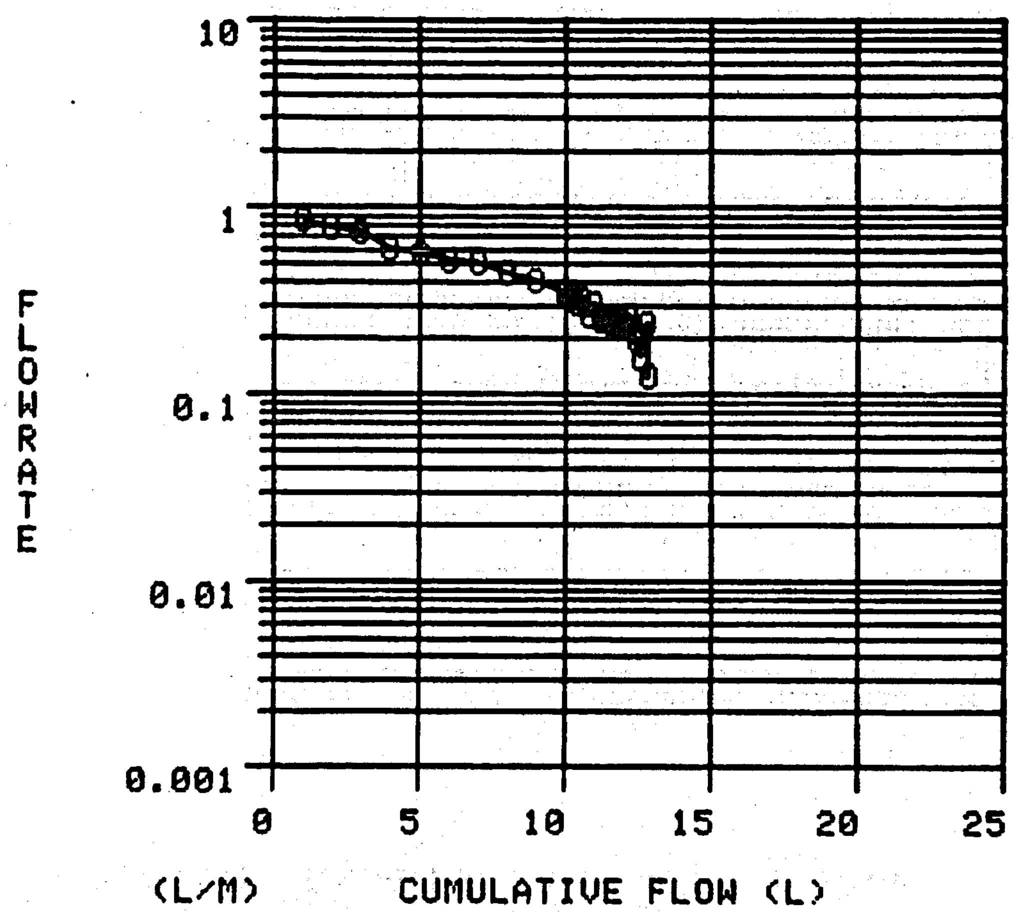
LITRES	MINS	L/MIN
1.000	1.75	0.571
2.000	3.45	0.588
3.000	5.25	0.556
4.000	7.37	0.472
5.000	9.53	0.463
6.000	12.00	0.405
7.000	14.78	0.360
8.000	18.00	0.311
9.000	21.67	0.272
10.000	26.75	0.197
10.446	30.00	0.137



SPR MEMBRANE FILTRATION TEST DATA RUN:69U-70D
DATE: 1 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .14 VOL(L): 12.83

C.E. NATCO--69U-70D

LITRES	MINS	L/MIN
1.000	1.17	0.855
2.000	2.43	0.794
3.000	3.77	0.746
4.000	5.43	0.602
5.000	7.18	0.571
6.000	9.08	0.526
7.000	11.03	0.513
8.000	13.27	0.446
9.000	15.73	0.407
10.000	18.57	0.352
10.200	19.17	0.333
10.400	19.82	0.308
10.600	20.43	0.328
10.800	21.18	0.267
11.000	21.83	0.308
11.200	22.62	0.253
11.400	23.42	0.250
11.600	24.25	0.241
11.800	25.13	0.227
12.000	25.95	0.244
12.200	26.70	0.267
12.400	27.72	0.196
12.600	28.98	0.159
12.800	29.80	0.244



440

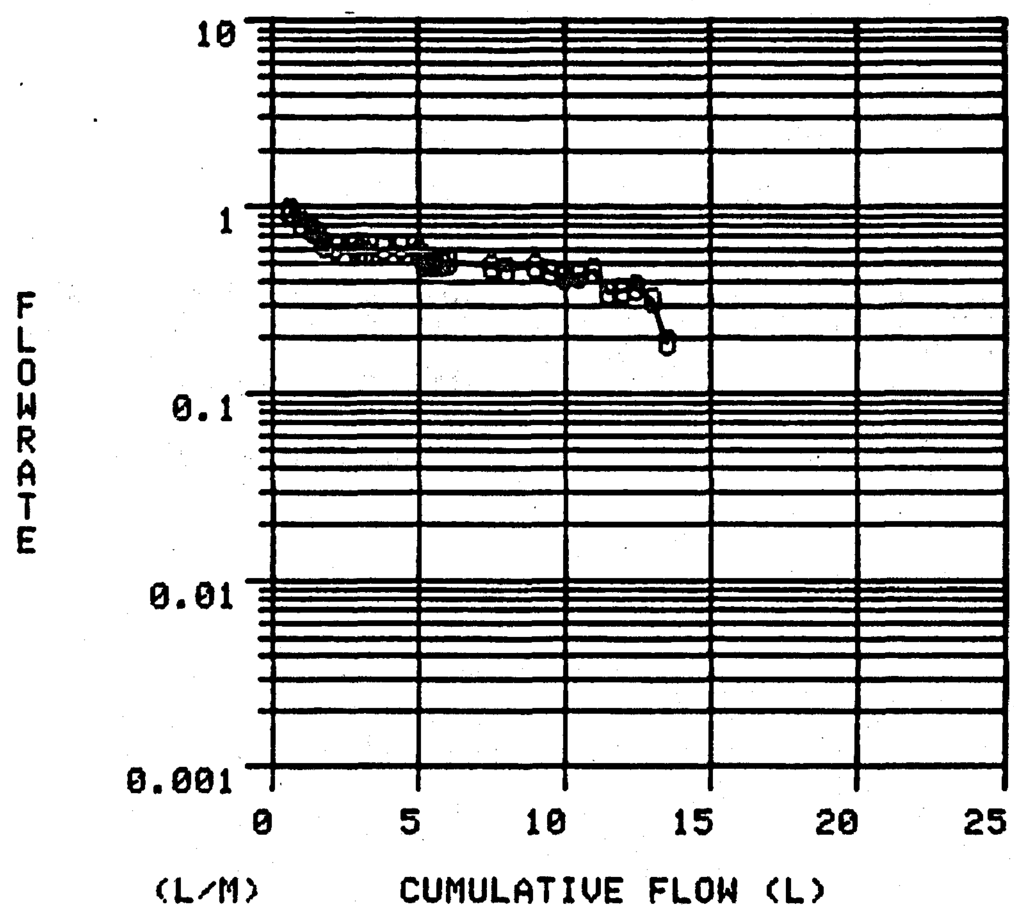
C.E. NATCO--69U-70D

LITRES	MINS	L/MIN
12.800	29.80	0.244
12.825	30.00	0.125

SPR MEMBRANE FILTRATION TEST DATA RUN:77U-780
DATE: 1 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .13 VOL(L): 13.5

C.E. NATCO--77U-78D

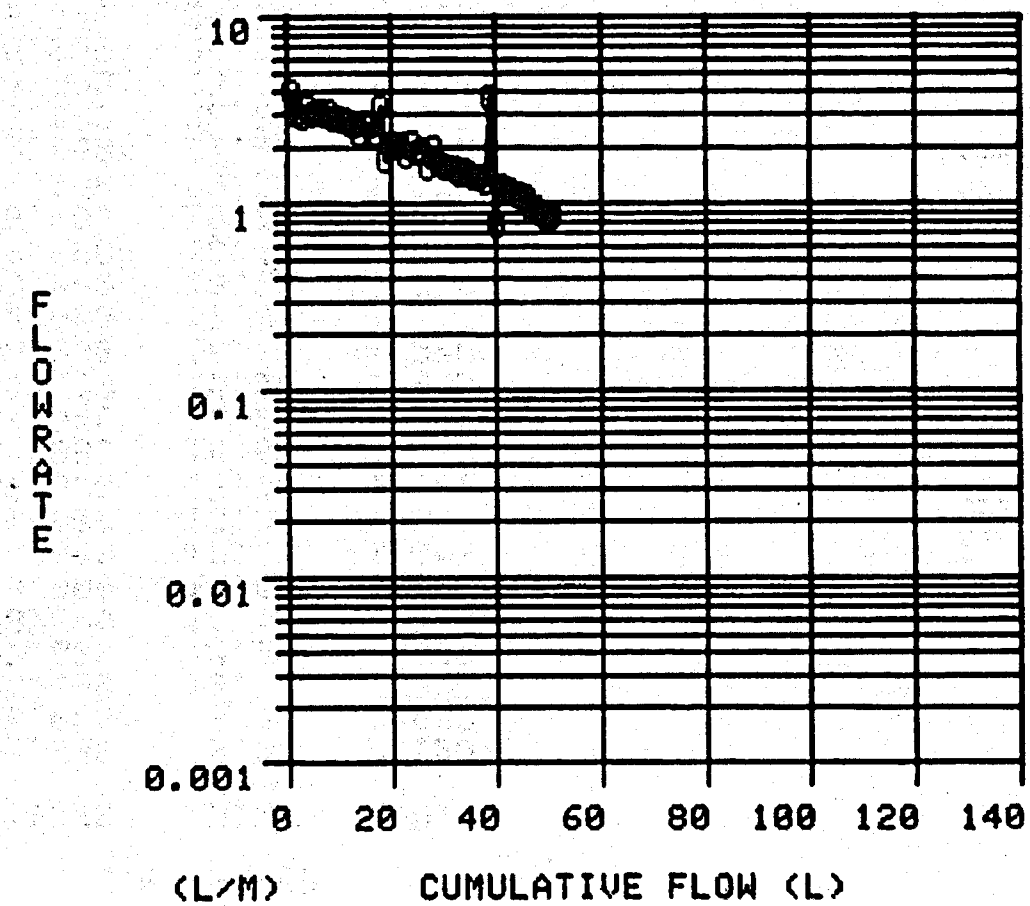
LITRES	MINS	L/MIN
0.600	0.63	0.952
1.000	1.12	0.816
1.400	1.65	0.755
1.600	1.93	0.714
1.800	2.25	0.625
2.200	2.90	0.615
2.800	3.85	0.632
3.000	4.20	0.571
3.200	4.55	0.571
3.800	5.55	0.600
4.400	6.53	0.612
5.000	7.58	0.571
5.200	7.98	0.500
5.400	8.38	0.500
5.600	8.78	0.500
5.800	9.18	0.500
6.000	9.57	0.513
7.500	12.65	0.487
8.000	13.72	0.467
9.000	15.77	0.488
9.500	16.88	0.450
10.000	18.05	0.427
10.500	19.20	0.435
11.000	20.30	0.455



SPR MEMBRANE FILTRATION TEST DATA RUN:403C
DATE: 29 JAN 79 PSIG: 20 FILTER: 8.8M SS(MG/L): .07 VOL(L):51

C.E. NATCO

LITRES	MINS	L/MIN
1.000	0.25	4.000
2.000	0.58	3.030
3.000	0.92	2.941
4.000	1.22	3.333
5.000	1.55	3.030
6.000	1.87	3.125
7.000	2.20	3.030
8.000	2.52	3.125
9.000	2.87	2.857
10.000	3.22	2.857
11.000	3.58	2.778
12.000	3.95	2.703
13.000	4.33	2.632
14.000	4.75	2.381
15.000	5.12	2.703
16.000	5.50	2.632
17.000	5.92	2.381
18.000	6.22	3.333
19.000	6.80	1.724
20.000	7.28	2.083
21.000	7.77	2.041
22.000	8.25	2.083
23.000	8.80	1.818
24.000	9.27	2.128



443

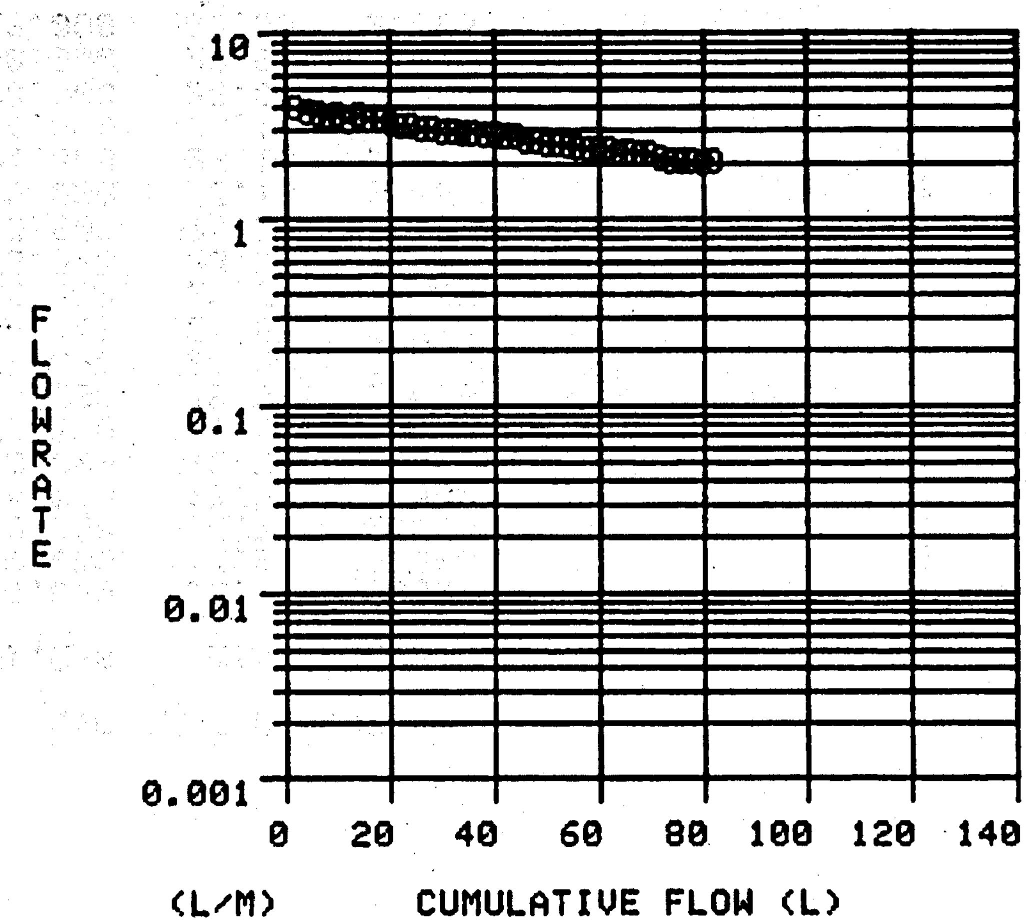
C.E. NATCO

LITRES	MINS	L/MIN
24.000	9.27	2.128
25.000	9.80	1.887
26.000	10.32	1.923
27.000	10.95	1.587
28.000	11.45	2.000
29.000	12.05	1.667
30.000	12.67	1.613
31.000	13.30	1.587
32.000	13.93	1.587
33.000	14.62	1.449
34.000	15.28	1.515
35.000	15.97	1.449
36.000	16.70	1.370
37.000	17.43	1.370
38.000	18.20	1.299
39.000	18.47	3.704
40.000	19.77	0.769
41.000	20.58	1.235
42.000	21.42	1.190
43.000	22.28	1.163
44.000	23.17	1.124
45.000	24.08	1.099
46.000	25.00	1.087
47.000	26.07	0.935
48.000	27.12	0.952
49.000	28.27	0.870
50.000	29.42	0.870
51.000	30.58	0.862

SPR MEMBRANE FILTRATION TEST DATA RUN:407C
DATE: 30 JAN 79 PSIG: 20 FILTER: 8.0M SS(MG/L): .01 VOL(L): 81.9

C.E. NATCO--407

LITRES	MINS	L/MIN
2.000	0.50	4.000
4.000	1.03	3.774
6.000	1.57	3.704
8.000	2.13	3.571
10.000	2.68	3.636
12.000	3.27	3.390
14.000	3.82	3.636
16.000	4.40	3.448
18.000	4.98	3.448
20.000	5.58	3.333
22.000	6.20	3.226
24.000	6.83	3.175
26.000	7.48	3.077
28.000	8.13	3.077
30.000	8.80	2.985
32.000	9.47	2.985
34.000	10.15	2.941
36.000	10.83	2.941
38.000	11.53	2.857
40.000	12.23	2.857
42.000	12.95	2.778
44.000	13.67	2.778
46.000	14.42	2.667
48.000	15.17	2.667



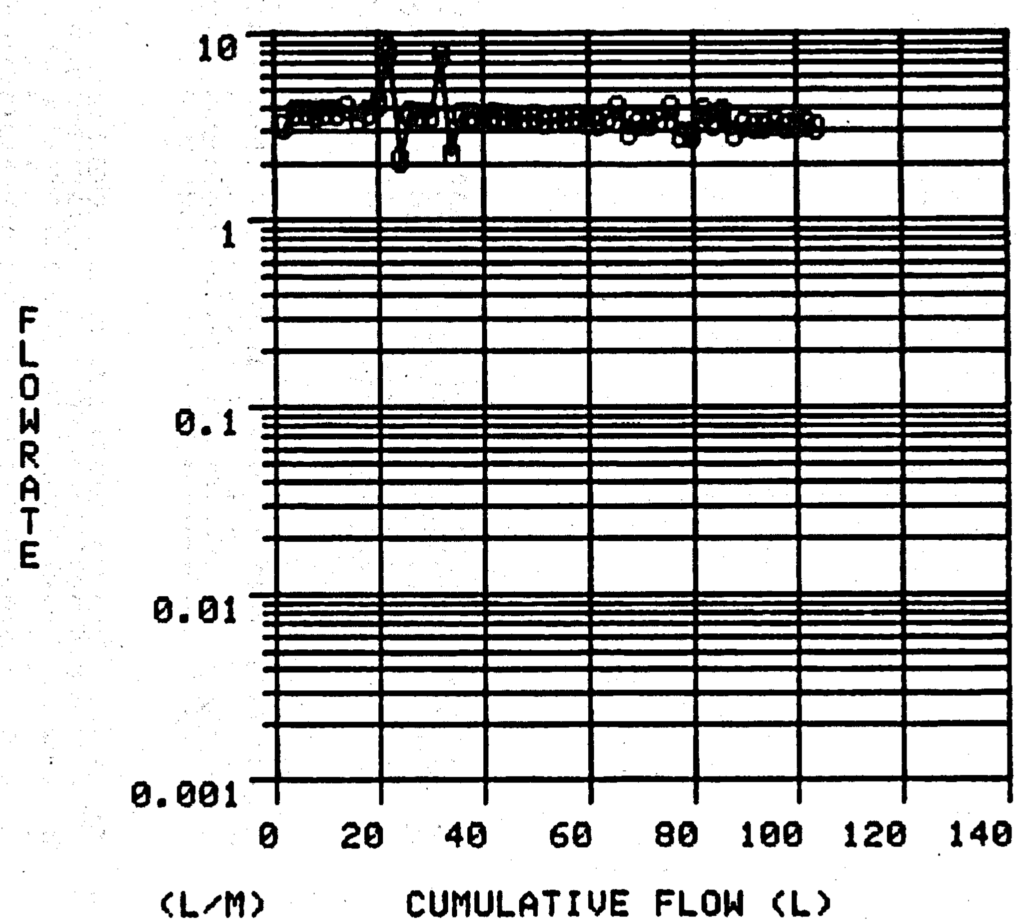
C.E. NATCO--407

LITRES	MINS	L/MIN
48.000	15.17	2.667
50.000	15.95	2.564
52.000	16.73	2.564
54.000	17.52	2.532
56.000	18.33	2.469
58.000	19.15	2.439
60.000	19.97	2.439
62.000	20.80	2.410
64.000	21.65	2.353
66.000	22.50	2.353
68.000	23.38	2.273
70.000	24.25	2.299
72.000	25.18	2.151
74.000	26.13	2.105
76.000	27.10	2.062
78.000	28.07	2.062
80.000	29.05	2.041
82.000	30.00	2.105

SPR MEMBRANE FILTRATION TEST DATA RUN:N3
DATE: 29 FEB 79 PSIG: 6 SS(MG/L):.01 FILTER:10.0N VOL(L): 104

C.E. NATCO--N3

LITRES	MINS	L/MIN
2.000	0.62	3.226
4.000	1.15	3.774
6.000	1.68	3.774
8.000	2.22	3.704
10.000	2.75	3.774
12.000	3.28	3.774
14.000	3.78	4.000
16.000	4.35	3.509
18.000	4.88	3.774
20.000	5.35	4.255
22.000	5.59	8.333
24.000	6.53	2.128
26.000	7.07	3.704
28.000	7.62	3.636
30.000	8.17	3.636
32.000	8.43	7.692
34.000	9.30	2.299
36.000	9.85	3.636
38.000	10.40	3.636
40.000	10.97	3.509
42.000	11.52	3.636
44.000	12.08	3.571
46.000	12.65	3.509
48.000	13.22	3.509



C.E. NATCO--N3

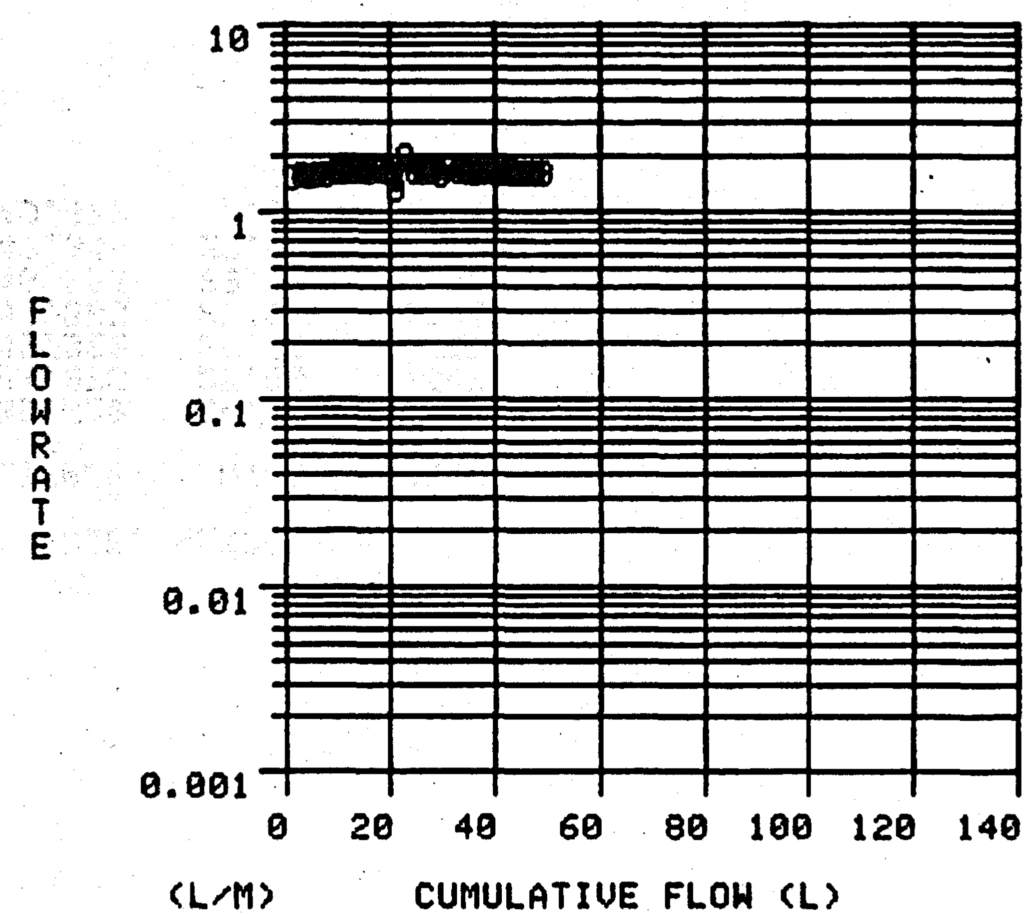
LITRES	MINS	L/MIN
48.000	13.22	3.509
50.000	13.78	3.571
52.000	14.37	3.390
54.000	14.95	3.448
56.000	15.52	3.509
58.000	16.08	3.571
60.000	16.67	3.390
62.000	17.27	3.333
64.000	17.83	3.571
66.000	18.33	4.000
68.000	19.00	2.985
70.000	19.60	3.333
72.000	20.20	3.333
74.000	20.78	3.448
76.000	21.28	4.000
78.000	21.98	2.857
80.000	22.68	2.857
82.000	23.20	3.846
84.000	23.80	3.333
86.000	24.33	3.774
88.000	25.02	2.899
90.000	25.63	3.279
92.000	26.25	3.226
94.000	26.87	3.226
96.000	27.47	3.333
98.000	28.10	3.175
100.000	28.72	3.226
102.000	29.33	3.279
104.000	29.97	3.125

SPR MEMBRANE FILTRATION TEST DATA RUN:N5

DATE: 1 FEB 79 PSIG: 10 FILTER:10.0N SS(MG/L):<.01 VOL(L):49.5

C.E. NATCO--N5

LITRES	MINS	L/MIN
1.552	1.00	1.552
3.145	2.00	1.593
4.723	3.00	1.578
6.322	4.00	1.599
7.932	5.00	1.610
9.592	6.00	1.660
11.258	7.00	1.666
12.933	8.00	1.675
14.625	9.00	1.692
16.293	10.00	1.668
17.983	11.00	1.690
19.661	12.00	1.678
21.000	13.00	1.339
23.012	14.00	2.012
24.682	15.00	1.670
26.355	16.00	1.673
28.013	17.00	1.658
29.623	18.00	1.610
31.347	19.00	1.724
33.013	20.00	1.666
34.677	21.00	1.664
36.322	22.00	1.645
37.973	23.00	1.651
39.628	24.00	1.655



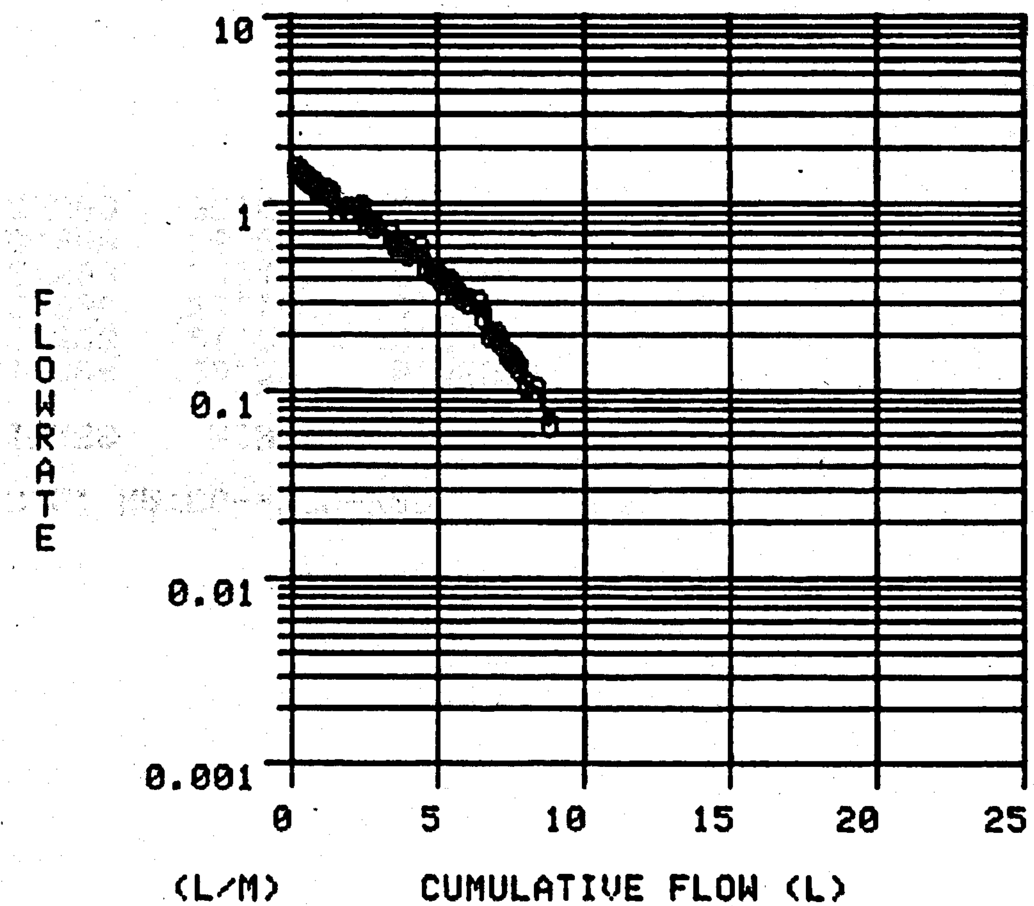
C.E. NATCO--N5

LITRES	MINS	L/MIN
39.628	24.00	1.655
41.275	25.00	1.647
42.922	26.00	1.647
44.563	27.00	1.641
46.203	28.00	1.640
47.846	29.00	1.643
49.477	30.00	1.631

SPR MEMBRANE FILTRATION TEST DATA   RUN:27
DATE: 29 JAN 79   PSIG: 50   FILTER:0.45M   SS(MG/L):.17   VOL(L):8.8

BAKER--27

LITRES	MINS	L/MIN
0.200	0.13	1.538
0.400	0.27	1.429
0.600	0.42	1.333
0.800	0.58	1.250
1.000	0.75	1.176
1.200	0.92	1.176
1.400	1.10	1.111
1.600	1.32	0.909
2.000	1.75	0.930
2.400	2.17	0.952
2.600	2.42	0.800
2.800	2.68	0.769
3.400	3.55	0.690
3.600	3.88	0.606
3.800	4.22	0.588
4.000	4.58	0.556
4.400	5.27	0.580
4.600	5.70	0.465
4.800	6.15	0.444
5.000	6.63	0.417
5.200	7.15	0.385
5.400	7.67	0.385
5.600	8.25	0.345
5.800	8.87	0.323



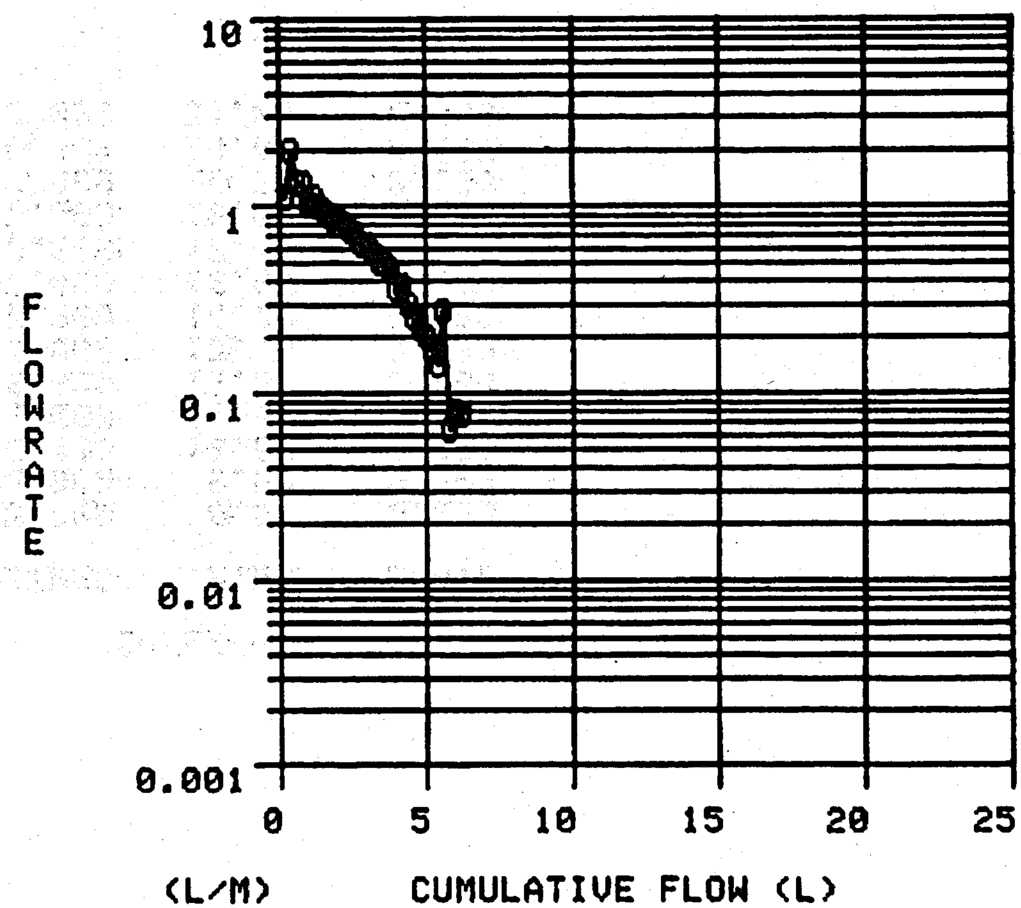
C.E. NATCO--77U-78D

LITRES	MINS	L/MIN
11.000	20.30	0.455
11.500	21.72	0.352
12.000	23.10	0.362
12.500	24.45	0.370
13.000	26.00	0.323
13.500	28.65	0.189

SPR MEMBRANE FILTRATION TEST DATA RUN:32
DATE: 30 JAN 79 PSIG:50 FILTER:0.45M SS(MG/L):.25 VOL(L):6.2

BAKER--32

LITRES	MINS	L/MIN
0.200	0.18	1.111
0.400	0.28	2.000
0.600	0.43	1.333
0.800	0.58	1.333
1.000	0.77	1.053
1.200	0.95	1.111
1.400	1.15	1.000
1.600	1.37	0.909
1.800	1.60	0.870
2.000	1.83	0.870
2.200	2.08	0.800
2.400	2.35	0.741
2.600	2.63	0.714
2.800	2.95	0.625
3.000	3.27	0.625
3.200	3.62	0.571
3.400	4.02	0.500
3.600	4.42	0.500
3.800	4.85	0.465
4.000	5.40	0.364
4.200	5.93	0.377
4.400	6.60	0.299
4.600	7.38	0.256
4.800	8.27	0.225



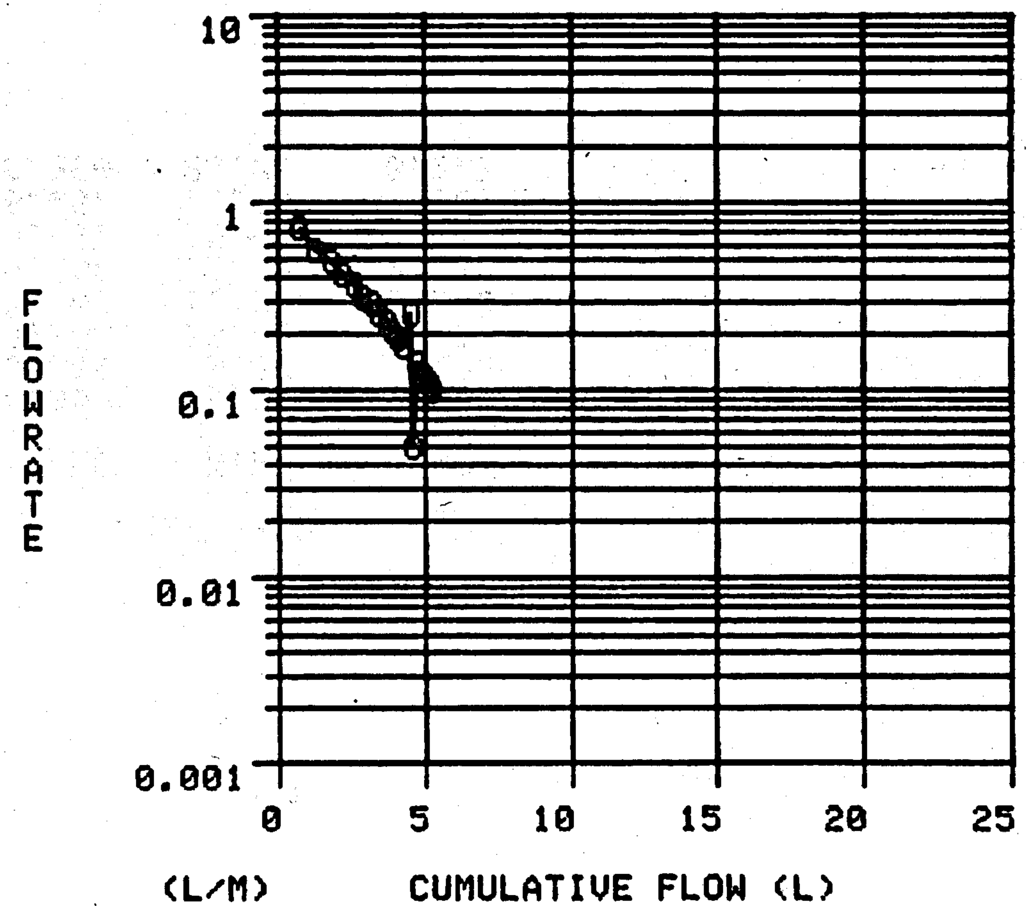
BAKER--27

LITRES	MINS	L/MIN
5.800	8.87	0.323
6.000	9.53	0.303
6.400	10.87	0.299
6.600	11.67	0.250
6.800	12.67	0.200
7.000	13.68	0.198
7.200	14.78	0.182
7.400	16.05	0.157
7.600	17.43	0.145
7.800	18.93	0.133
8.000	20.77	0.109
8.400	24.67	0.103
8.820	31.00	0.066

SPR MEMBRANE FILTRATION TEST DATA RUN:71UP-72
DATE: 1 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .14 VOL(L): 5.3

BAKER--71UP-72

LITRES	MINS	L/MIN
0.739	1.00	0.739
1.304	2.00	0.565
1.796	3.00	0.492
2.212	4.00	0.416
2.576	5.00	0.364
2.892	6.00	0.316
3.183	7.00	0.291
3.438	8.00	0.255
3.671	9.00	0.233
3.879	10.00	0.208
4.068	11.00	0.189
4.241	12.00	0.173
4.499	13.00	0.258
4.549	14.00	0.050
4.689	15.00	0.140
4.810	16.00	0.121
4.931	17.00	0.121
5.042	18.00	0.111
5.150	19.00	0.108
5.251	20.00	0.101



BAKER--32

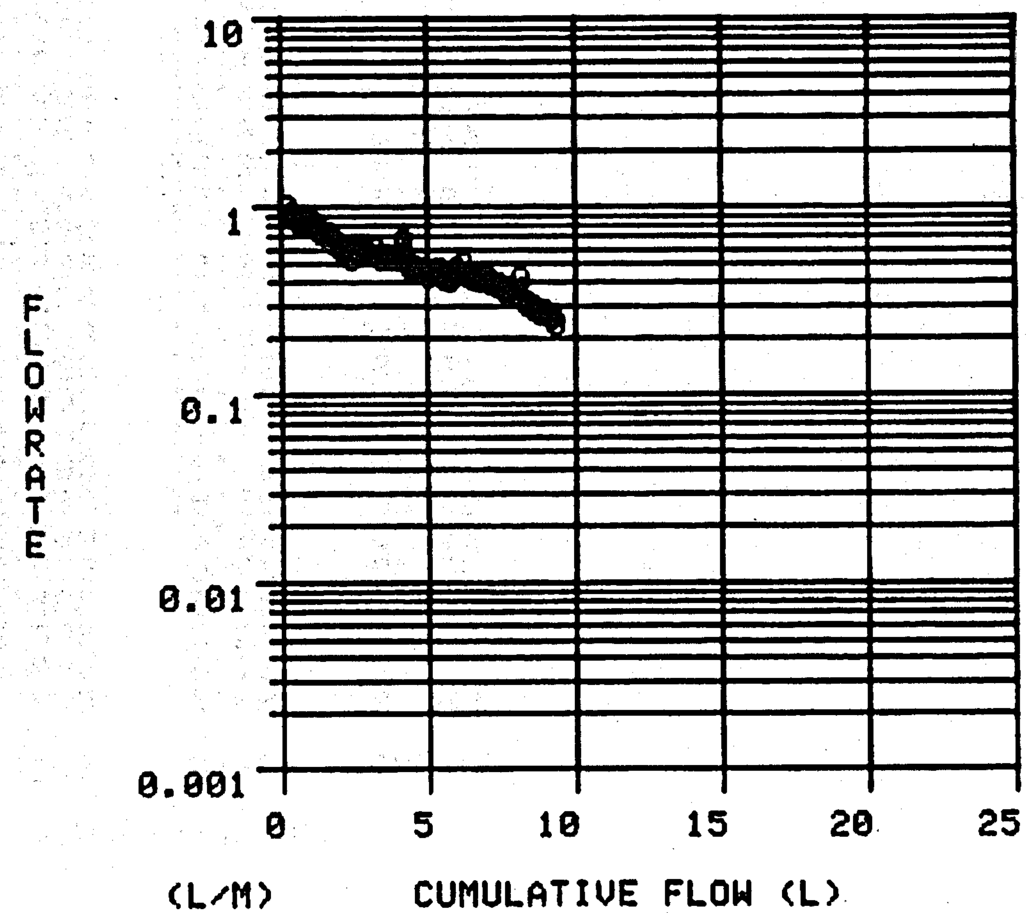
LITRES	MINS	L/MIN
4.800	8.27	0.225
5.000	9.27	0.200
5.200	10.43	0.172
5.400	11.83	0.143
5.600	12.55	0.278
5.800	15.67	0.064
6.000	18.15	0.081
6.200	20.75	0.077

SPR MEMBRANE FILTRATION TEST DATA RUN:37U-38D

DATE: 30 JAN 79 PSIG: 50 FILTER:0.45M SS(MG/L): .18 VOL(L): 9.4

BAKER--37-38D

LITRES	MINS	L/MIN
0.200	0.20	1.000
0.400	0.42	0.909
0.600	0.65	0.870
0.800	0.90	0.800
1.000	1.13	0.870
1.200	1.38	0.800
1.400	1.65	0.741
1.600	1.93	0.714
1.800	2.23	0.667
2.000	2.55	0.625
2.200	2.90	0.571
2.400	3.27	0.541
2.600	3.62	0.571
2.800	3.97	0.571
3.000	4.32	0.571
3.200	4.65	0.606
3.400	5.02	0.541
3.600	5.38	0.556
3.800	5.75	0.541
4.000	6.12	0.541
4.200	6.42	0.667
4.400	6.83	0.488
4.600	7.25	0.476
4.800	7.68	0.465



BAKER--37-38D

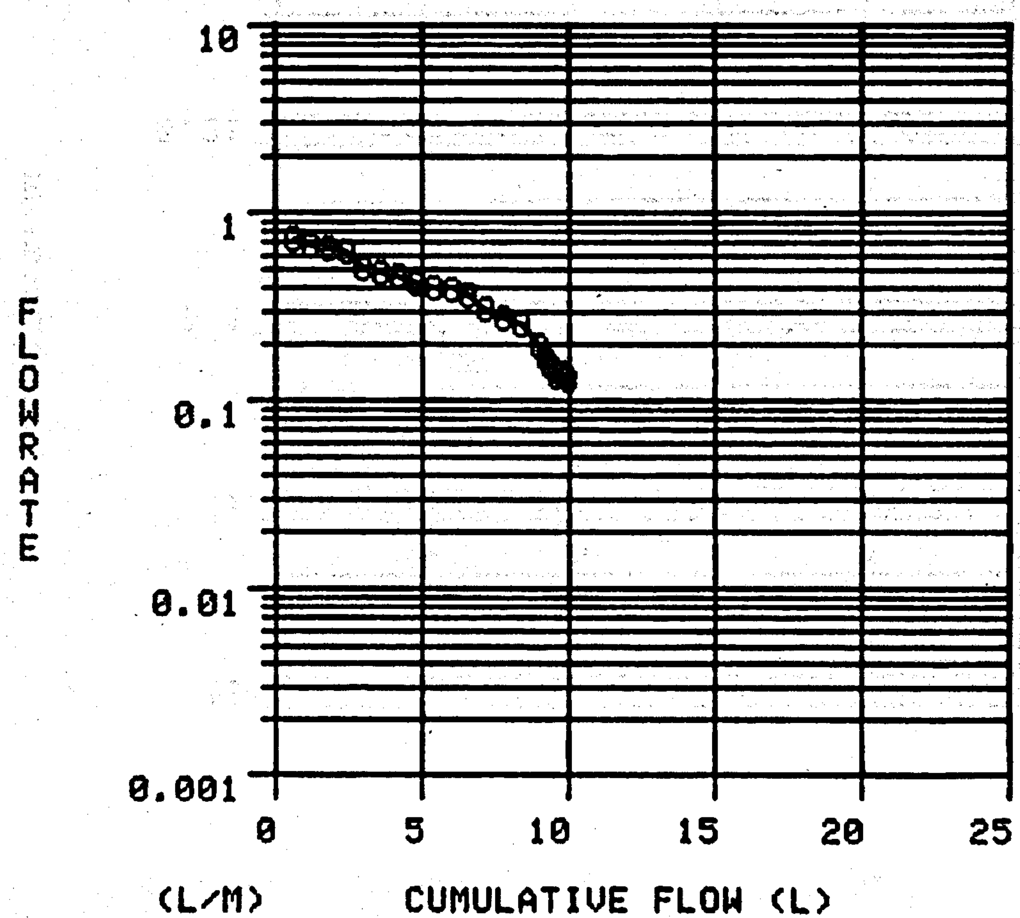
LITRES	MINS	L/MIN
4.800	7.68	0.465
5.000	8.13	0.444
5.200	8.57	0.455
5.400	9.00	0.465
5.600	9.47	0.426
5.800	9.95	0.417
6.000	10.38	0.465
6.200	10.78	0.500
6.400	11.23	0.444
6.600	11.70	0.426
6.800	12.18	0.417
7.000	12.65	0.426
7.200	13.15	0.400
7.400	13.67	0.385
7.600	14.22	0.364
7.800	14.77	0.364
8.000	15.35	0.345
8.200	15.83	0.417
8.400	16.48	0.308
8.600	17.17	0.290
8.800	17.90	0.274
9.000	18.63	0.274
9.200	19.40	0.260
9.400	20.22	0.244

SPR MEMBRANE FILTRATION TEST DATA RUN:44U-45D

DATE: 31 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .16 VOL(L): 10.2

BAKER--44U-45D

LITRES	MINS	L/MIN
0.600	0.82	0.732
1.200	1.70	0.682
1.800	2.62	0.652
2.400	3.58	0.625
3.000	4.75	0.513
3.600	6.00	0.480
4.200	7.30	0.462
4.800	8.72	0.423
5.400	10.22	0.400
6.000	11.73	0.397
6.600	13.37	0.366
7.200	15.33	0.306
7.800	17.50	0.276
8.400	19.83	0.258
9.000	22.88	0.197
9.200	24.07	0.168
9.400	25.37	0.154
9.600	26.85	0.135
9.800	28.27	0.141
10.000	29.80	0.131

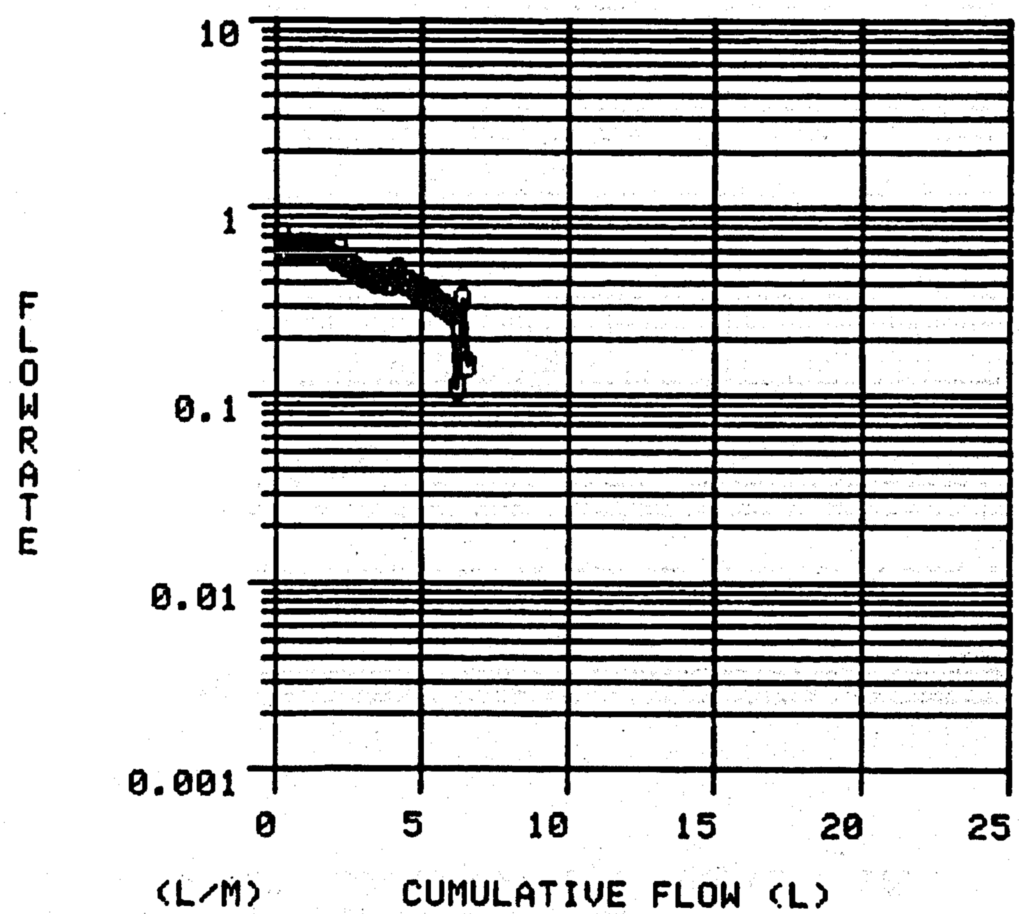


459

SPR MEMBRANE FILTRATION TEST DATA RUN:53U-54D
DATE: 31 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L):.15 VOL(L): 6.7

BAKER--53U-54D

LITRES	MINS	L/MIN
0.200	0.28	0.714
0.400	0.62	0.588
0.600	0.95	0.606
0.800	1.28	0.606
1.000	1.60	0.625
1.200	1.93	0.606
1.400	2.27	0.588
1.600	2.60	0.606
1.800	2.95	0.571
2.000	3.32	0.541
2.200	3.65	0.606
2.400	4.05	0.500
2.600	4.45	0.500
2.800	4.88	0.465
3.000	5.33	0.444
3.200	5.78	0.444
3.400	6.27	0.408
3.600	6.75	0.417
3.800	7.25	0.400
4.000	7.75	0.400
4.200	8.18	0.465
4.400	8.68	0.400
4.600	9.18	0.400
4.800	9.73	0.364



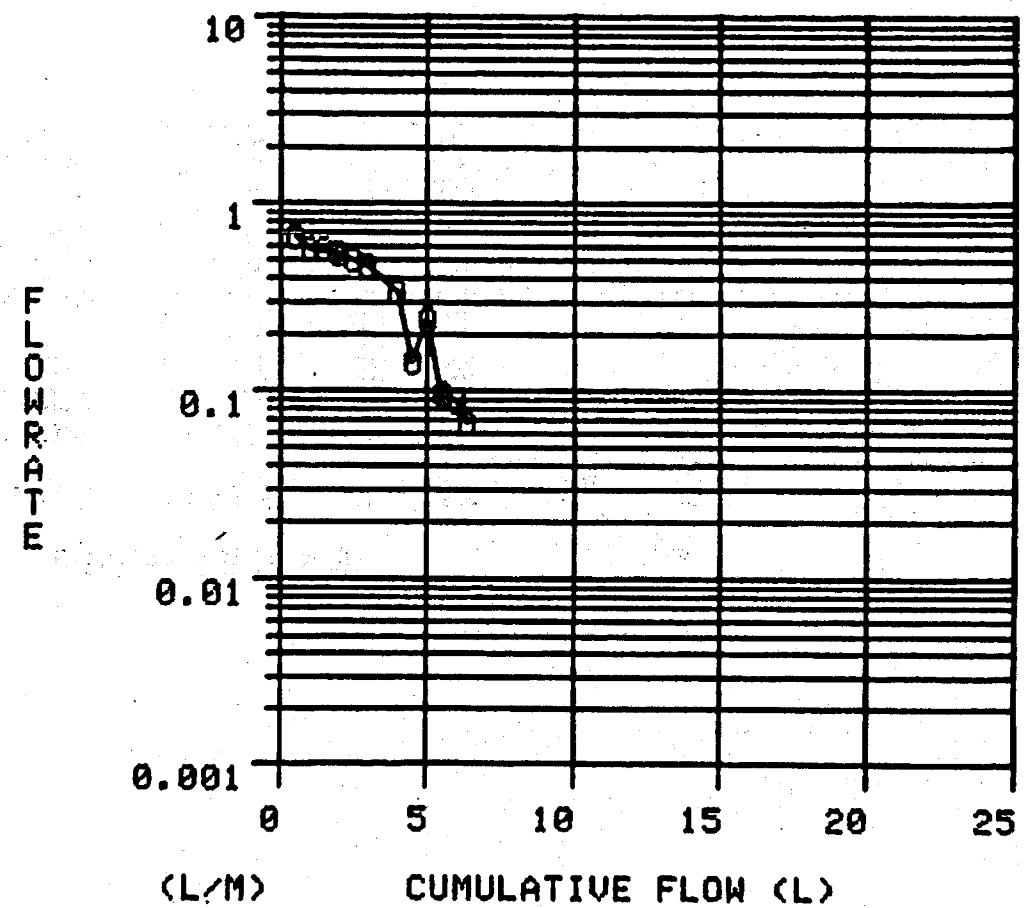
BAKER--53U-54D

LITRES	MINS	L/MIN
4.800	9.73	0.364
5.000	10.28	0.364
5.200	10.88	0.333
5.400	11.48	0.333
5.600	12.13	0.308
5.800	12.80	0.299
6.000	13.52	0.278
6.200	15.33	0.110
6.400	15.95	0.323
6.600	16.33	0.145

SPR MEMBRANE FILTRATION TEST DATA RUN:58U-59D
DATE: 31 JAN 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .17 VOL(L): 6.35

BAKER--58U-59D

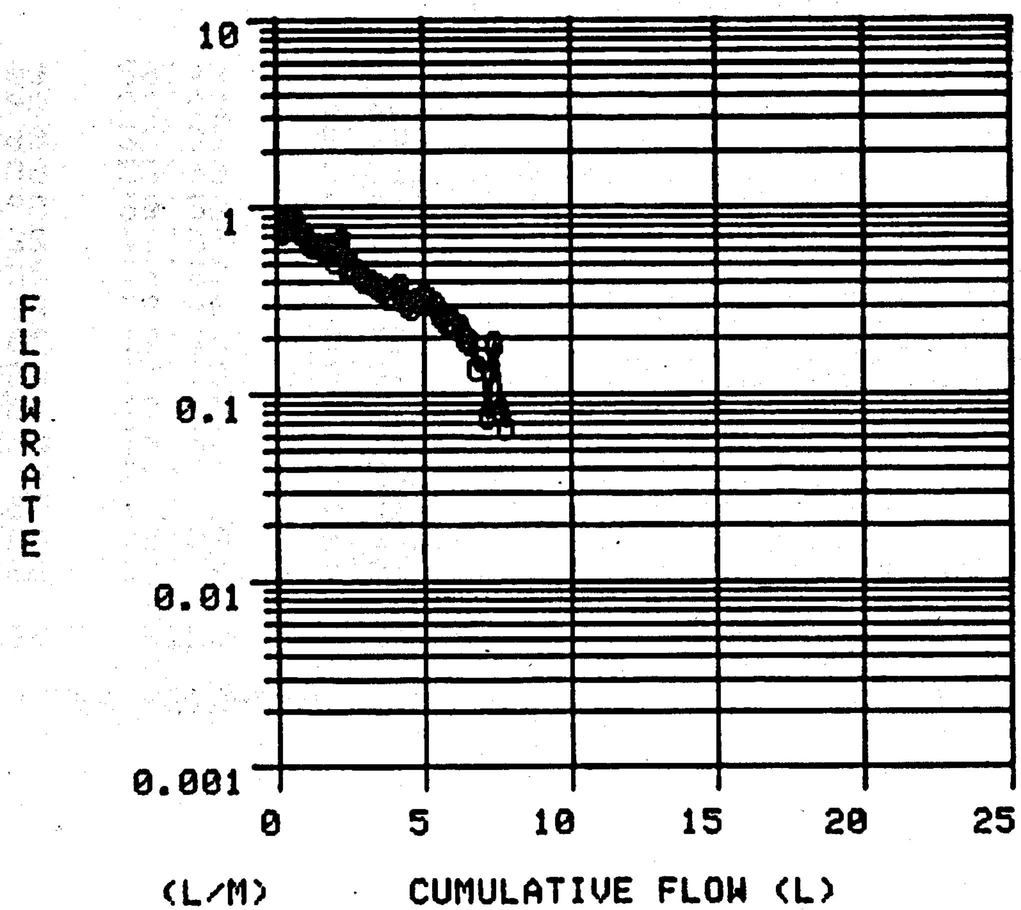
LITRES	MINS	L/MIN
0.500	0.75	0.667
1.000	1.62	0.575
1.500	2.50	0.568
2.000	3.42	0.543
2.500	4.42	0.500
3.000	5.50	0.463
4.000	8.45	0.339
4.500	11.92	0.144
5.000	14.00	0.240
5.500	19.17	0.097
6.000	24.83	0.088
6.350	30.00	0.068



SPR MEMBRANE FILTRATION TEST DATA RUN:67U-68D
DATE: 1 FEB 79 PSIG: 50 FILTLER: 0.45M SS(MG/L): .16 VOL(L): 7.98

BAKER--67U-68D

LITRES	MINS	L/MIN
0.200	0.27	0.741
0.400	0.50	0.870
0.600	0.73	0.870
0.800	1.00	0.741
1.000	1.28	0.714
1.200	1.60	0.625
1.400	1.92	0.625
1.600	2.25	0.606
1.800	2.57	0.625
2.000	2.95	0.526
2.200	3.25	0.667
2.400	3.67	0.476
2.600	4.08	0.488
2.800	4.53	0.444
3.000	5.02	0.408
3.200	5.52	0.400
3.400	6.05	0.377
3.600	6.60	0.364
3.800	7.20	0.333
4.000	7.80	0.333
4.200	8.33	0.377
4.400	8.98	0.308
4.600	9.67	0.290
4.800	10.30	0.317



BAKER--67U-68D

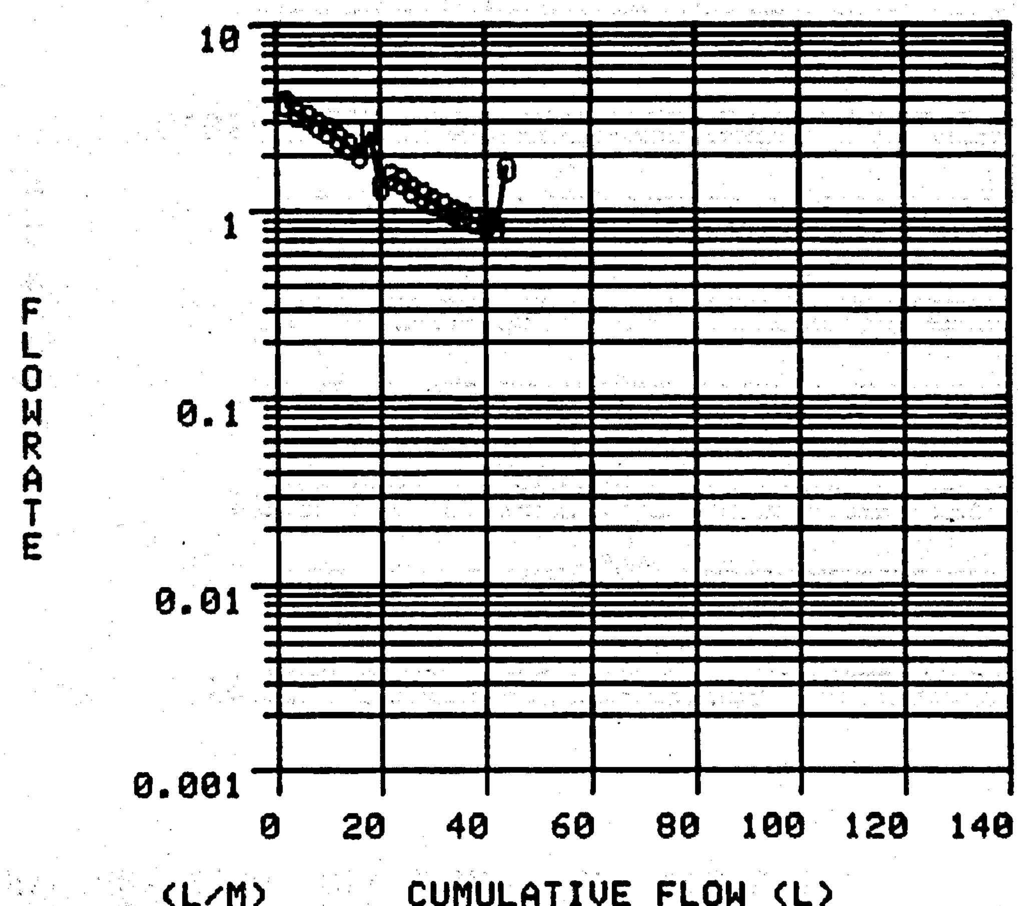
LITRES	MINS	L/MIN
4.800	10.30	0.317
5.000	10.90	0.333
5.200	11.53	0.317
5.400	12.20	0.299
5.600	12.95	0.267
5.800	13.77	0.244
6.000	14.60	0.241
6.200	15.47	0.230
6.400	16.48	0.198
6.600	17.53	0.190
6.800	18.98	0.138
7.000	20.27	0.155
7.200	22.90	0.076
7.400	23.97	0.187
7.600	26.43	0.081
7.800	29.40	0.067

SPR MEMBRANE FILTRATION TEST DATA RUN:404C

DATE: 29 JAN 79 PSIG: 20 FILTER: 8.0M SS(MG/L): .17 VOL(L):44

BAKER--404

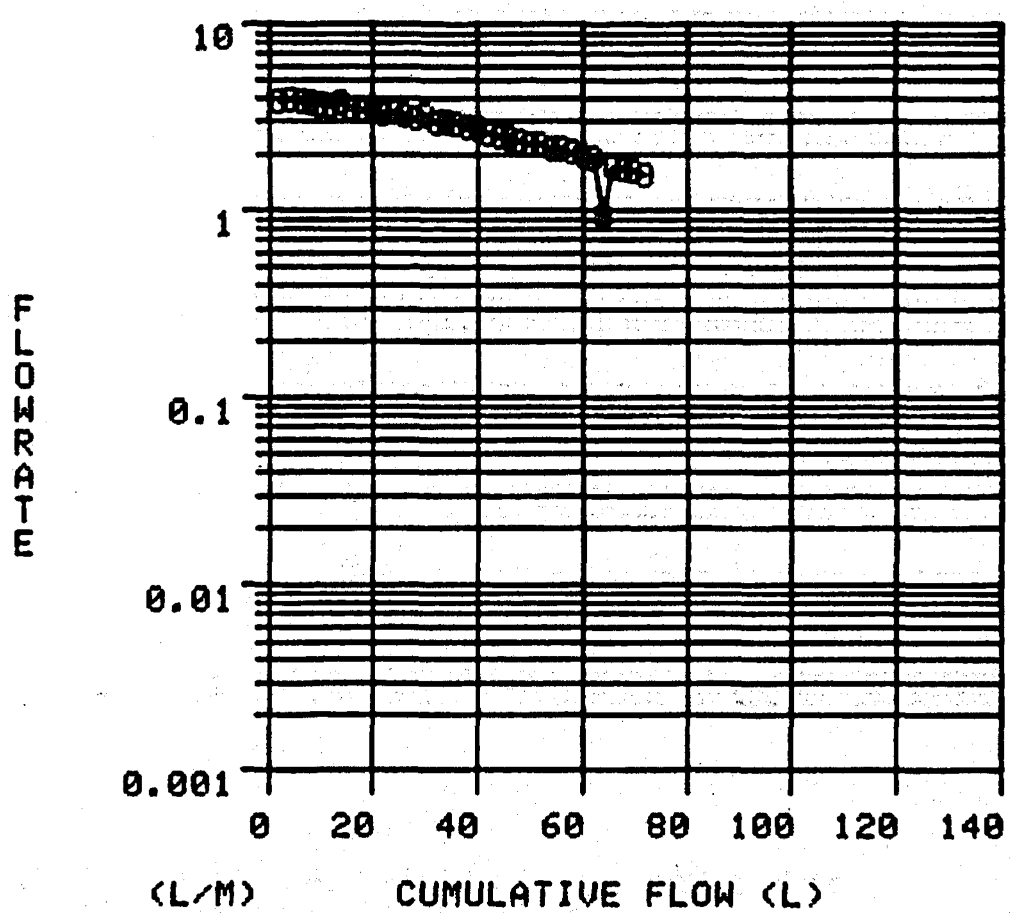
LITRES	MINS	L/MIN
2.000	0.53	3.774
4.000	1.13	3.333
6.000	1.75	3.226
8.000	2.43	2.941
10.000	3.17	2.703
12.000	3.98	2.469
14.000	4.87	2.247
16.000	5.87	2.000
18.000	6.63	2.632
20.000	8.10	1.361
22.000	9.40	1.538
24.000	10.78	1.449
26.000	12.32	1.299
28.000	13.97	1.212
30.000	15.75	1.124
32.000	17.65	1.053
34.000	19.70	0.976
36.000	21.82	0.943
38.000	24.05	0.897
40.000	26.40	0.851
42.000	28.83	0.823
44.000	30.00	1.709



SPR MEMBRANE FILTRATION TEST DATA RUN:408C
DATE: 30 JAN 79 PSIG: 20 FILTER: 8.0M SS(MG/L): .03 VOL(L): 73

BAKER--408

LITRES	MINS	L/MIN
2.000	0.52	3.846
4.000	1.03	3.922
6.000	1.55	3.846
8.000	2.08	3.774
10.000	2.62	3.704
12.000	3.17	3.636
14.000	3.70	3.774
16.000	4.27	3.509
18.000	4.85	3.448
20.000	5.43	3.448
22.000	6.03	3.333
24.000	6.62	3.390
26.000	7.23	3.279
28.000	7.87	3.125
30.000	8.48	3.279
32.000	9.15	2.985
34.000	9.82	2.985
36.000	10.50	2.941
38.000	11.22	2.778
40.000	11.95	2.740
42.000	12.72	2.597
44.000	13.52	2.500
46.000	14.33	2.469
48.000	15.17	2.381



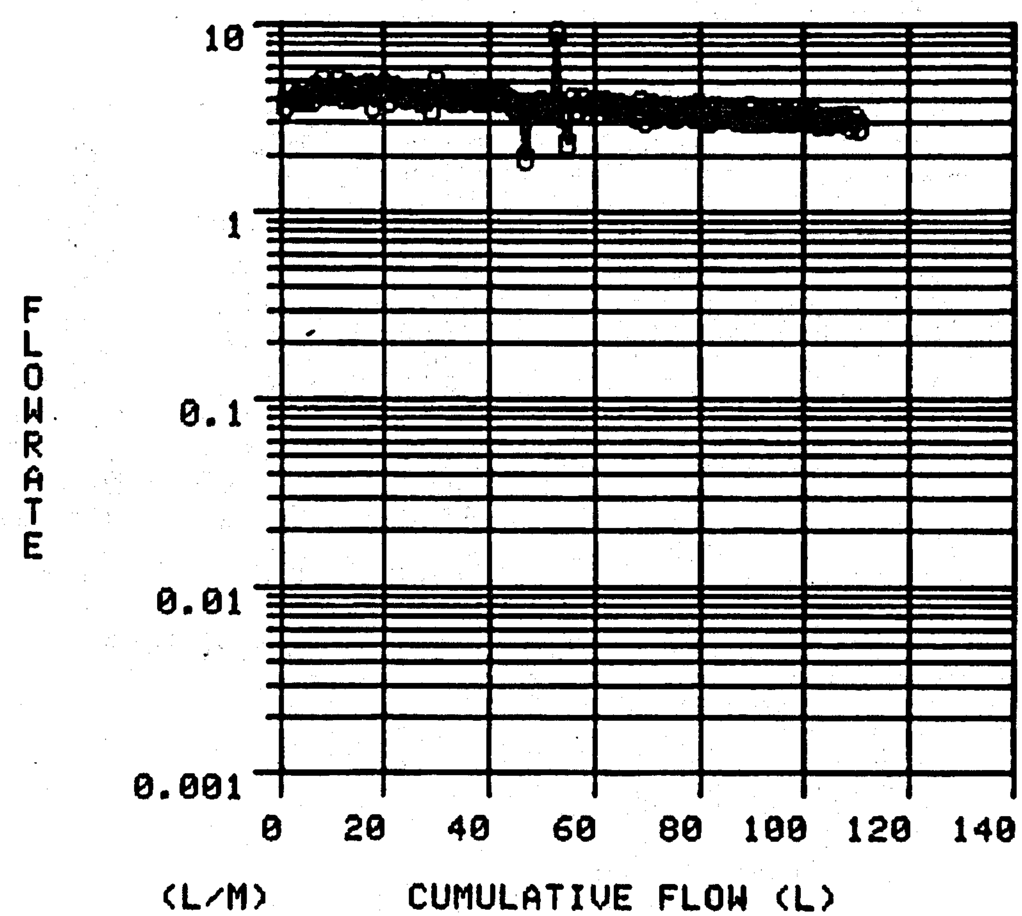
BAKER--408

LITRES	MINS	L/MIN
48.000	15.17	2.381
50.000	16.05	2.273
52.000	16.93	2.273
54.000	17.85	2.174
56.000	18.78	2.151
58.000	19.75	2.062
60.000	20.75	2.000
62.000	21.78	1.942
64.000	23.88	0.952
66.000	25.03	1.739
68.000	26.22	1.681
70.000	27.43	1.653
72.000	28.70	1.575

SPR MEMBRANE FILTRATION TEST DATA RUN:BD-10
DATE: 29 JAN 79 PSIG: 6 FILTER:10.0N SS(MG/L): .02 VOL(L): 111

BAKER--BD-10

LITRES	MINS	L/MIN
1.000	0.27	3.704
2.000	0.50	4.348
3.000	0.75	4.000
4.000	1.00	4.000
5.000	1.25	4.000
6.000	1.50	4.000
7.000	1.72	4.545
8.000	1.92	5.000
9.000	2.15	4.348
10.000	2.38	4.348
11.000	2.58	5.000
12.000	2.82	4.167
13.000	3.03	4.762
14.000	3.27	4.167
15.000	3.50	4.348
16.000	3.72	4.545
17.000	3.93	4.762
18.000	4.20	3.704
19.000	4.42	4.545
20.000	4.63	4.762
21.000	4.88	4.000
22.000	5.10	4.545
23.000	5.33	4.348
24.000	5.57	4.167



BAKER--BD-10

LITRES	MINS	L/MIN
24.000	5.57	4.167
25.000	5.80	4.348
26.000	6.03	4.348
27.000	6.28	4.000
28.000	6.52	4.167
29.000	6.80	3.571
30.000	7.00	5.000
31.000	7.23	4.348
32.000	7.47	4.167
33.000	7.72	4.000
34.000	7.95	4.348
35.000	8.20	4.000
36.000	8.43	4.348
37.000	8.67	4.167
38.000	8.92	4.000
39.000	9.17	4.000
40.000	9.40	4.348
41.000	9.63	4.348
42.000	9.88	4.000
43.000	10.12	4.167
44.000	10.38	3.846
45.000	10.65	3.704
46.000	10.92	3.704
47.000	11.43	1.961
48.000	11.70	3.704
49.000	11.97	3.704
50.000	12.23	3.846
51.000	12.50	3.704
52.000	12.77	3.704
53.000	12.88	9.091
54.000	13.18	3.333

BAKER--BD-10

LITRES	MINS	L/MIN
54.000	13.18	3.333
55.000	13.60	2.381
56.000	13.85	4.000
57.000	14.13	3.571
58.000	14.38	4.000
59.000	14.67	3.448
60.000	14.93	3.846
61.000	15.22	3.448
62.000	15.48	3.846
63.000	15.75	3.704
64.000	16.03	3.571
65.000	16.30	3.704
66.000	16.58	3.571
67.000	16.87	3.448
68.000	17.17	3.333
69.000	17.43	3.846
70.000	17.75	3.125
71.000	18.02	3.704
72.000	18.32	3.333
73.000	18.60	3.571
74.000	18.88	3.571
75.000	19.18	3.333
76.000	19.48	3.333
77.000	19.77	3.448
78.000	20.05	3.571
79.000	20.35	3.333
80.000	20.62	3.704
81.000	20.93	3.226
82.000	21.25	3.125
83.000	21.53	3.571
84.000	21.83	3.333

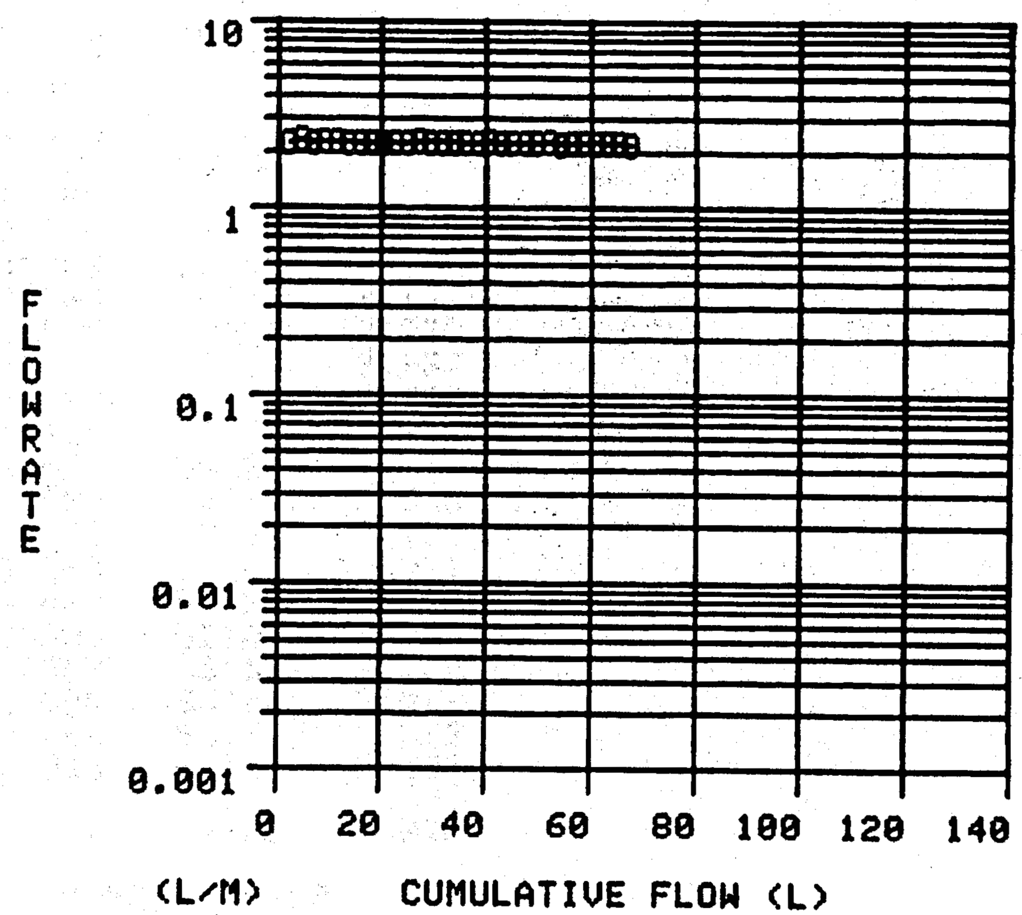
BAKER--BD-10

LITRES	MINS	L/MIN
84.000	21.83	3.333
85.000	22.13	3.333
86.000	22.42	3.448
87.000	22.73	3.226
88.000	23.03	3.333
89.000	23.35	3.125
90.000	23.63	3.571
91.000	23.95	3.125
92.000	24.25	3.333
93.000	24.57	3.125
94.000	24.87	3.333
95.000	25.18	3.226
96.000	25.50	3.125
97.000	25.80	3.333
98.000	26.12	3.125
99.000	26.43	3.226
100.000	26.73	3.333
101.000	27.05	3.125
102.000	27.35	3.333
103.000	27.68	3.030
104.000	28.00	3.125
105.000	28.33	3.030
106.000	28.65	3.125
107.000	28.97	3.125
108.000	29.28	3.226
109.000	29.62	2.941
110.000	29.93	3.226
111.000	30.28	2.857

SPR MEMBRANE FILTRATION TEST DATA RUN:4
DATE: 1 FEB 79 PSIG:10 FILTER:10.0N SS(MG/L):<.001 VOL(L):67.9

BAKER--4

LITRES	MINS	L/MIN
2.235	1.00	2.235
4.558	2.00	2.323
6.818	3.00	2.260
9.107	4.00	2.289
11.389	5.00	2.282
13.656	6.00	2.267
15.898	7.00	2.242
18.148	8.00	2.250
20.383	9.00	2.235
22.638	10.00	2.255
24.887	11.00	2.249
27.178	12.00	2.291
29.443	13.00	2.265
31.713	14.00	2.270
33.982	15.00	2.269
36.237	16.00	2.255
38.486	17.00	2.249
40.767	18.00	2.281
43.018	19.00	2.251
45.268	20.00	2.250
47.529	21.00	2.261
49.783	22.00	2.254
52.059	23.00	2.276
54.286	24.00	2.227



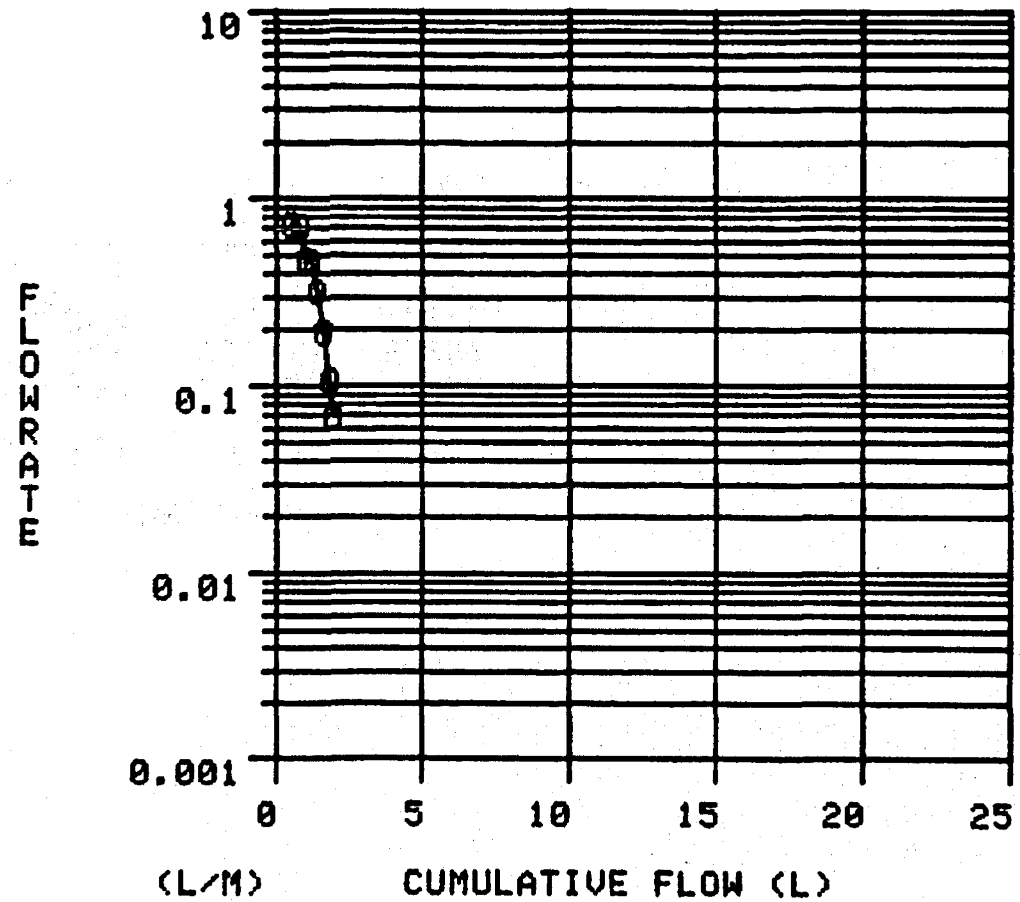
BAKER--4

LITRES	MINS	L/MIN
54.286	24.00	2.227
56.543	25.00	2.257
58.788	26.00	2.245
61.058	27.00	2.270
63.298	28.00	2.240
65.549	29.00	2.251
67.772	30.00	2.223

SPR MEMBRANE FILTRATION TEST DATA RUN:79U-80D
DATE: 1 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .17 VOL(L): 1.95

L'EAU CLAIRE--79U-80D

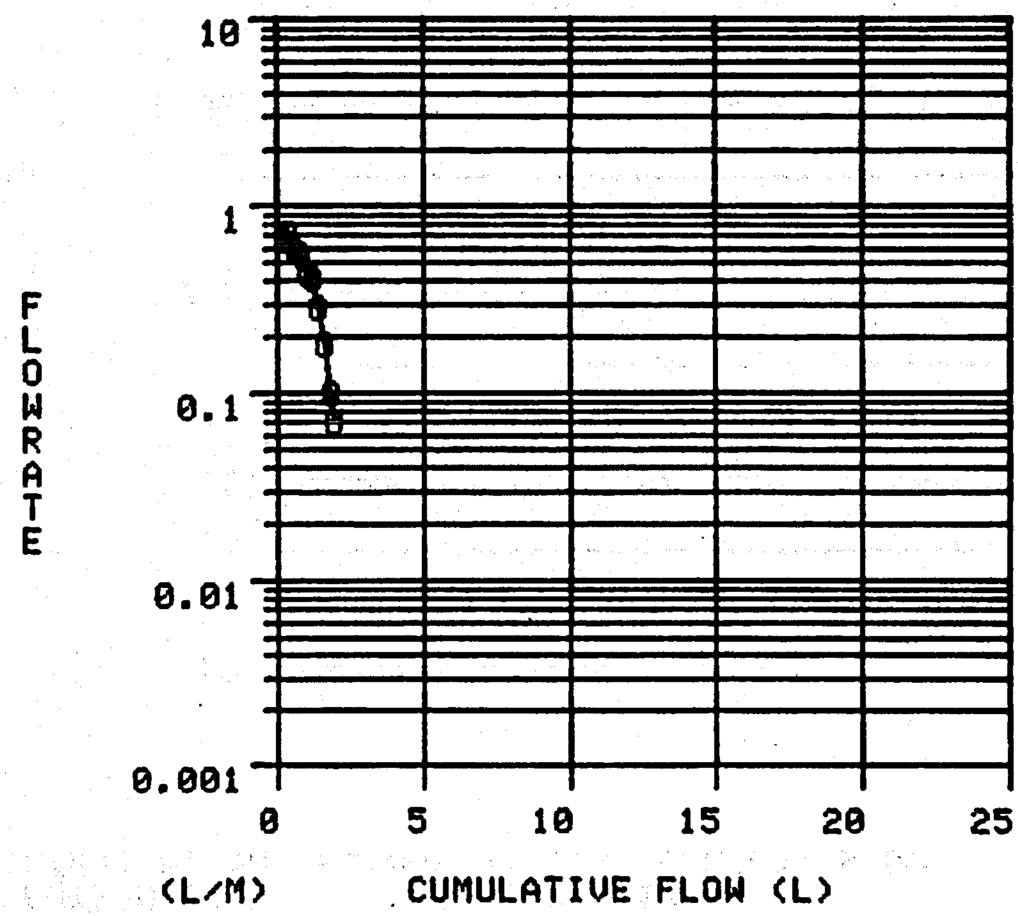
LITRES	MINS	L/MIN
0.500	0.68	0.735
0.800	1.10	0.714
1.000	1.52	0.476
1.200	1.95	0.465
1.400	2.58	0.317
1.600	3.62	0.192
1.800	5.52	0.105
1.950	7.67	0.070



SPR MEMBRANE FILTRATION TEST DATA RUN:81U-82D
DATE: 1 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .22 VOL(L): 1.94

L'EAU CLAIRE--81U-82D

LITRES	MINS	L/MIN
0.200	0.30	0.667
0.400	0.58	0.714
0.600	0.92	0.588
0.800	1.28	0.556
1.000	1.73	0.444
1.200	2.22	0.408
1.400	2.92	0.286
1.600	4.02	0.182
1.800	6.00	0.101
1.940	8.00	0.070

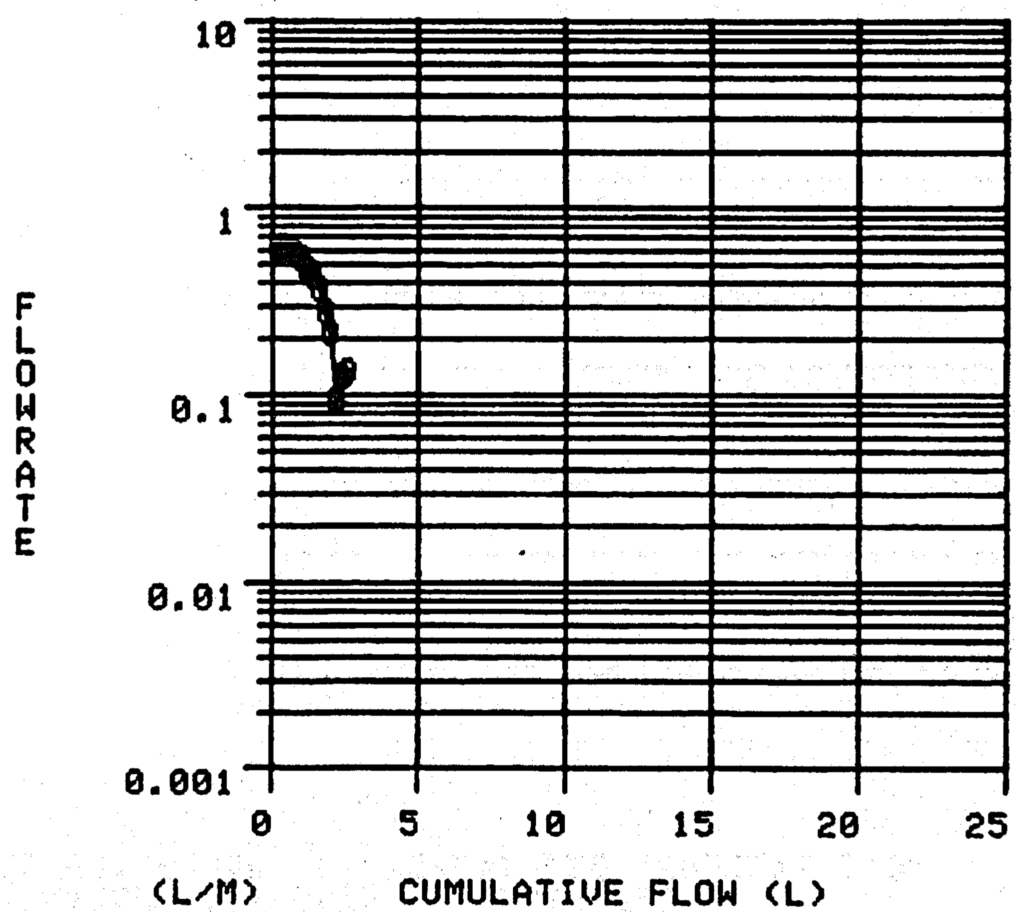


475

SPR MEMBRANE FILTRATION TEST DATA RUN:105U-106D
DATE: 2 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .16 VOL(L): 9.92

L'EAU CLAIRE--105U-106D

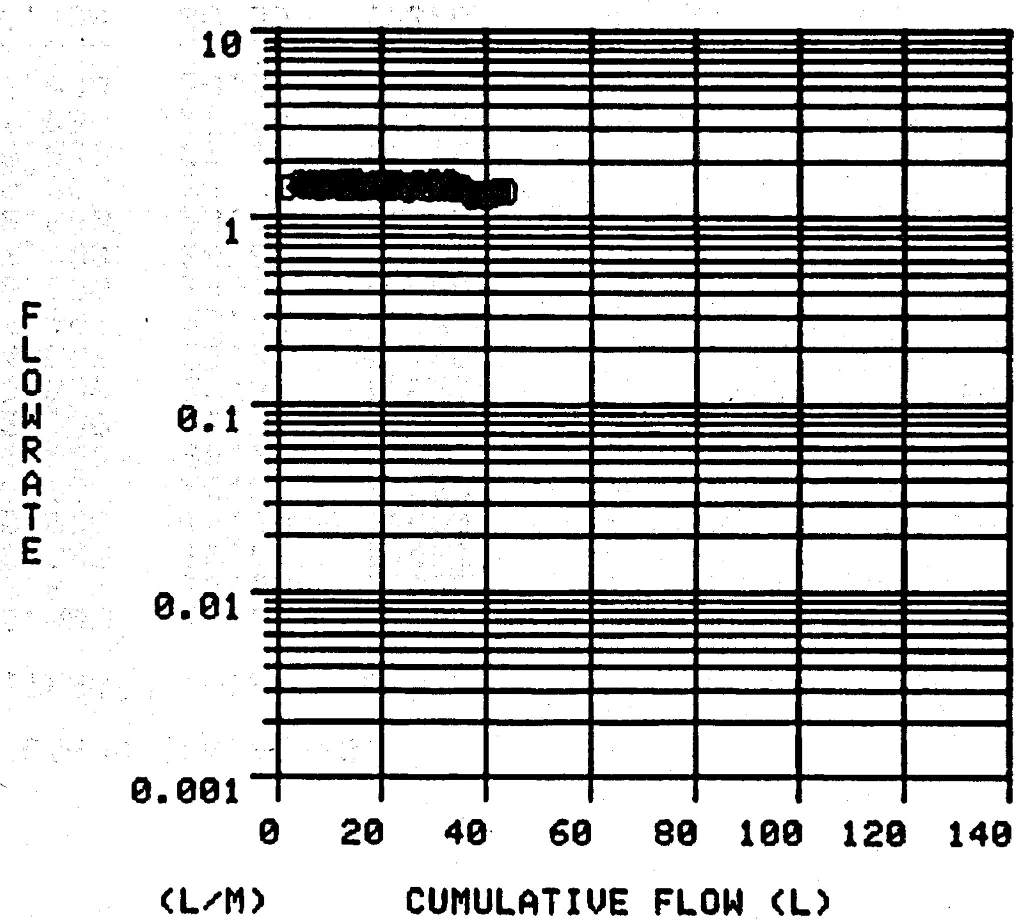
LITRES	MINS	L/MIN
0.200	0.33	0.606
0.400	0.65	0.625
0.600	0.98	0.606
0.800	1.33	0.571
1.000	1.70	0.541
1.200	2.12	0.476
1.400	2.58	0.435
1.600	3.12	0.370
1.800	3.83	0.282
2.000	4.75	0.217
2.200	6.85	0.095
2.400	8.45	0.125
2.600	9.92	0.136



SPR MEMBRANE FILTRATION TEST DATA RUN:8-A
DATE: 2 FEB 79 PSIG:10 FILTER:10.0N SS(MG/L):<.01 VOL(L):44

L'EAU CLAIRE--8-A

LITRES	MINS	L/MIN
2.000	1.38	1.449
4.000	2.68	1.538
5.000	3.35	1.493
6.000	4.02	1.493
7.000	4.67	1.538
8.000	5.35	1.471
9.000	6.00	1.538
10.000	6.67	1.493
11.000	7.32	1.538
12.000	8.00	1.471
13.000	8.63	1.587
14.000	9.32	1.449
15.000	9.95	1.587
16.000	10.63	1.471
17.000	11.30	1.493
18.000	11.97	1.493
19.000	12.62	1.538
20.000	13.32	1.429
21.000	13.97	1.538
22.000	14.65	1.471
23.000	15.30	1.538
24.000	15.97	1.493
25.000	16.68	1.408
26.000	17.35	1.493



L'EAU CLAIRE--8-A

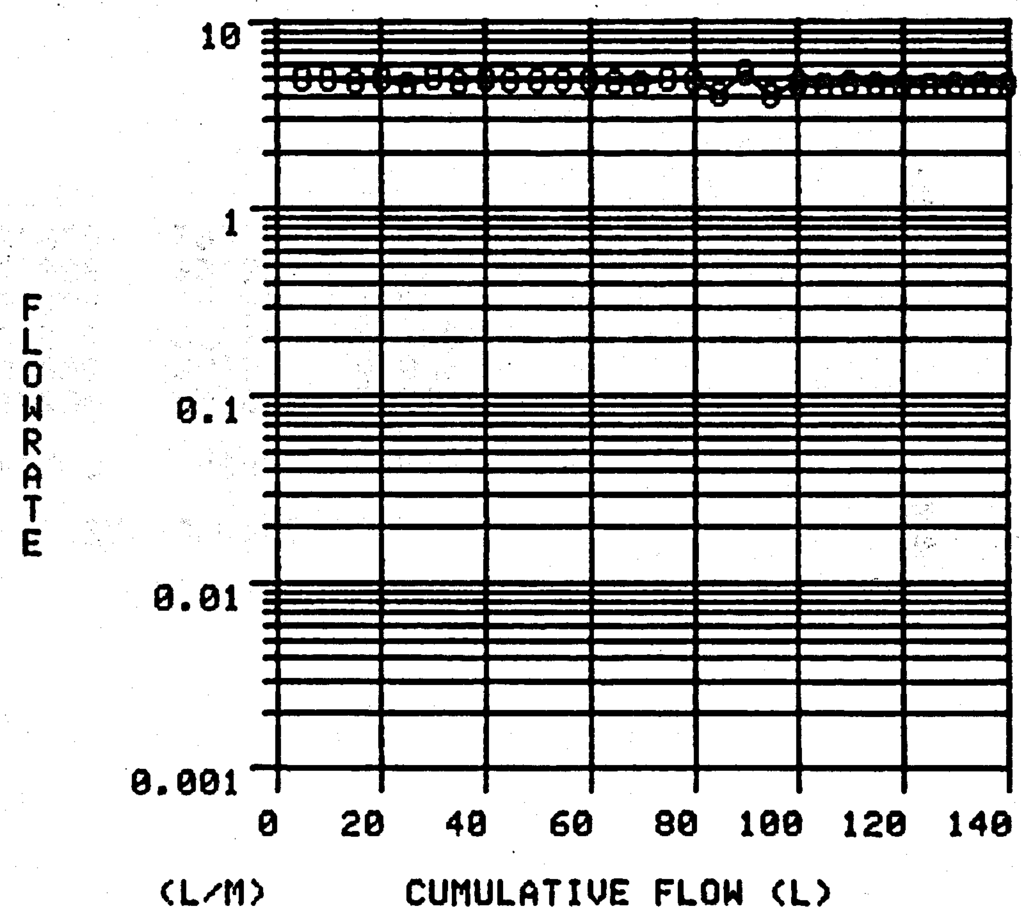
LITRES	MINS	L/MIN
26.000	17.35	1.493
27.000	18.00	1.538
28.000	18.68	1.471
29.000	19.38	1.429
30.000	20.02	1.563
31.000	20.70	1.471
32.000	21.38	1.471
33.000	22.02	1.563
34.000	22.72	1.429
35.000	23.40	1.471
36.000	24.10	1.429
37.000	24.87	1.299
38.000	25.62	1,333
39.000	26.37	1.333
40.000	27.13	1.316
41.000	27.88	1.333
42.000	28.60	1.389
43.000	29.32	1.389
44.000	30.05	1.370

SPR MEMBRANE FILTRATION TEST DATA RUN:8

DATE: 1 FEB 79 PSIG:20 FILTER:10.0N SS(MG/L):<.01 VOL(L):143

L'EAU CLAIRE--8

LITRES	MINS	L/MIN
5.000	1.00	5.000
10.000	2.00	5.000
15.000	3.03	4.854
20.000	4.03	5.000
25.000	5.10	4.673
30.000	6.08	5.102
35.000	7.12	4.808
40.000	8.12	5.000
45.000	9.13	4.950
50.000	10.15	4.902
55.000	11.17	4.902
60.000	12.18	4.950
65.000	13.22	4.808
70.000	14.27	4.762
75.000	15.27	5.000
80.000	16.28	4.950
85.000	17.47	4.202
90.000	18.40	5.376
95.000	19.62	4.098
100.000	20.67	4.762
105.000	21.77	4.545
110.000	22.83	4.717
115.000	23.90	4.673
120.000	24.98	4.630



L'EAU CLAIRE--8

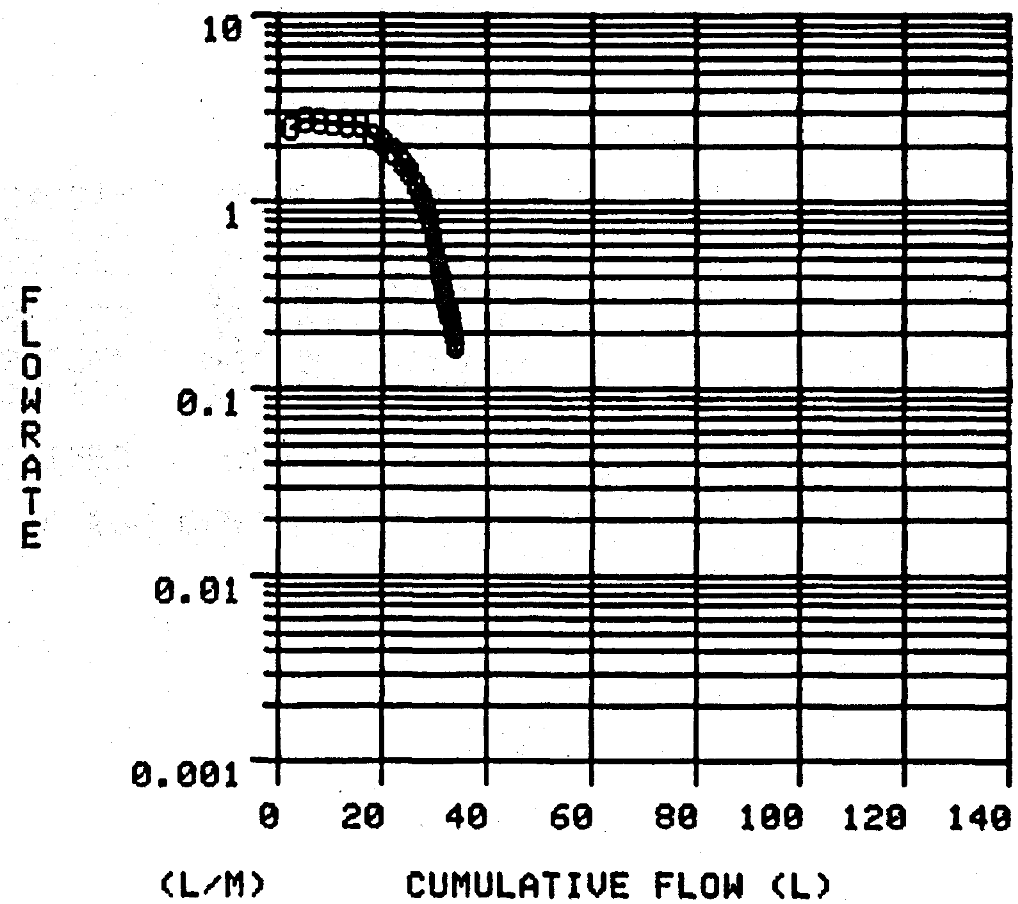
LITRES	MINS	L/MIN
120.000	24.98	4.630
125.000	26.07	4.587
130.000	27.15	4.630
135.000	28.23	4.630
140.000	29.32	4.587
143.000	29.98	4.545

SPR MEMBRANE FILTRATION TEST DATA RUN:N6

DATE: 1 FEB 79 PSIG: 20 FILTER:10.0N SS(MG/L):<.01 VOL(L): 34.02

L'EAU CLAIRE--N6

LITRES	MINS	L/MIN
2.511	1.00	2.511
5.248	2.00	2.737
7.935	3.00	2.687
10.605	4.00	2.670
13.198	5.00	2.593
15.793	6.00	2.595
18.042	7.00	2.249
20.147	8.00	2.105
22.008	9.00	1.861
23.656	10.00	1.648
25.113	11.00	1.457
26.356	12.00	1.243
27.418	13.00	1.062
28.349	14.00	0.931
29.132	15.00	0.783
29.785	16.00	0.653
30.328	17.00	0.543
30.801	18.00	0.473
31.218	19.00	0.417
31.597	20.00	0.379
31.933	21.00	0.336
32.234	22.00	0.301
32.507	23.00	0.273
32.757	24.00	0.250



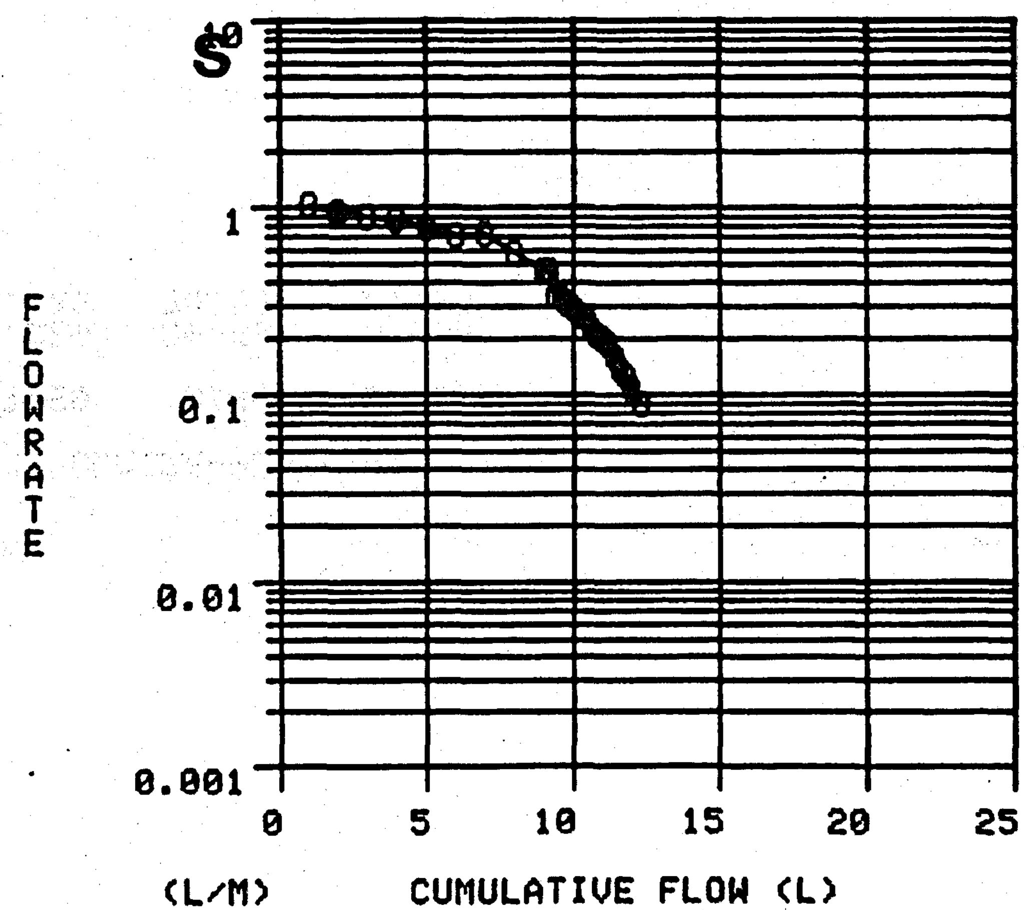
L'EAU CLAIRE--N6

LITRES	MINS	L/MIN
32.757	24.00	0.250
33.012	25.00	0.255
33.244	26.00	0.232
33.459	27.00	0.215
33.661	28.00	0.202
33.843	29.00	0.182
34.016	30.00	0.173

SPR MEMBRANE FILTLRATION TEST DATA RUN:--N1
DATE: 3 FEB 79 PSIG: 50 FILTER: 0.45M SS(MG/L): .18 VOL(L): 12.3

L'EAU CLAIRE--LAKE WATER

LITRES	MINS	L/MIN
1.000	0.97	1.031
2.000	2.03	0.943
3.000	3.15	0.893
4.000	4.30	0.870
5.000	5.58	0.781
6.000	6.97	0.719
7.000	8.33	0.735
8.000	10.05	0.581
9.000	12.20	0.465
9.200	12.63	0.465
9.400	13.22	0.339
9.600	13.82	0.333
9.800	14.47	0.308
10.000	15.15	0.294
10.200	15.90	0.267
10.400	16.67	0.260
10.600	17.53	0.233
10.800	18.48	0.211
11.000	19.48	0.200
11.200	20.55	0.187
11.400	21.80	0.160
11.600	23.25	0.138
11.800	24.83	0.127
12.000	26.68	0.108



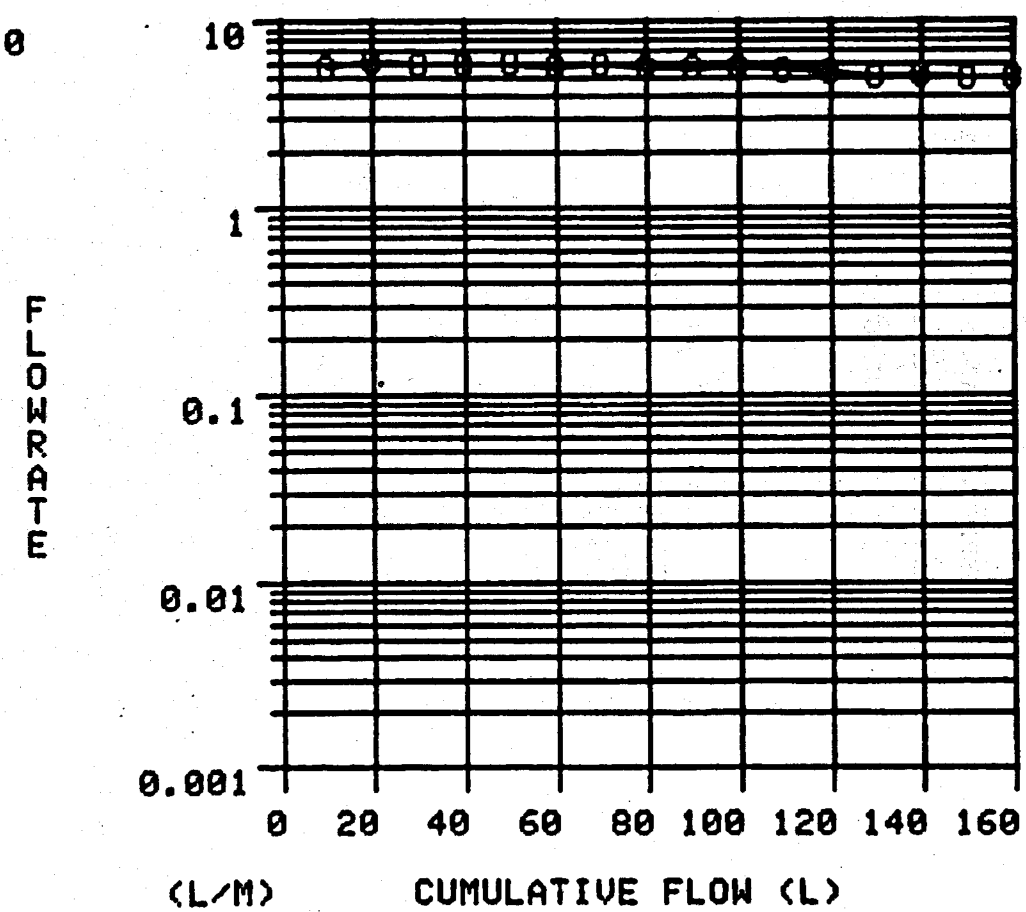
L'EAU CLAIRE--LAKE WATER

LITRES	MINS	L/MIN
12.000	26.68	0.108
12.300	30.02	0.090

SPR MEMBRANE FILTRATION TEST DATA RUN:N-10
DATE: 3 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L):.01 VOL(L):160

L'EAU CLAIRE: LAKE WATER-N10

LITRES	MINS	L/MIN
10.000	1.75	5.714
20.000	3.38	6.135
30.000	5.07	5.917
40.000	6.75	5.952
50.000	8.42	5.988
60.000	10.15	5.780
70.000	11.83	5.952
80.000	13.57	5.747
90.000	15.33	5.682
100.000	17.08	5.714
110.000	18.88	5.556
120.000	20.72	5.435
130.000	22.67	5.128
140.000	24.60	5.181
150.000	26.58	5.051
160.000	28.58	5.000



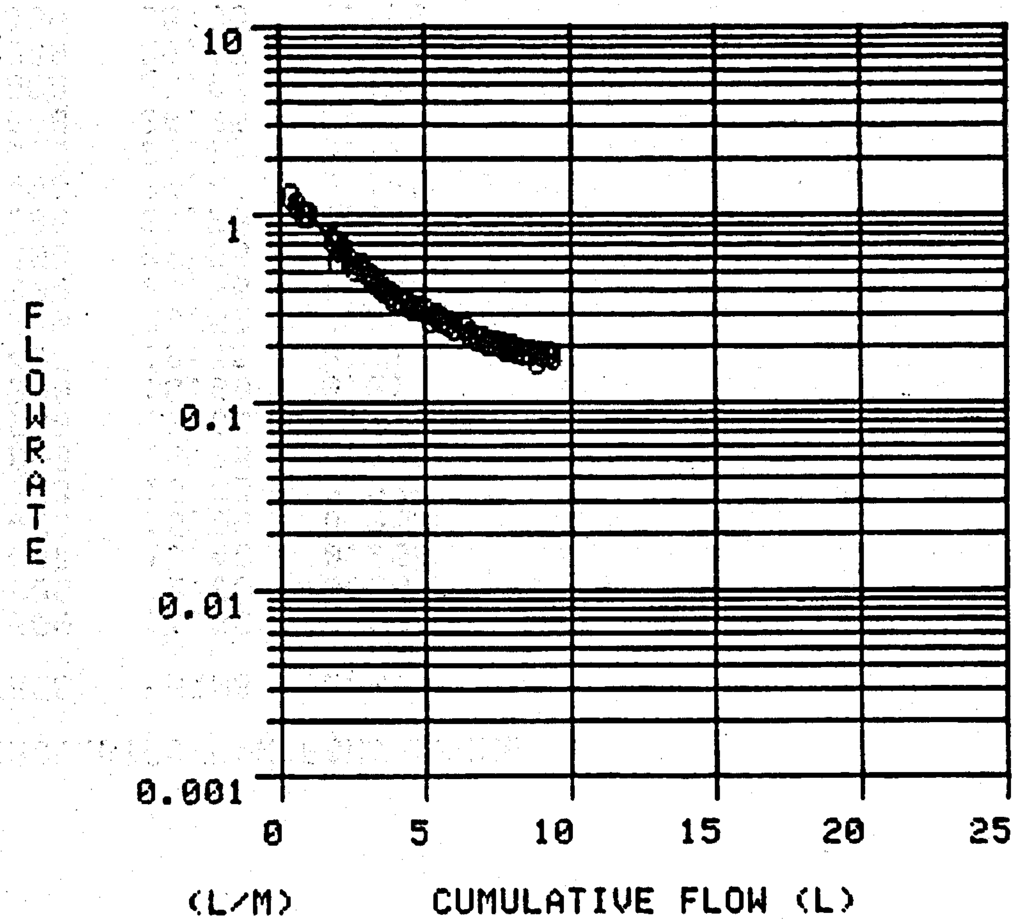
APPENDIX XII

EXPERIMENTAL DATA FROM THE FILTER INJECTION TESTS PERFORMED AT BRYAN MOUND

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-1
DATE: 23 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 2.78 VOL(L): 9.4

RECIRCULATED RAW POND BRINE

LITRES	MINS	L/MIN
0.400	0.32	1.250
0.600	0.50	1.111
0.800	0.70	1.000
1.000	0.90	1.000
1.800	2.00	0.741
2.000	2.35	0.571
2.200	2.65	0.667
2.400	3.00	0.571
2.600	3.38	0.526
2.800	3.75	0.541
3.000	4.15	0.500
3.200	4.58	0.465
3.400	5.05	0.426
3.600	5.55	0.400
3.800	6.08	0.377
4.000	6.65	0.351
4.200	7.23	0.345
4.400	7.82	0.339
4.600	8.45	0.317
4.800	9.08	0.317
5.000	9.73	0.308
5.200	10.45	0.278
5.400	11.13	0.294
5.600	11.85	0.278



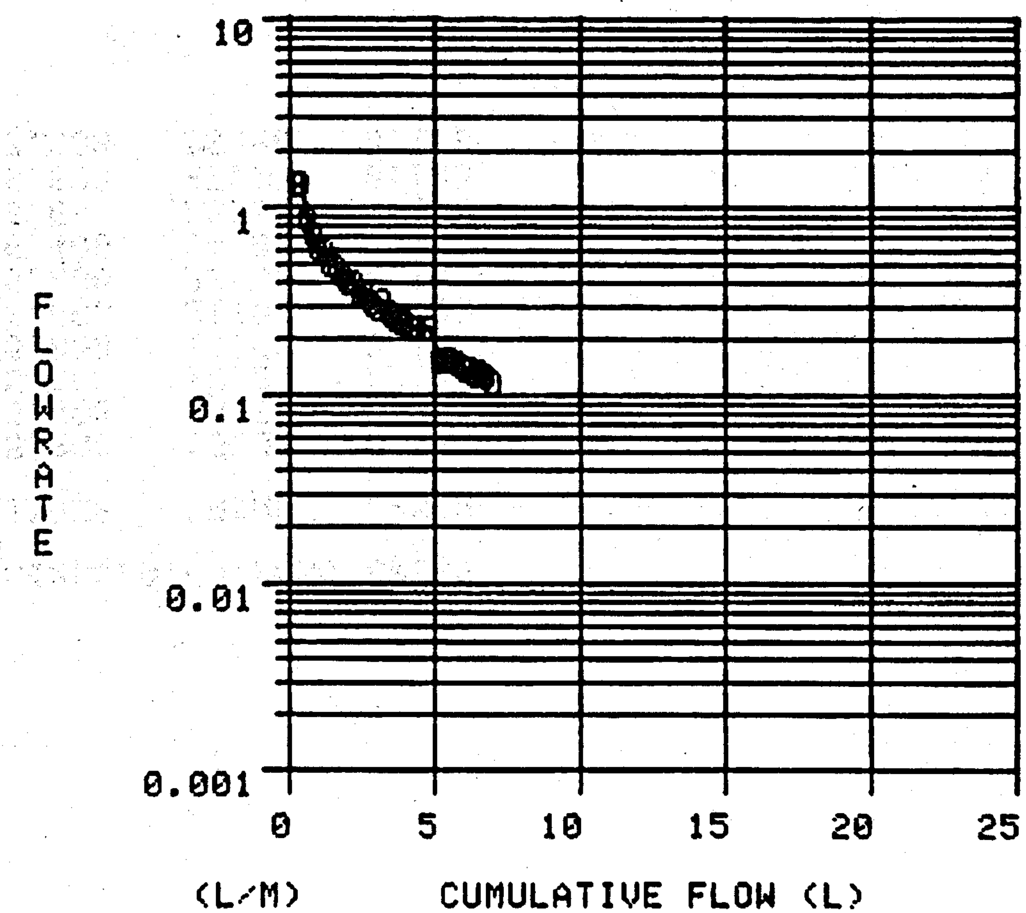
RECIRCULATED RAW POND BRINE

LITRES	MINS	L/MIN
5.600	11.85	0.278
5.800	12.60	0.267
6.000	13.40	0.250
6.400	15.00	0.250
6.600	15.85	0.235
6.800	16.75	0.222
7.000	17.65	0.222
7.200	18.60	0.211
7.400	19.55	0.211
7.600	20.52	0.206
7.800	21.55	0.194
8.000	22.55	0.200
8.200	23.60	0.190
8.400	24.68	0.185
8.600	25.75	0.187
8.800	26.95	0.167
9.000	28.05	0.182
9.200	29.15	0.182
9.350	30.00	0.176

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-2
DATE:24 FEB 79 PSIG: 50 FILTER: 0.4M SS(MG/L): 3.17 VOL(L): 7.2

RECIRCULATED POND BRINE

LITRES	MINS	L/MIN
0.200	0.15	1.333
0.400	0.30	1.333
0.600	0.53	0.870
0.800	0.81	0.714
1.000	1.14	0.606
1.200	1.48	0.588
1.400	1.88	0.500
1.600	2.29	0.488
1.800	2.75	0.435
2.000	3.25	0.400
2.200	3.75	0.400
2.400	4.34	0.339
2.600	4.91	0.351
2.800	5.56	0.308
3.000	6.25	0.290
3.200	6.88	0.317
3.400	7.60	0.278
3.600	8.38	0.256
3.800	9.19	0.247
4.000	10.00	0.247
4.200	10.88	0.227
4.400	11.75	0.230
4.800	13.50	0.229
5.200	15.60	0.154



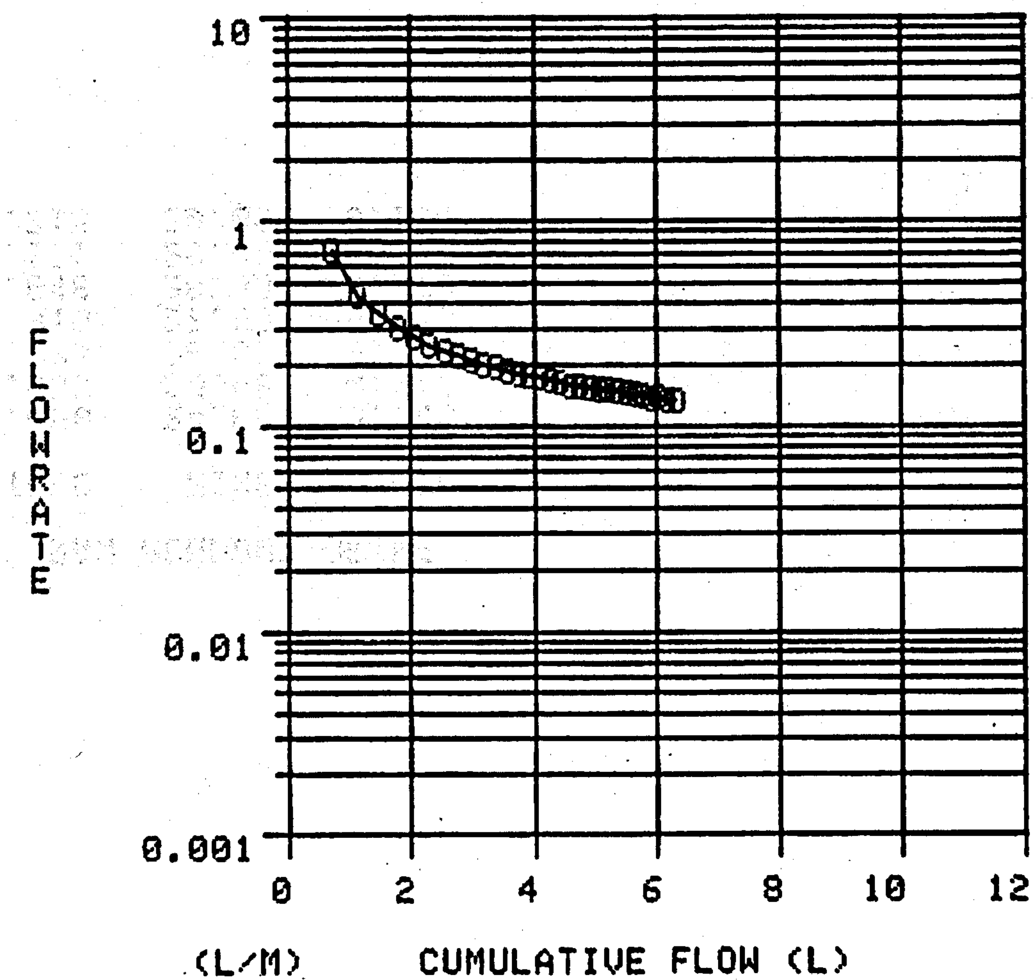
RECIRCULATED POND BRINE

LITRES	MINS	L/MIN
5.200	15.60	0.154
5.400	16.90	0.154
5.600	18.20	0.154
5.800	19.55	0.148
6.000	21.00	0.138
6.200	22.45	0.138
6.400	24.00	0.129
6.600	25.50	0.133
6.800	27.10	0.125
7.000	28.80	0.118

SPR MEMBRANE FILTRATION TEST DATA RUN: BM-7
DATE: 26 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 6.3 VOL(L): 6.32

RAW PONDOUT BRINE

LITRES	MINS	L/MIN
0.716	1.00	0.716
1.146	2.00	0.430
1.496	3.00	0.350
1.800	4.00	0.304
2.073	5.00	0.273
2.321	6.00	0.248
2.555	7.00	0.234
2.777	8.00	0.222
2.986	9.00	0.209
3.186	10.00	0.200
3.380	11.00	0.194
3.566	12.00	0.186
3.747	13.00	0.181
3.923	14.00	0.176
4.096	15.00	0.173
4.264	16.00	0.168
4.428	17.00	0.164
4.586	18.00	0.158
4.742	19.00	0.156
4.896	20.00	0.154
5.047	21.00	0.151
5.197	22.00	0.150
5.345	23.00	0.148
5.490	24.00	0.145



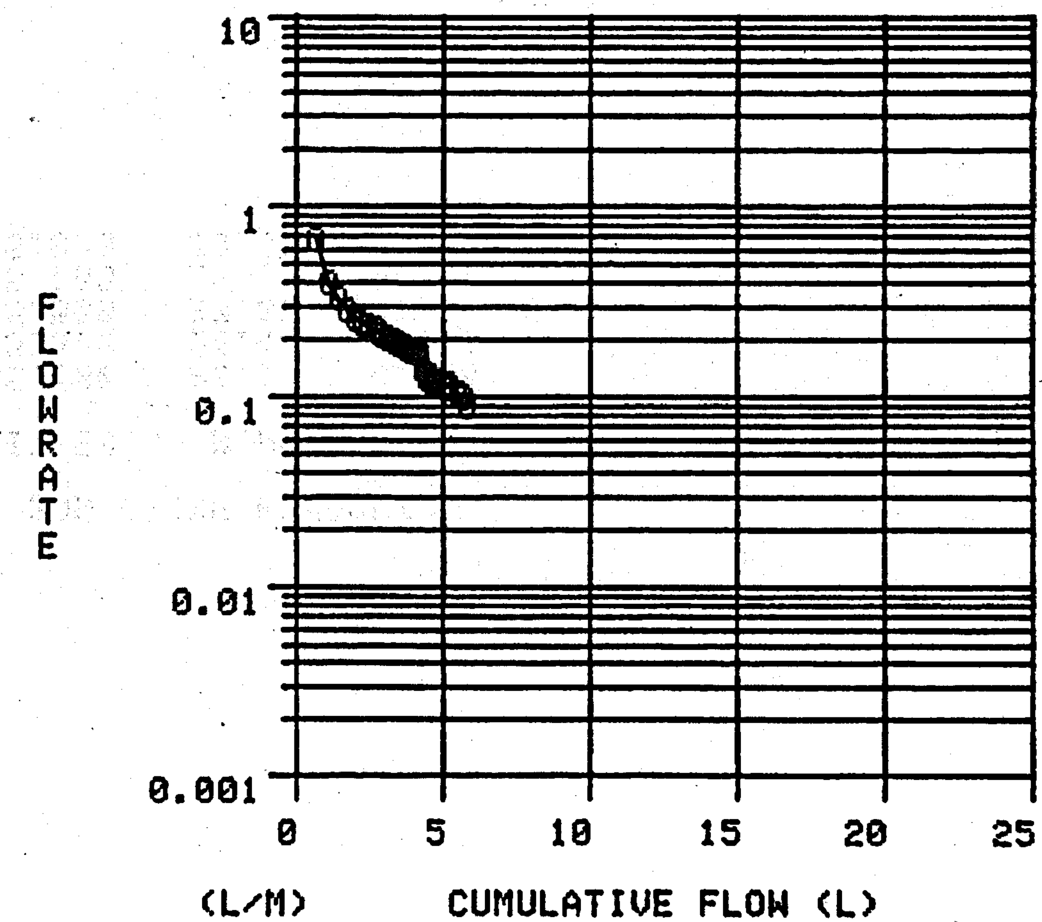
RAW PONDOUT BRINE

LITRES	MINS	L/MIN
5.490	24.00	0.145
5.633	25.00	0.143
5.774	26.00	0.141
5.910	27.00	0.136
6.048	28.00	0.138
6.181	29.00	0.133
6.315	30.00	0.134

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-11
DATE: 27 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 5.53 VOL(L):5.96

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
0.684	1.00	0.684
1.088	2.00	0.404
1.418	3.00	0.330
1.704	4.00	0.286
1.964	5.00	0.260
2.211	6.00	0.247
2.447	7.00	0.236
2.676	8.00	0.229
2.888	9.00	0.212
3.094	10.00	0.206
3.291	11.00	0.197
3.481	12.00	0.190
3.665	13.00	0.184
3.842	14.00	0.177
4.015	15.00	0.173
4.185	16.00	0.170
4.300	16.93	0.137
4.400	17.73	0.125
4.500	18.55	0.122
4.600	19.33	0.128
4.700	20.17	0.119
4.800	21.00	0.120
5.000	22.72	0.116
5.100	23.60	0.114



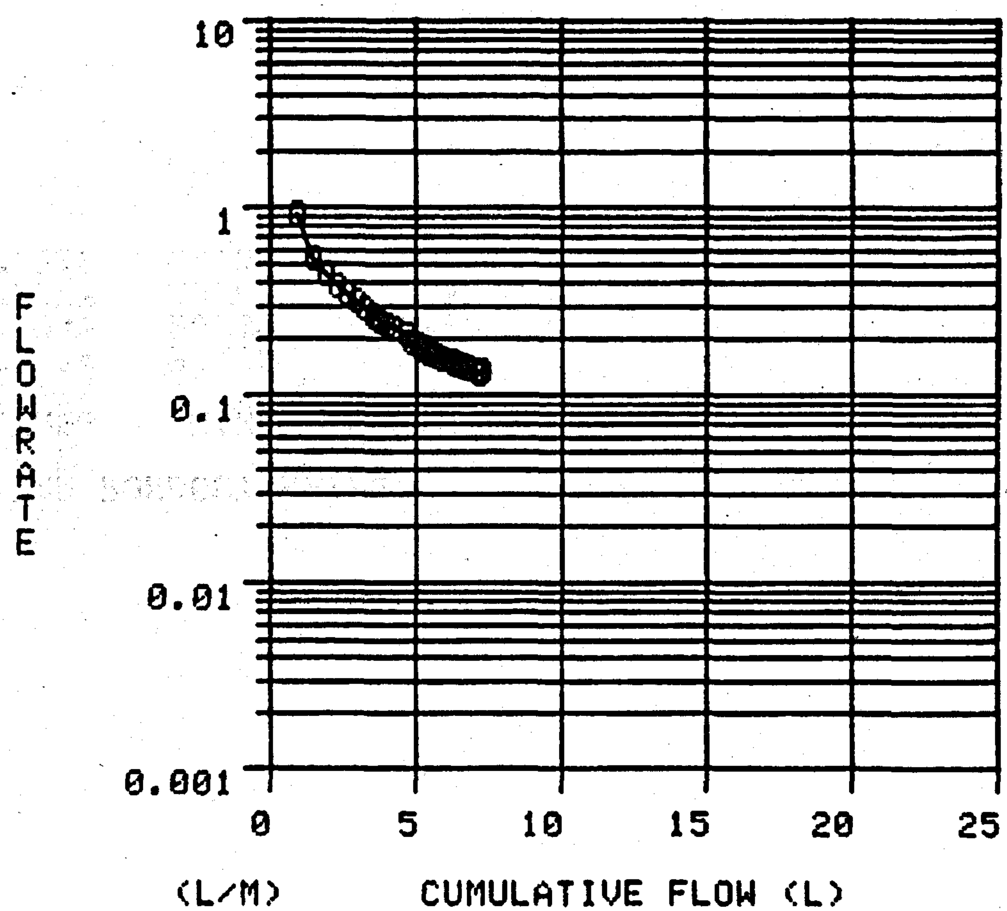
RAW BRINE PONDOUT

LITRES	MINS	L/MIN
5.100	23.60	0.114
5.200	24.45	0.118
5.500	27.33	0.104
5.700	29.33	0.100
5.800	30.45	0.089

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-17
DATE: 28 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L):-- VOL(L): 7.31

RAW PONDOUT BRINE

LITRES	MINS	L/MIN
0.930	1.00	0.930
1.475	2.00	0.545
1.921	3.00	0.446
2.309	4.00	0.388
2.657	5.00	0.348
2.974	6.00	0.317
3.264	7.00	0.290
3.531	8.00	0.267
3.784	9.00	0.253
4.023	10.00	0.239
4.251	11.00	0.228
4.677	13.00	0.213
4.869	14.00	0.192
5.056	15.00	0.187
5.234	16.00	0.178
5.404	17.00	0.170
5.571	18.00	0.167
5.734	19.00	0.163
5.893	20.00	0.159
6.199	22.00	0.153
6.347	23.00	0.148
6.492	24.00	0.145
6.634	25.00	0.142
6.774	26.00	0.140



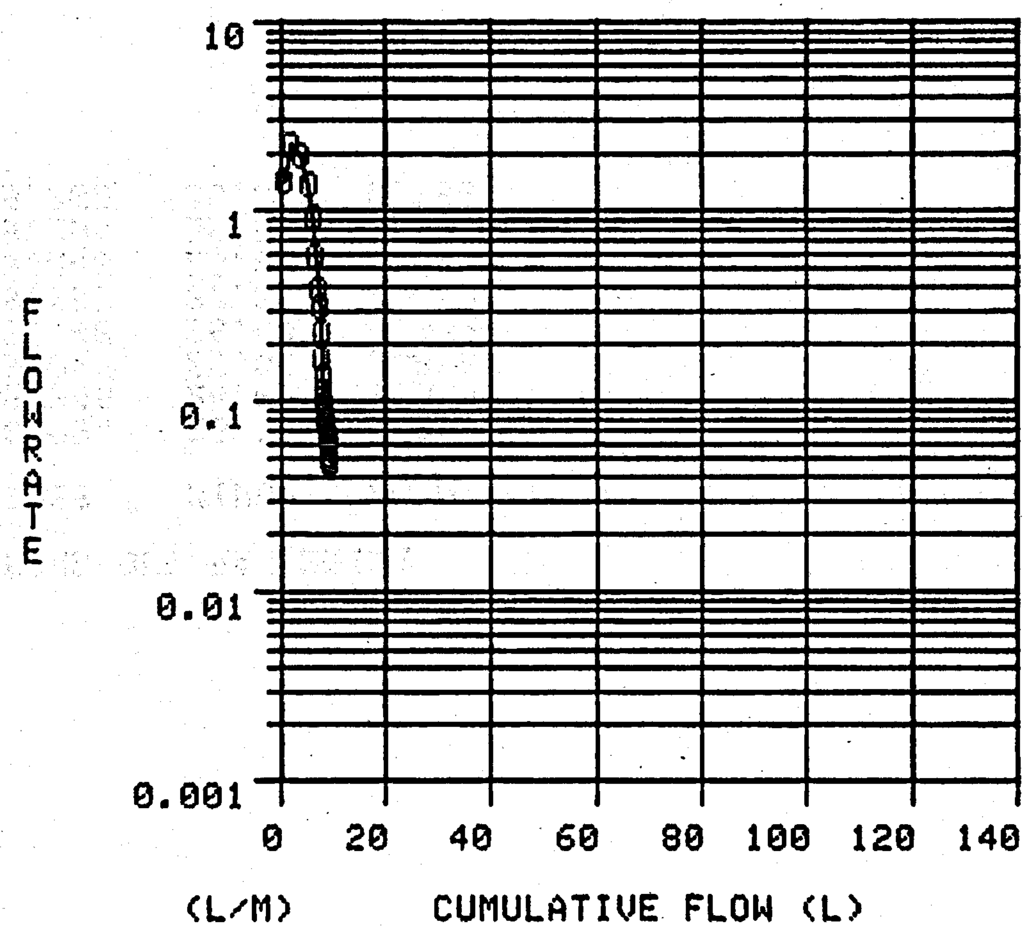
RAW PONDOUT BRINE

LITRES	MINS	L/MIN
6.774	26.00	0.140
7.045	28.00	0.136
7.175	29.00	0.130
7.310	30.00	0.135

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-3
DATE: 23 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L): .214 VOL(L): 9.4

POND OUT RAW BRINE

LITRES	MINS	L/MIN
0.722	0.50	1.444
1.843	1.00	2.242
3.792	2.00	1.949
5.178	3.00	1.386
6.109	4.00	0.931
6.696	5.00	0.587
7.086	6.00	0.390
7.402	7.00	0.316
7.634	8.00	0.232
7.805	9.00	0.171
7.940	10.00	0.135
8.053	11.00	0.113
8.157	12.00	0.104
8.253	13.00	0.096
8.344	14.00	0.091
8.430	15.00	0.086
8.509	16.00	0.079
8.586	17.00	0.077
8.660	18.00	0.074
8.733	19.00	0.073
8.802	20.00	0.069
8.870	21.00	0.068
8.935	22.00	0.065
8.994	23.00	0.059



497

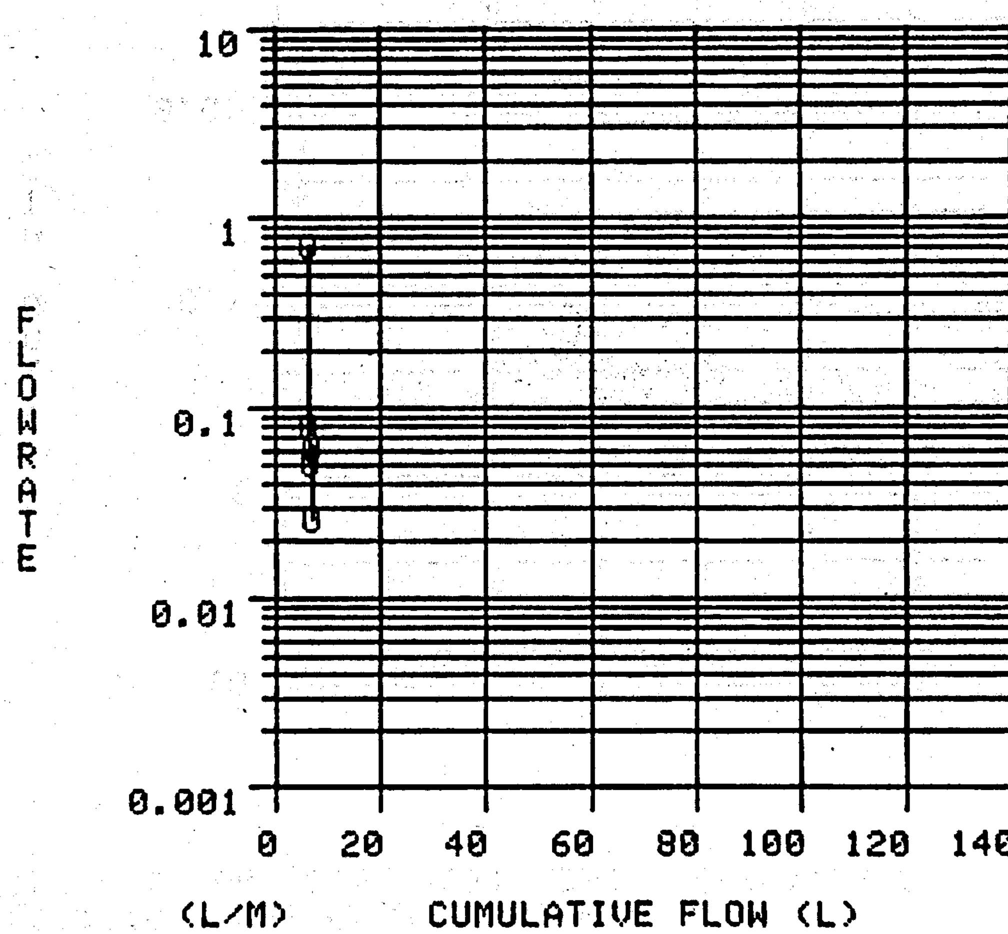
POND OUT RAW BRINE

LITRES	MINS	L/MIN
8.994	23.00	0.059
9.046	24.00	0.052
9.096	25.00	0.050
9.148	26.00	0.052
9.197	27.00	0.049
9.246	28.00	0.049
9.294	29.00	0.048
9.360	30.00	0.066

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-4
DATE: 24 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L):.44 VOL(L): 7.0

RAW BRINE POND OUT

LITRES	MINS	L/MIN
6.200	8.62	0.720
6.400	11.12	0.080
6.600	15.00	0.052
6.800	18.20	0.063
7.000	25.92	0.026

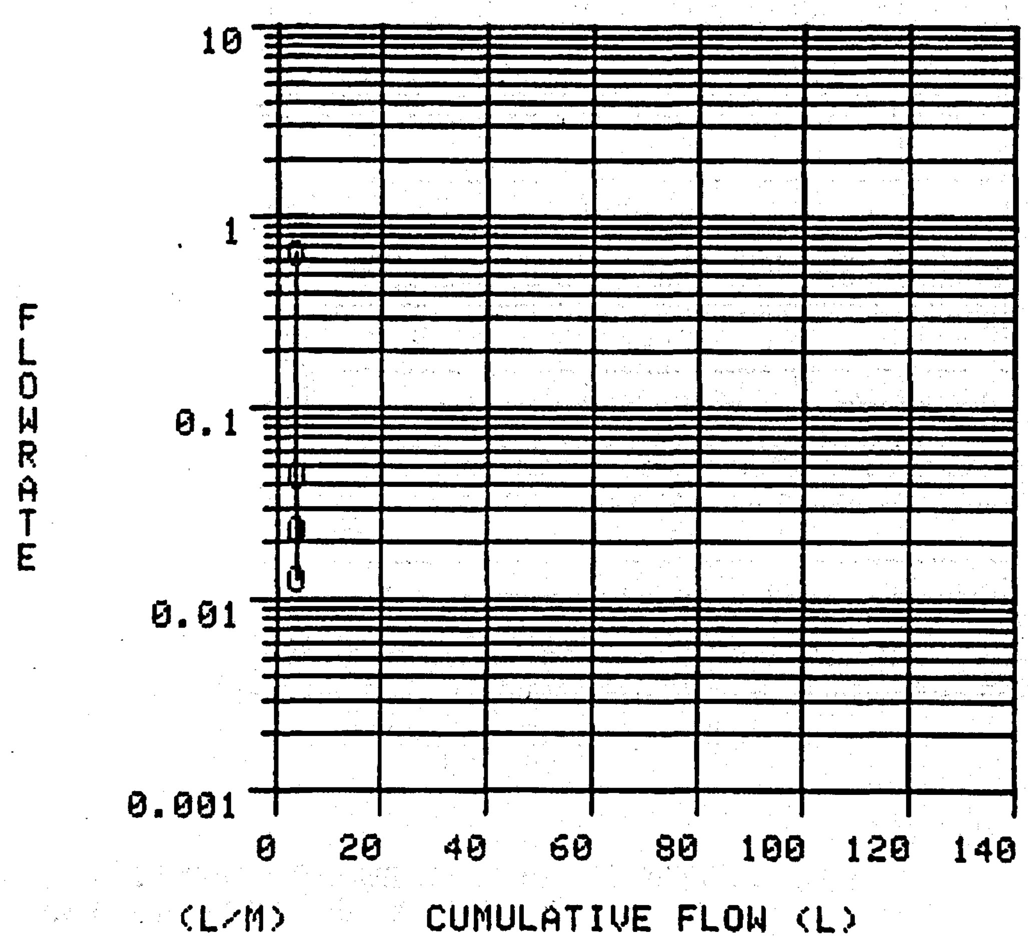


SPR MEMBRANE FILTRATION TEST DATA RUN:BM-5
DATE: 26 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L): .293 VOL(L): 3.8

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
3.500	5.38	0.650
3.600	7.63	0.044
3.700	11.92	0.023
3.750	15.83	0.013

500

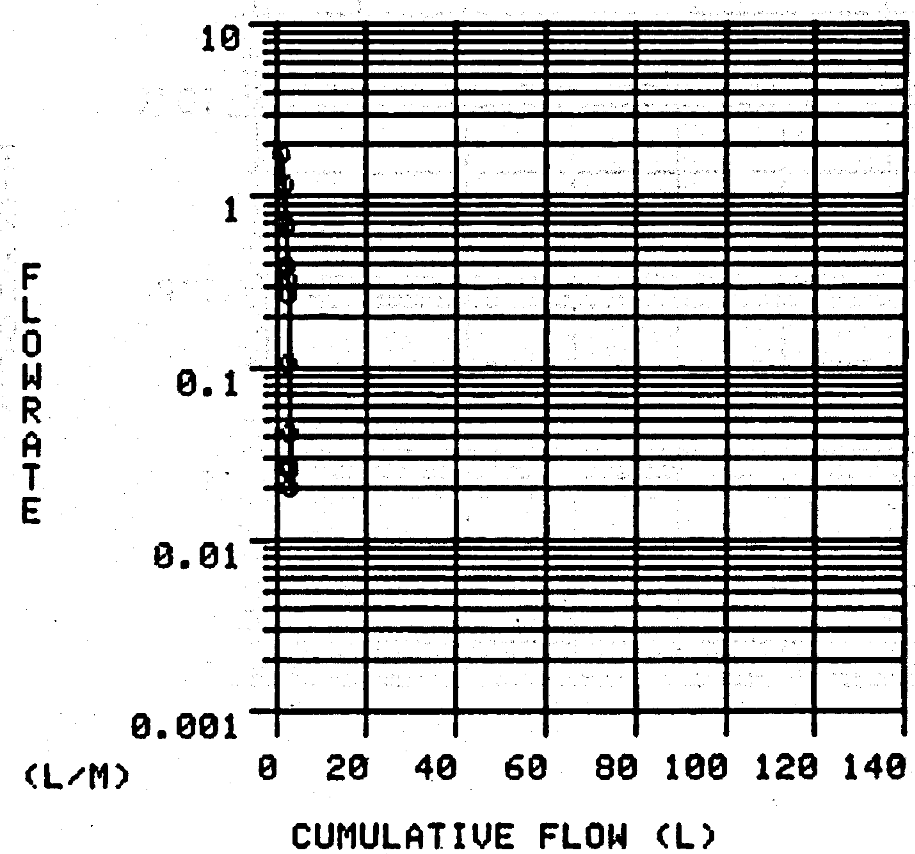


SPR MEMBRANE FILTRATION TEST DATA RUN:BM-6

DATE: 27 FEB 79 PSIG: 6 FILTER: 10N SS(mg/L): 1.03 VOL(L): 3.01

RAW SURGE POND

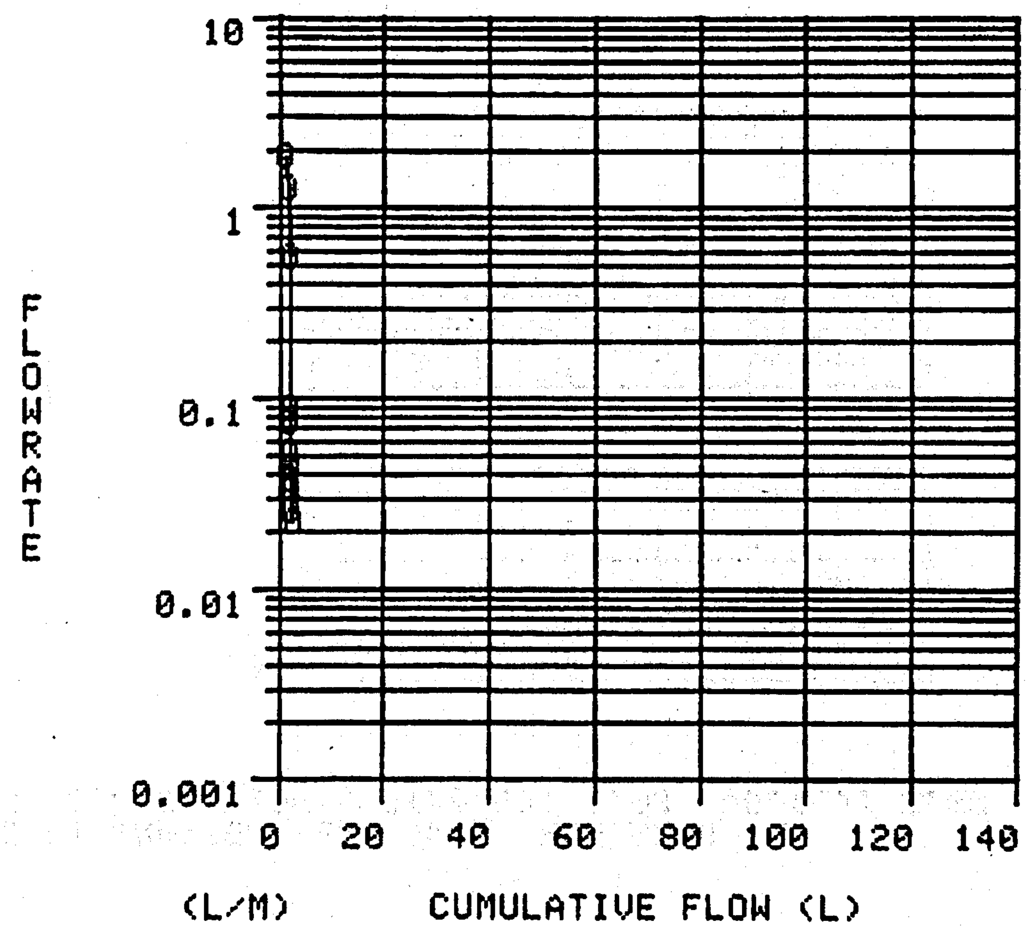
LITRES	MINS	L/MIN
0.903	0.50	1.780
1.625	1.00	1.170
2.077	1.50	0.680
2.334	2.00	0.390
2.400	2.20	0.330
2.500	2.57	0.270
2.700	4.42	0.108
2.800	6.17	0.027
2.900	8.55	0.042
3.000	12.33	0.026
3.010	12.83	0.020



SPR MEMBRANE FILTRATION TEST DATA RUN:BM-8
DATE: 28 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L): 1.1 VOL(L): 2.4

RAW BRINE PONDOUT

LITRES	MINS	L/MIN
0.939	0.50	1.878
1.586	1.00	1.294
1.867	1.50	0.562
1.886	2.00	0.038
1.931	2.50	0.090
1.969	3.00	0.076
2.000	3.58	0.053
2.100	5.83	0.044
2.200	8.75	0.034
2.300	12.58	0.026
2.355	15.00	0.023

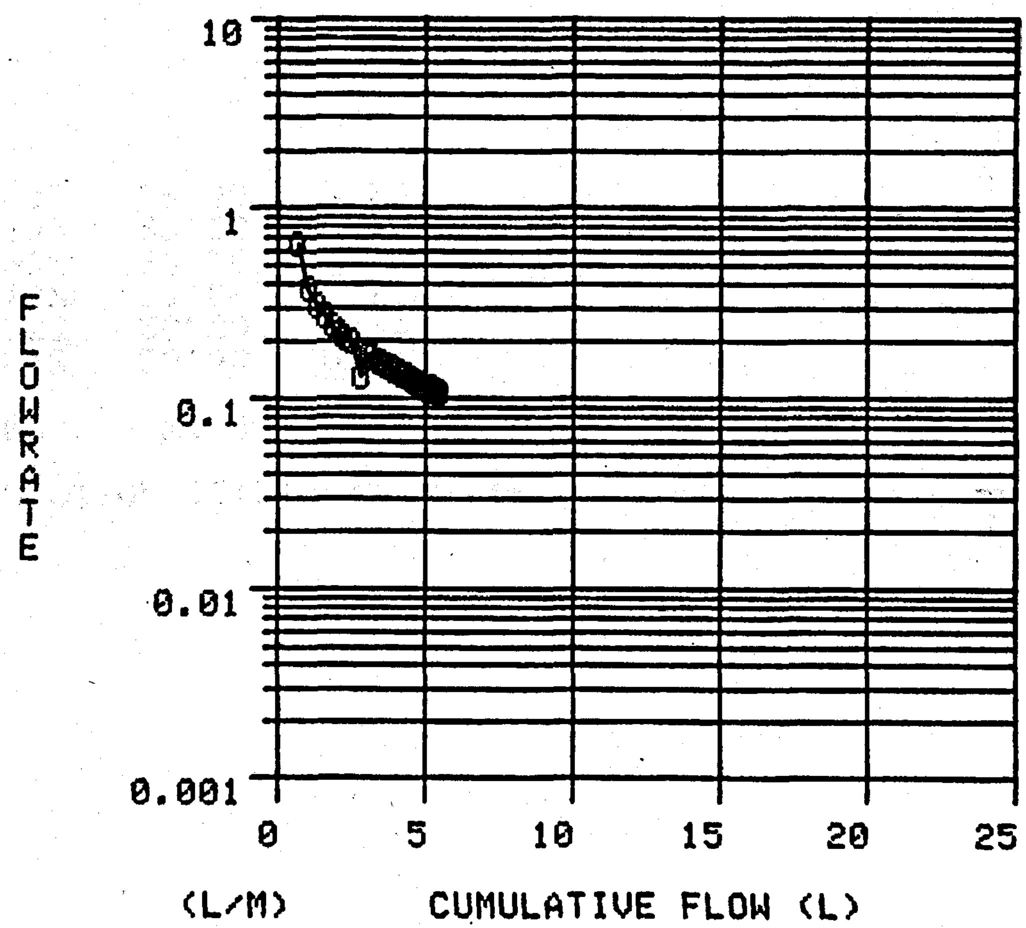


SPR MEMBRANE FILTRATION TEST DATA RUN:BM-9

DATE: 27 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L): -- VOL(L): 5.49

REINJECTION SITE: RAW BRINE

LITRES	MINS	L/MIN
0.659	1.00	0.659
1.040	2.00	0.381
1.350	3.00	0.310
1.620	4.00	0.270
1.860	5.00	0.240
2.080	6.00	0.220
2.290	7.00	0.210
2.490	8.00	0.200
2.850	10.00	0.130
3.019	11.00	0.169
3.184	12.00	0.165
3.342	13.00	0.158
3.497	14.00	0.155
3.646	15.00	0.149
3.792	16.00	0.146
3.932	17.00	0.140
4.070	18.00	0.138
4.204	19.00	0.134
4.336	20.00	0.132
4.463	21.00	0.127
4.587	22.00	0.124
4.708	23.00	0.121
4.828	24.00	0.120
4.943	25.00	0.115



503

REINJECTION SITE: RAW BRINE

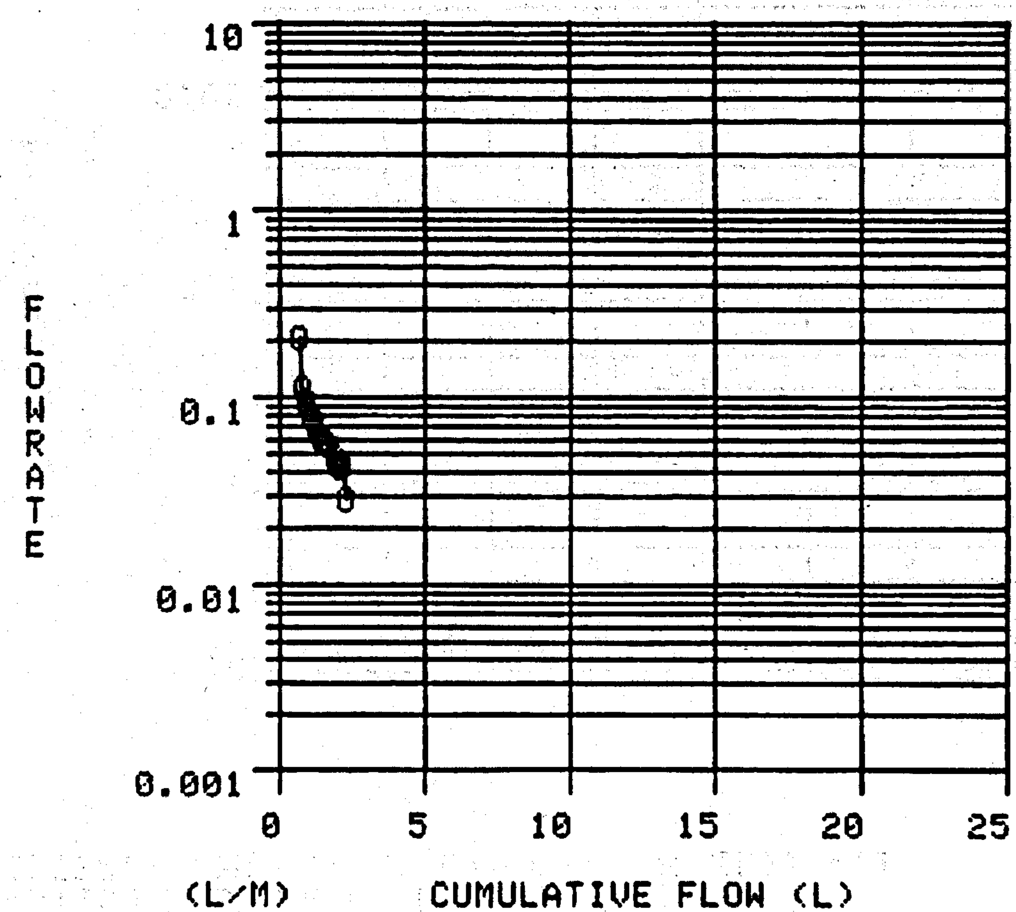
LITRES	MINS	L/MIN
4.943	25.00	0.115
5.053	26.00	0.110
5.167	27.00	0.114
5.276	28.00	0.109
5.383	29.00	0.107
5.488	30.00	0.105

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-14

DATE: 28 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L): 6.8 VOL(L): 2.3

REINJECTION SITE: BM-14

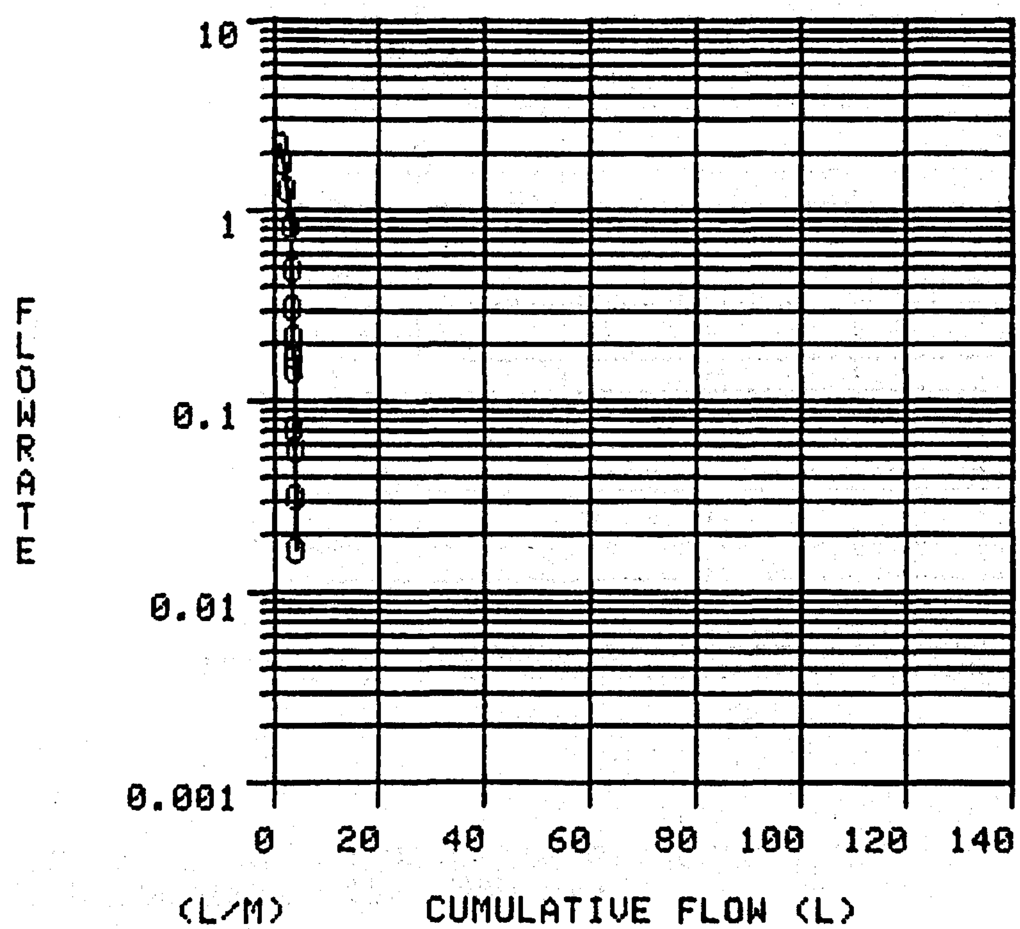
LITRES	MINS	L/MIN
0.650	3.12	0.208
0.750	4.00	0.114
0.850	5.03	0.097
0.950	6.17	0.088
1.050	7.42	0.080
1.150	8.75	0.075
1.250	10.17	0.070
1.350	11.72	0.065
1.450	13.42	0.059
1.550	15.15	0.058
1.650	16.93	0.056
1.850	21.08	0.048
1.950	23.33	0.044
2.050	25.67	0.043
2.150	28.00	0.043
2.250	31.48	0.029



SPR MEMBRANE FILTRATION TEST DATA RUN:BM-10
DATE: 27 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L):.024 VOL(L): 4.1

REINJECTION SITE-RAW BRINE

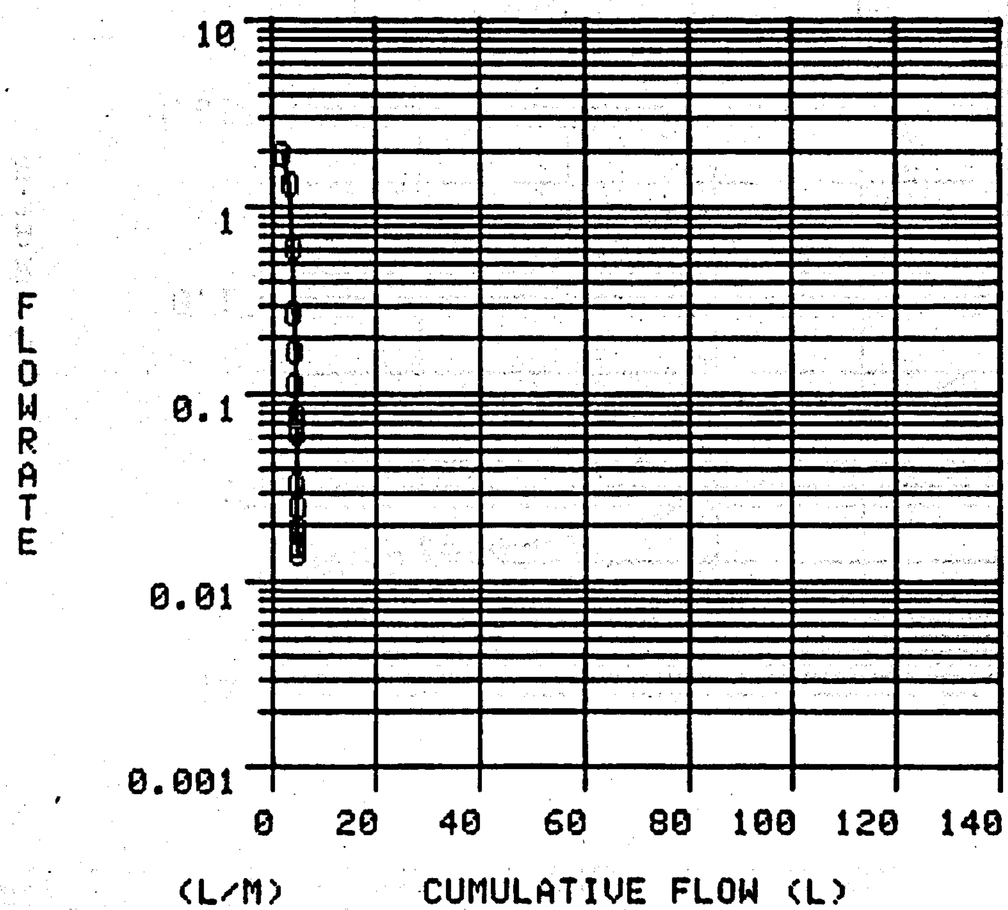
LITRES	MINS	L/MIN
1.106	0.50	2.212
1.998	1.00	1.784
2.638	1.50	1.280
3.055	2.00	0.834
3.302	2.50	0.494
3.455	3.00	0.306
3.564	3.50	0.218
3.651	4.00	0.174
3.724	4.50	0.146
3.800	5.55	0.072
3.900	7.33	0.056
4.000	10.50	0.032
4.100	16.50	0.017



SPR MEMBRANE FILTRATION TEST DATA RUN:BM-12
DATE 28 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L): 6.3 VOL(L): 5.0

REINJECTION SITE: BM-12

LITRES	MINS	L/MIN
1.923	1.00	1.923
3.255	2.00	1.332
3.864	3.00	0.609
4.132	4.00	0.268
4.217	4.50	0.170
4.400	6.13	0.112
4.500	7.42	0.078
4.600	9.00	0.063
4.700	12.00	0.033
4.800	16.00	0.025
4.900	21.16	0.019
5.000	28.10	0.014
5.030	30.00	0.016

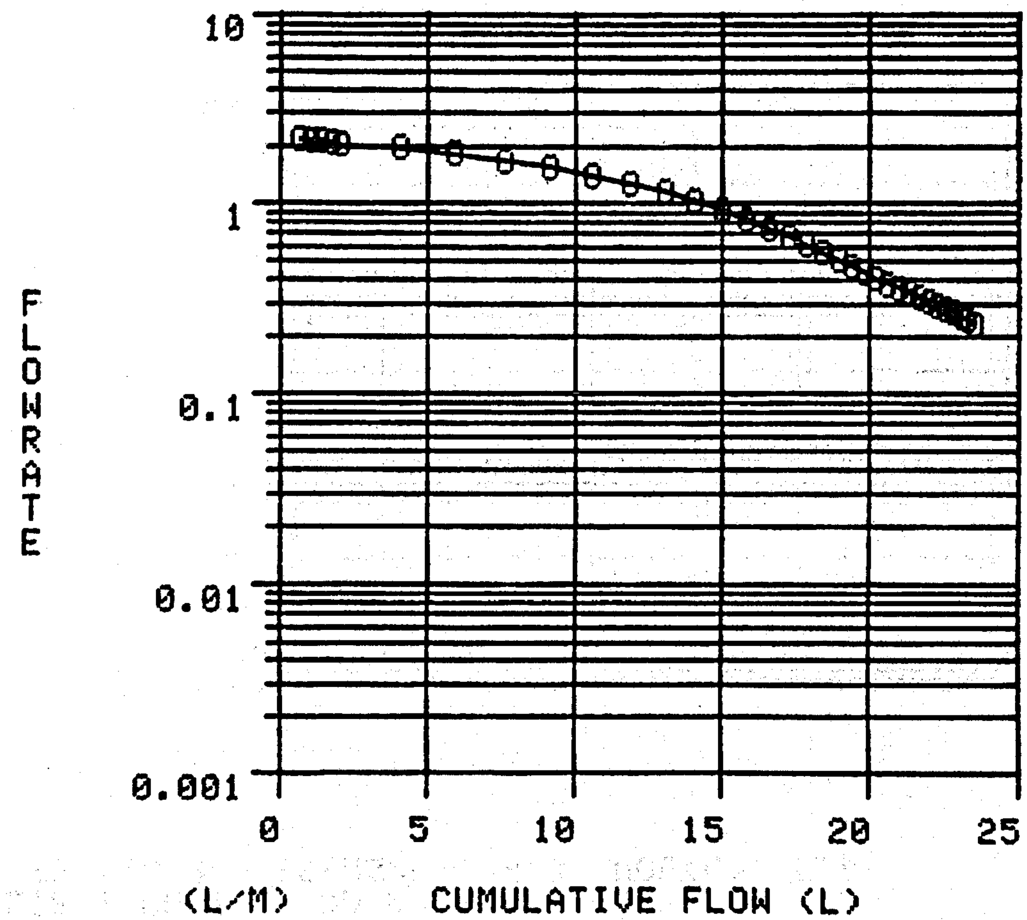


SPR MEMBRANE FILTRATION TEST DATA RUN:BM-13

DATE: 26 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L):.042 VOL(L): 23.6

ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
0.667	0.33	2.199
1.031	0.50	2.180
1.390	0.67	2.150
1.743	0.83	2.127
2.086	1.00	2.054
4.078	2.00	1.992
5.927	3.00	1.849
7.619	4.00	1.692
9.182	5.00	1.563
10.600	6.00	1.418
11.886	7.00	1.286
13.047	8.00	1.161
14.095	9.00	1.048
15.026	10.00	0.931
15.859	11.00	0.833
16.604	12.00	0.745
17.279	13.00	0.675
17.889	14.00	0.610
18.447	15.00	0.558
18.961	16.00	0.514
19.432	17.00	0.471
19.871	18.00	0.439
20.277	19.00	0.406
20.661	20.00	0.384



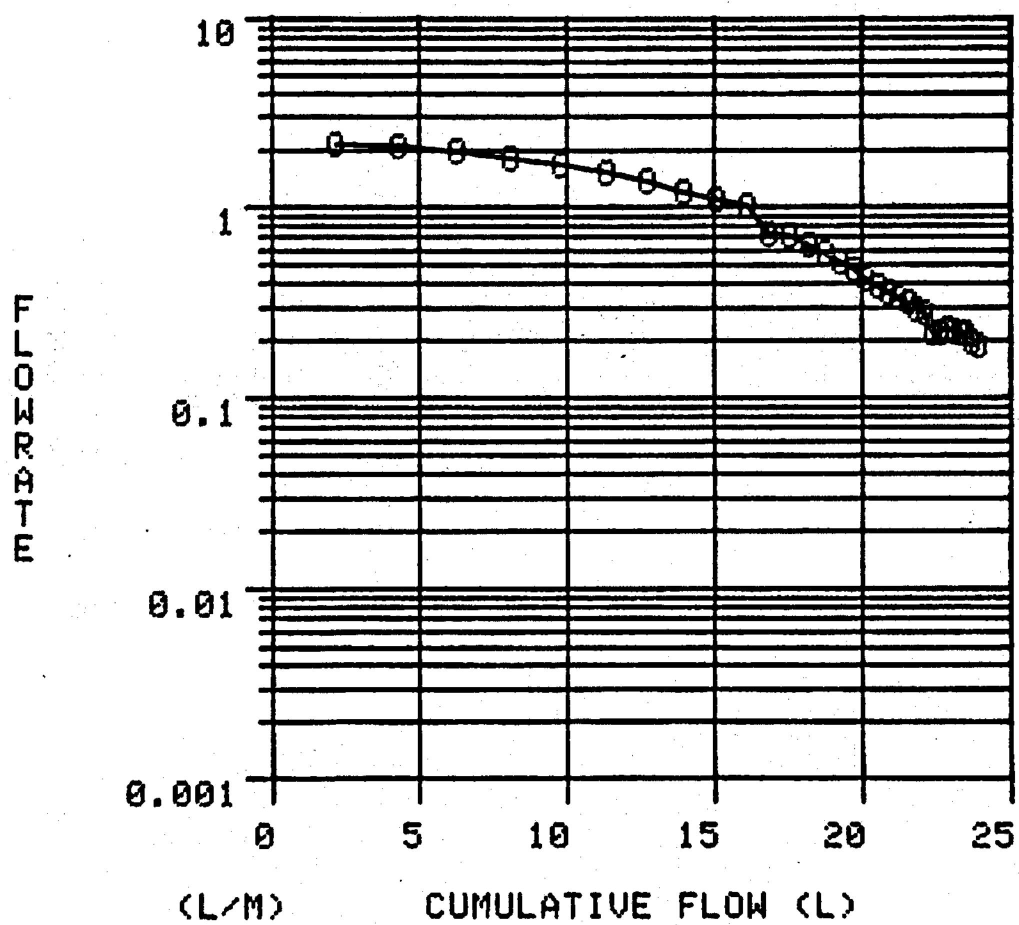
ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
20.661	20.00	0.384
21.024	21.00	0.363
21.369	22.00	0.345
21.695	23.00	0.326
22.004	24.00	0.309
22.297	25.00	0.293
22.577	26.00	0.280
22.847	27.00	0.270
23.104	28.00	0.257
23.350	29.00	0.246
23.585	30.00	0.235

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-15
DATE: 27 FEB 79 PSIG: 44 FILTER: 0.4N SS(MG/L):.013 VOL(L): 23.4

ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
2.171	1.00	2.171
4.311	2.00	2.140
6.293	3.00	1.982
8.129	4.00	1.836
9.830	5.00	1.701
11.376	6.00	1.546
12.753	7.00	1.377
13.972	8.00	1.219
15.077	9.00	1.105
16.103	10.00	1.026
16.831	11.00	0.728
17.545	12.00	0.714
18.181	13.00	0.636
18.760	14.00	0.579
19.279	15.00	0.519
19.750	16.00	0.471
20.173	17.00	0.423
20.562	18.00	0.389
20.924	19.00	0.362
21.260	20.00	0.336
21.578	21.00	0.318
21.872	22.00	0.294
22.153	23.00	0.281
22.419	24.00	0.221



ULTRAFILTERED BRINE

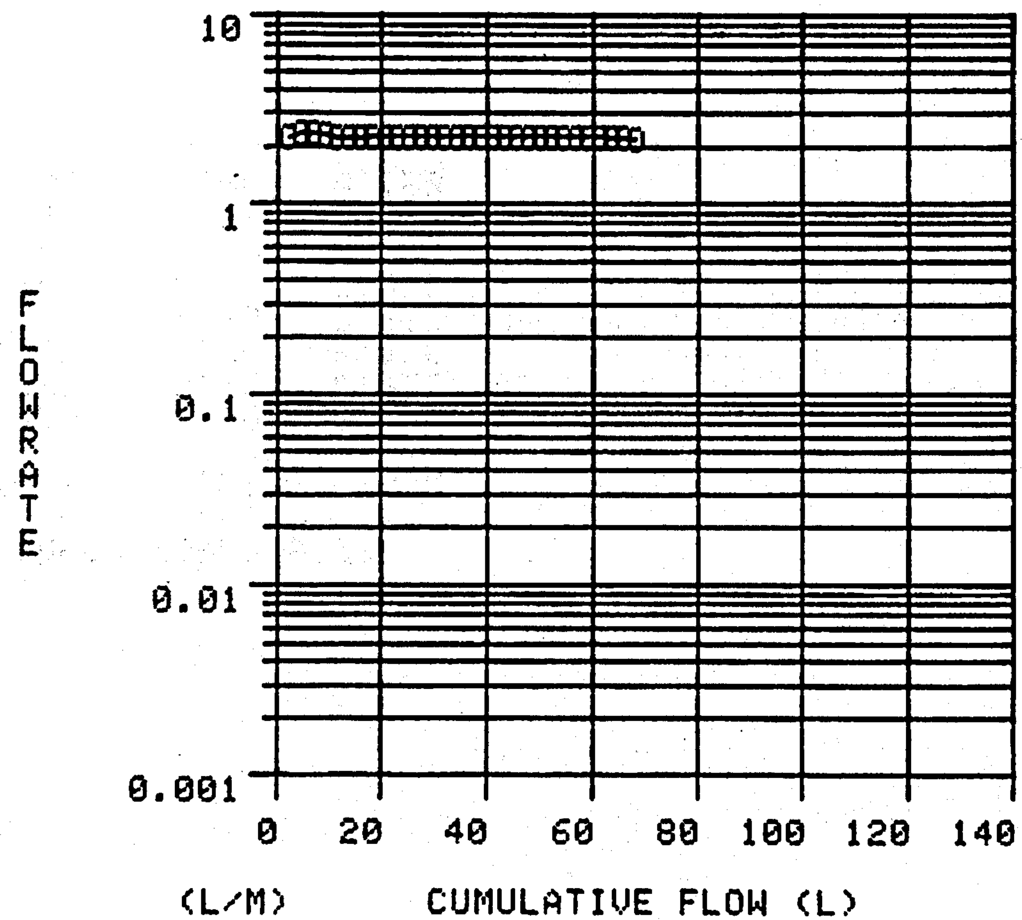
LITRES	MINS	L/MIN
22.419	24.00	0.221
22.668	25.00	0.221
22.903	26.00	0.235
23.126	27.00	0.223
23.340	28.00	0.221
23.545	29.00	0.221
23.742	30.00	0.197
23.932	31.00	0.190

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-16

DATE: 26 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L): .006 VOL(L):68.1

ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
2.252	1.00	2.252
4.612	2.00	2.360
6.974	3.00	2.362
9.297	4.00	2.323
11.556	5.00	2.259
13.800	6.00	2.244
16.062	7.00	2.262
18.328	8.00	2.266
20.593	9.00	2.265
22.860	10.00	2.267
25.128	11.00	2.268
27.393	12.00	2.265
29.659	13.00	2.266
31.927	14.00	2.268
34.196	15.00	2.269
36.462	16.00	2.266
38.731	17.00	2.269
40.998	18.00	2.267
43.264	19.00	2.266
45.531	20.00	2.267
47.801	21.00	2.270
50.070	22.00	2.269
52.336	23.00	2.266
54.602	24.00	2.266



ULTRAFILTERED BRINE

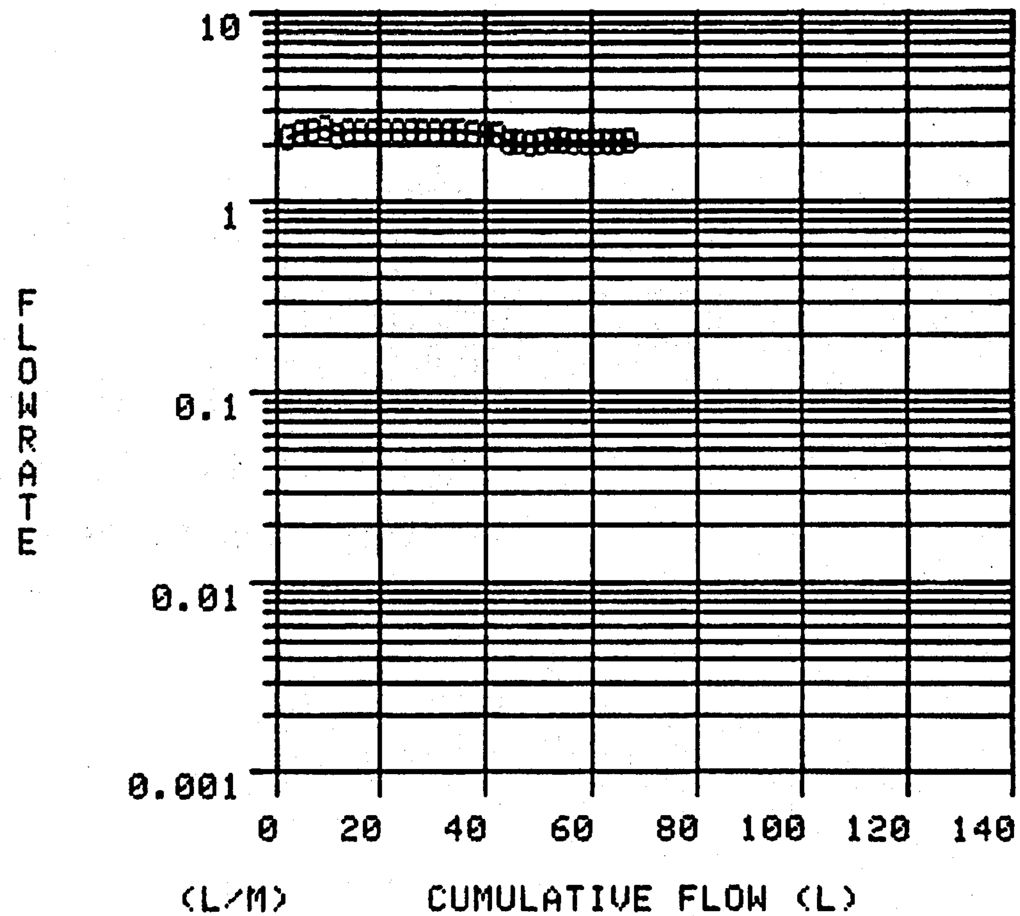
LITRES	MINS	L/MIN
54.602	24.00	2.266
56.868	25.00	2.266
59.136	26.00	2.268
61.401	27.00	2.265
63.665	28.00	2.264
65.918	29.00	2.253
68.129	30.00	2.211

SPR MEMBRANE FILTRATION TEST DATA   RUN:BM-18

DATE: 27 FEB 79   PSIG: 6   FILTER:10.0N   SS(MG/L):.004   VOL(L): 67.4

ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
2.197	1.00	2.197
4.540	2.00	2.343
6.914	3.00	2.374
9.379	4.00	2.465
11.645	5.00	2.266
14.027	6.00	2.382
16.391	7.00	2.364
18.756	8.00	2.365
21.138	9.00	2.382
23.504	10.00	2.366
25.886	11.00	2.382
28.255	12.00	2.369
30.624	13.00	2.369
33.009	14.00	2.385
35.380	15.00	2.371
37.725	16.00	2.345
40.030	17.00	2.305
42.320	18.00	2.290
44.420	19.00	2.100
46.478	20.00	2.058
48.506	21.00	2.028
50.564	22.00	2.058
52.700	23.00	2.136
54.811	24.00	2.111



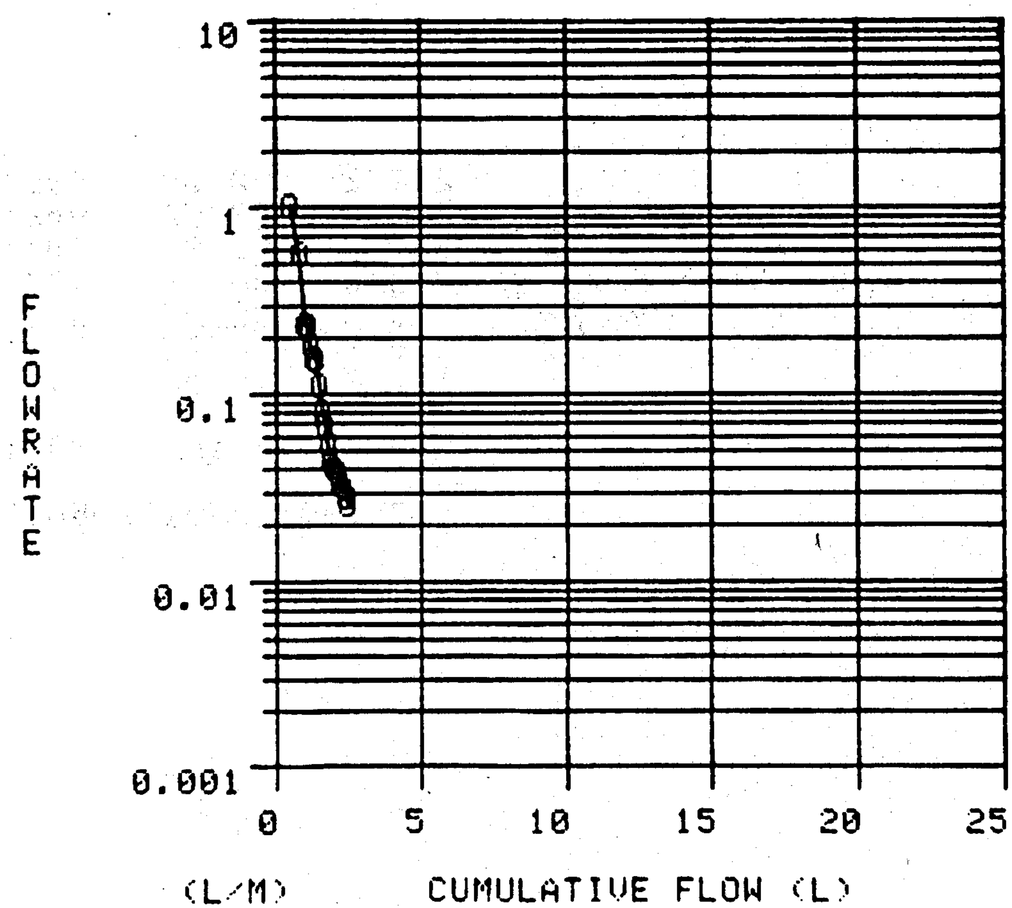
ULTRAFILTERED BRINE

LITRES	MINS	L/MIN
54.811	24.00	2.111
56.905	25.00	2.094
58.995	26.00	2.090
61.075	27.00	2.080
63.149	28.00	2.074
65.246	29.00	2.097
67.363	30.00	2.117

SPR MEMBRANE FILTRATION TEST DATA RUN:BM:20
DATE: 28 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L): .36 VOL(L): 2.5

COL D:10PPM ALUM+.2 4500

LITRES	MINS	L/MIN
0.513	0.50	1.026
0.797	1.00	0.568
1.000	1.85	0.239
1.100	2.28	0.233
1.200	2.82	0.185
1.300	3.45	0.159
1.400	4.10	0.154
1.500	5.00	0.111
1.600	6.23	0.081
1.700	7.68	0.069
1.800	9.48	0.056
1.900	11.73	0.044
2.000	14.18	0.041
2.100	16.72	0.039
2.200	19.58	0.035
2.300	22.73	0.032
2.400	26.22	0.029
2.500	30.08	0.026

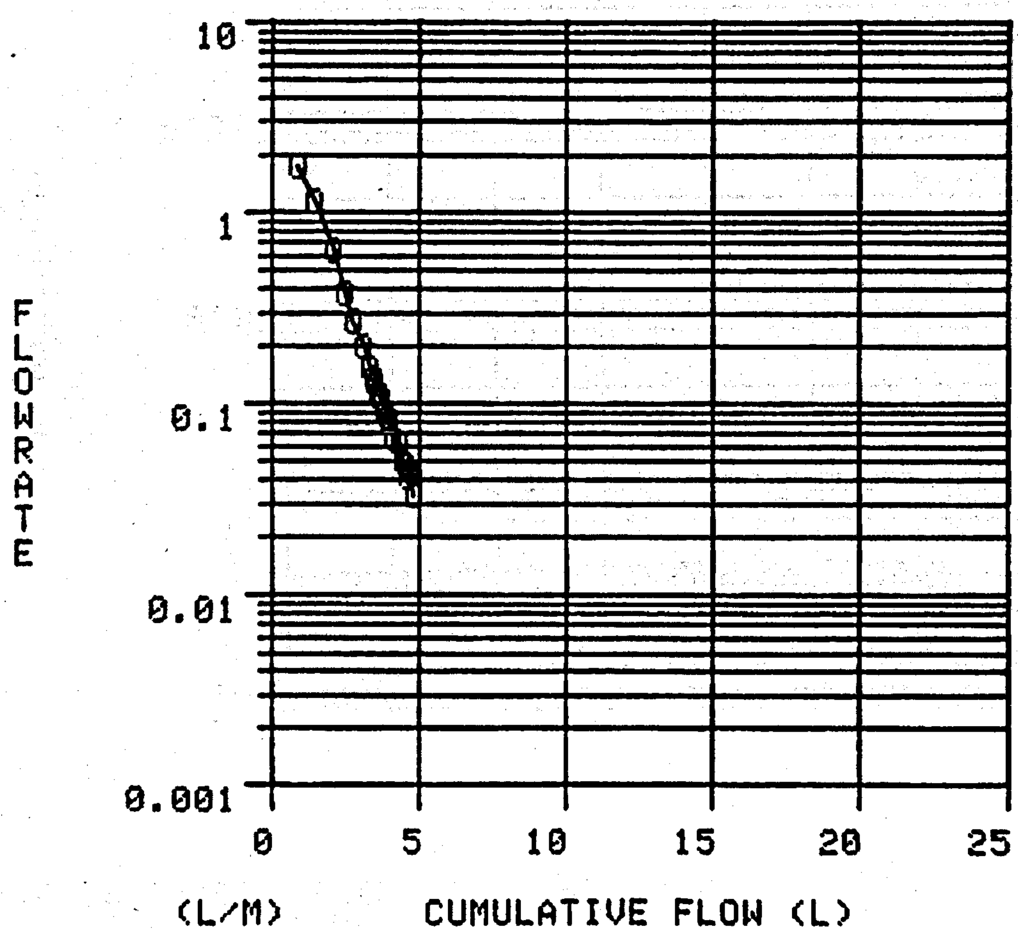


SPR MEMBRANE FILTRATION TEST DATA RUN:BM-21

DATE:28 FEB 79 PSIG: 50 FILTER: 0.4N SS(MG/L): .251 VOL(L): 4.8

COL C-NO CHEMICAL FEED

LITRES	MINS	L/MIN
0.887	0.50	1.774
1.455	1.00	1.136
2.091	2.00	0.636
2.470	3.00	0.379
2.740	4.00	0.270
3.100	5.77	0.203
3.300	7.07	0.154
3.400	7.80	0.137
3.500	8.58	0.128
3.600	9.45	0.115
3.700	10.40	0.105
3.800	11.50	0.091
3.900	12.67	0.085
4.000	13.92	0.080
4.100	15.42	0.067
4.300	18.70	0.061
4.400	20.70	0.050
4.500	22.77	0.048
4.600	25.17	0.042
4.700	27.42	0.044
4.785	30.00	0.033



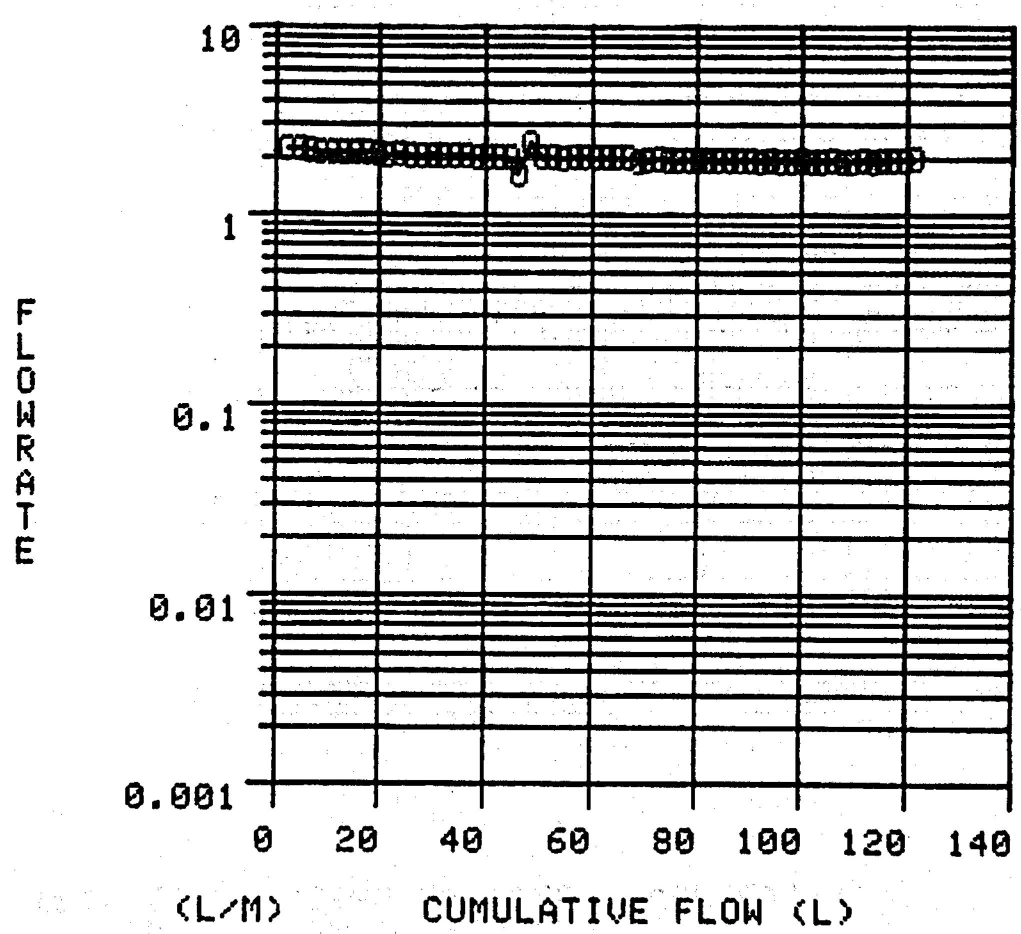
517

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-22
DATE: 27 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L):.002 VOL(L):121.6

COL D:10PPM ALUM+.2 4500

LITRES	MINS	L/MIN
2.230	1.00	2.230
4.462	2.00	2.232
6.652	3.00	2.190
8.822	4.00	2.170
10.989	5.00	2.167
13.171	6.00	2.182
15.334	7.00	2.163
17.510	8.00	2.176
19.654	9.00	2.144
21.753	10.00	2.099
23.864	11.00	2.111
25.958	12.00	2.094
28.050	13.00	2.092
30.156	14.00	2.106
32.248	15.00	2.092
34.339	16.00	2.091
36.437	17.00	2.098
38.476	18.00	2.039
40.514	19.00	2.038
42.562	20.00	2.048
44.587	21.00	2.025
46.246	22.00	1.659
48.650	23.00	2.404
50.675	24.00	2.025

518



COL D:10PPM ALUM+.2 4500

LITRES	MINS	L/MIN
50.675	24.00	2.025
52.713	25.00	2.038
54.713	26.00	2.000
56.765	27.00	2.052
58.806	28.00	2.041
60.830	29.00	2.024
62.866	30.00	2.036
64.887	31.00	2.021
66.916	32.00	2.029
68.853	33.00	1.937
70.805	34.00	1.952
72.818	35.00	2.013
74.775	36.00	1.957
76.728	37.00	1.953
78.688	38.00	1.960
80.634	39.00	1.946
82.595	40.00	1.961
84.546	41.00	1.951
86.496	42.00	1.950
88.446	43.00	1.950
90.410	44.00	1.964
92.351	45.00	1.941
94.298	46.00	1.947
96.232	47.00	1.934
98.166	48.00	1.934
100.112	49.00	1.946
102.040	50.00	1.928
103.980	51.00	1.940
105.927	52.00	1.947
107.861	53.00	1.934
109.791	54.00	1.930

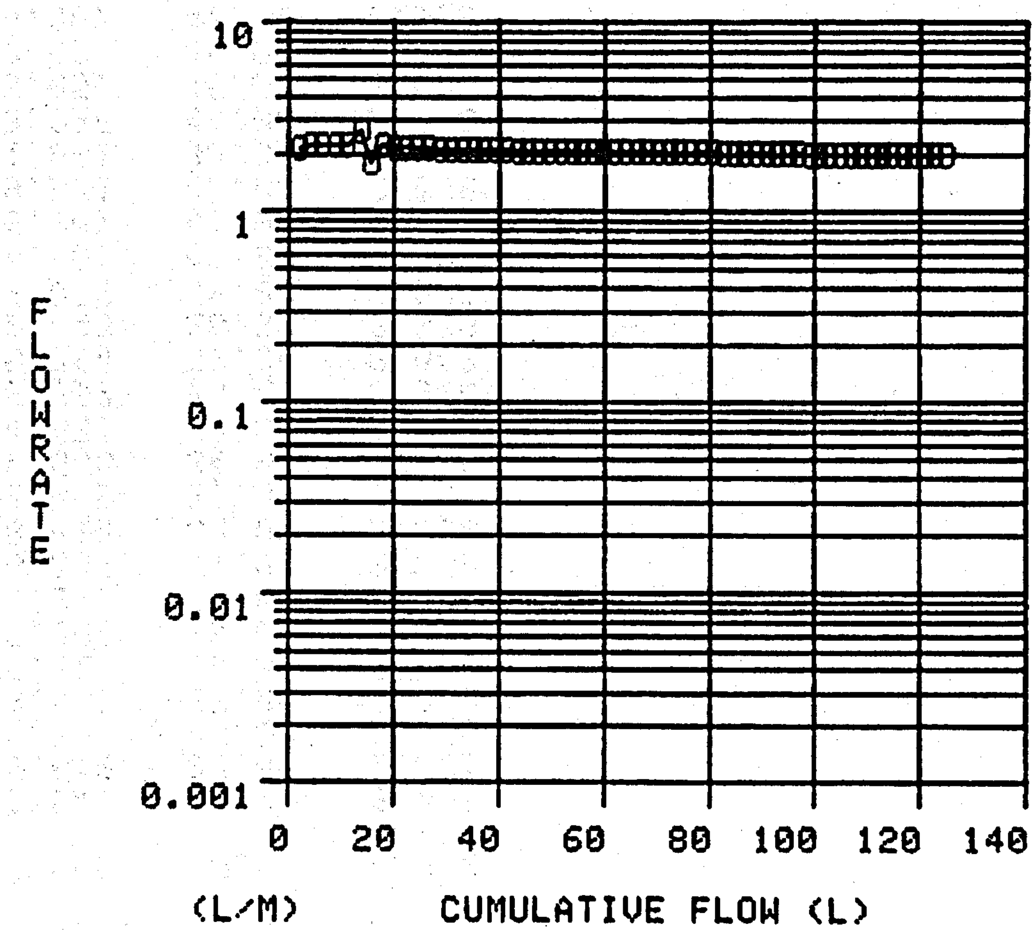
COL D:10PPM ALUM+.2 4500

LITRES	MINS	L/MIN
109.791	54.00	1.930
111.742	55.00	1.951
113.667	56.00	1.925
115.620	57.00	1.953
117.589	58.00	1.969
119.564	59.00	1.975
121.556	60.00	1.992

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-23
DATE:28 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L): <.001 VOL(L): 125

COL D:10PPM ALUM+.2 4500

LITRES	MINS	L/MIN
2.152	1.00	2.152
4.398	2.00	2.246
6.646	3.00	2.248
8.887	4.00	2.241
11.140	5.00	2.253
13.780	6.00	2.640
15.613	7.00	1.833
17.847	8.00	2.234
20.022	9.00	2.175
22.210	10.00	2.188
24.385	11.00	2.175
26.536	12.00	2.151
28.664	13.00	2.128
30.804	14.00	2.140
32.923	15.00	2.119
35.043	16.00	2.120
37.163	17.00	2.120
39.281	18.00	2.118
41.404	19.00	2.123
43.507	20.00	2.103
45.598	21.00	2.091
47.674	22.00	2.076
49.750	23.00	2.076
51.841	24.00	2.091



COL D:10PPM ALUM+.2 4500

LITRES	MINS	L/MIN
51.841	24.00	2.091
53.912	25.00	2.071
55.981	26.00	2.069
58.052	27.00	2.071
60.122	28.00	2.070
62.206	29.00	2.084
64.278	30.00	2.072
66.346	31.00	2.068
68.414	32.00	2.068
70.499	33.00	2.085
72.565	34.00	2.066
74.631	35.00	2.066
76.697	36.00	2.066
78.764	37.00	2.067
80.843	38.00	2.079
82.872	39.00	2.029
84.901	40.00	2.029
86.941	41.00	2.040
88.971	42.00	2.030
91.001	43.00	2.030
93.026	44.00	2.025
95.051	45.00	2.025
97.091	46.00	2.040
99.087	47.00	1.996
101.080	48.00	1.993
103.074	49.00	1.994
105.079	50.00	2.005
107.073	51.00	1.994
109.069	52.00	1.996
111.066	53.00	1.997
113.056	54.00	1.990

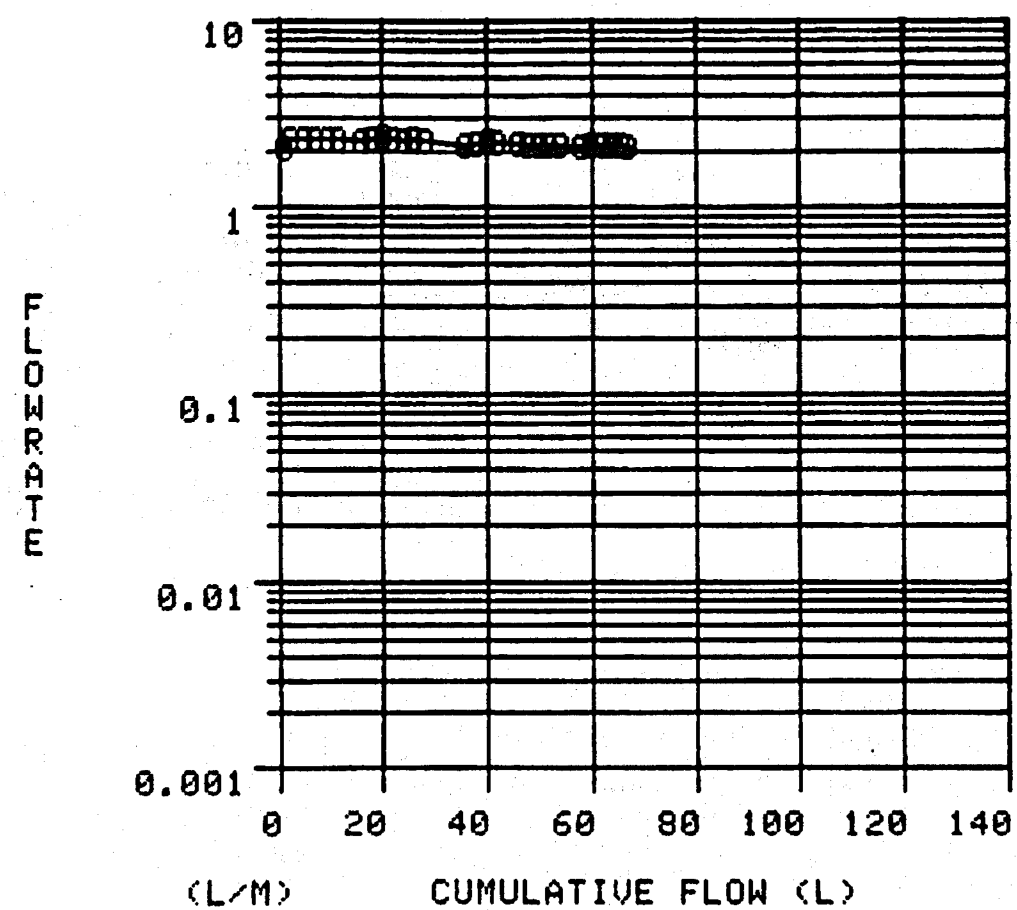
COL D:10PPM ALUM+.2 4500

LITRES	MINS	L/MIN
113.056	54.00	1.990
115.059	55.00	2.003
117.050	56.00	1.991
119.047	57.00	1.997
121.041	58.00	1.994
123.033	59.00	1.992
125.042	60.00	2.009

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-24
DATE: 28 FEB 79   PSIG: 6   FILTER:10.0N   SS(MG/L):<.001   VOL(L): 67.2

COL C: NO CHEMICAL FEED

LITRES	MINS	L/MIN
1.047	0.50	2.094
2.218	1.00	2.342
4.561	2.00	2.343
6.903	3.00	2.342
9.233	4.00	2.330
11.564	5.00	2.331
16.000	7.70	2.299
18.000	8.55	2.353
20.000	9.38	2.410
22.000	10.23	2.353
24.000	11.10	2.299
26.000	11.96	2.326
28.000	12.83	2.299
36.000	15.70	2.151
38.000	16.60	2.222
40.000	17.48	2.273
42.000	18.37	2.247
46.000	20.18	2.210
48.000	21.10	2.174
50.000	22.03	2.151
52.000	22.95	2.174
54.000	23.88	2.151
58.000	25.75	2.139
60.000	26.67	2.174



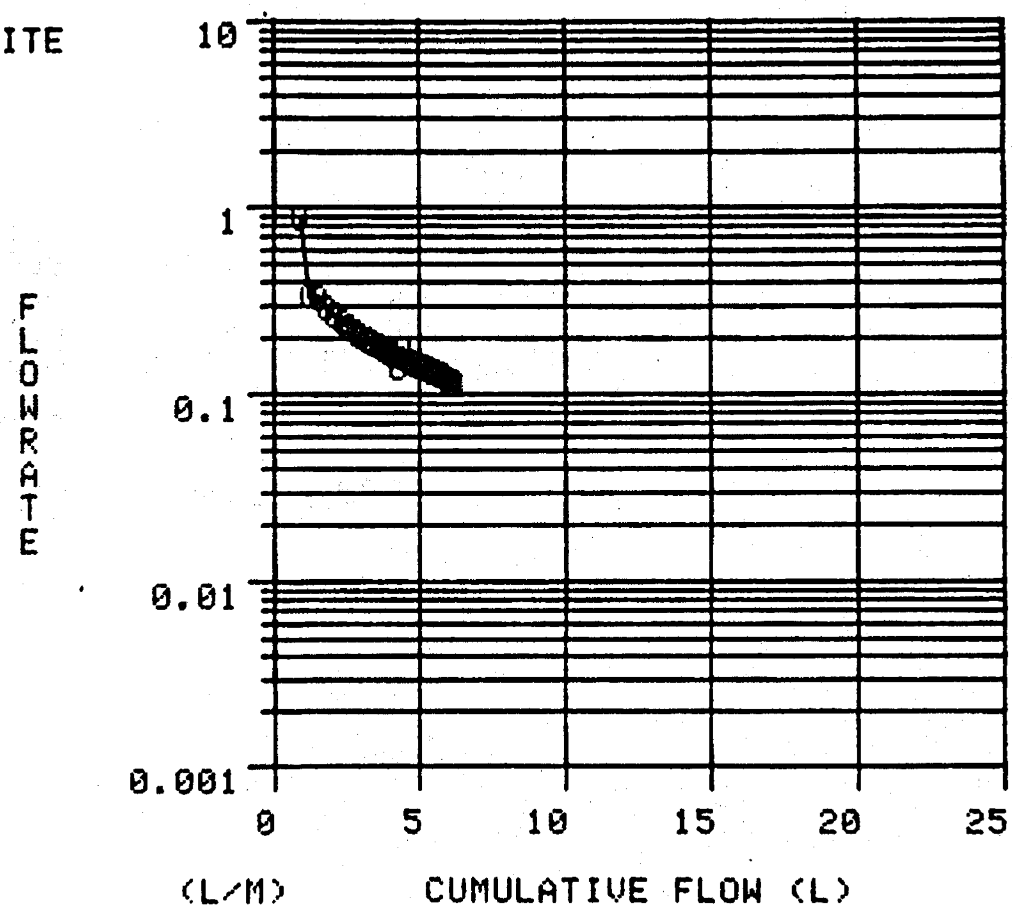
COL C: NO CHEMICAL FEED

LITRES	MINS	L/MIN
60.000	26.67	2.174
62.000	27.60	2.151
64.000	28.53	2.151
66.000	29.45	2.174
67.174	30.00	2.135

SPR FILTRATION TEST DATA   RUN:BM-25
DATE: 27 FEB 79   PSIG: 50   FILTER: 0.4N   SS(MG/L): .46   VOL(L): 6.2

1UM PREFILTER-REINJECTION SITE

LITRES	MINS	L/MIN
0.889	1.00	0.889
1.225	2.00	0.336
1.556	3.00	0.331
1.846	4.00	0.290
2.109	5.00	0.263
2.356	6.00	0.247
2.584	7.00	0.228
2.802	8.00	0.218
3.007	9.00	0.205
3.203	10.00	0.196
3.391	11.00	0.188
3.572	12.00	0.181
3.748	13.00	0.176
3.919	14.00	0.171
4.083	15.00	0.164
4.224	16.00	0.141
4.401	17.00	0.177
4.553	18.00	0.152
4.702	19.00	0.149
4.848	20.00	0.146
4.990	21.00	0.142
5.130	22.00	0.140
5.268	23.00	0.138
5.401	24.00	0.133



1UM PREFILTER-REINJECTION SITE

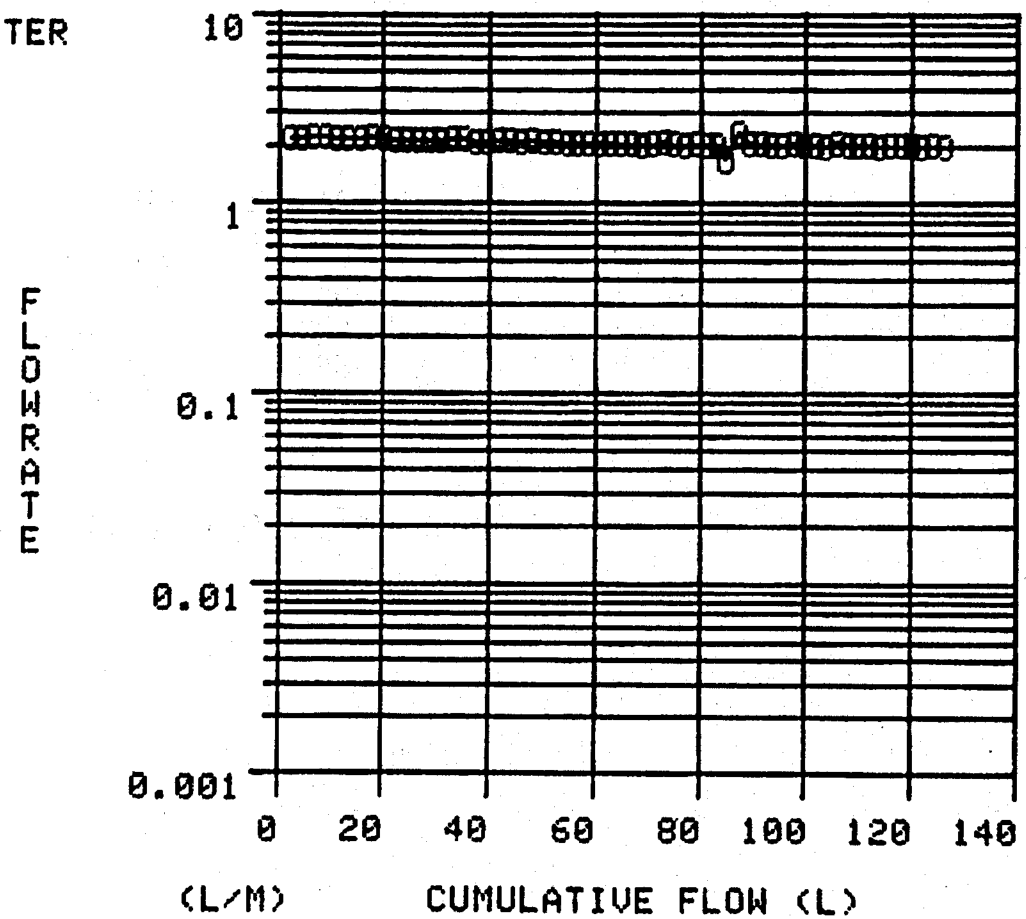
LITRES	MINS	L/MIN
5.401	24.00	0.133
5.533	25.00	0.132
5.661	26.00	0.128
5.787	27.00	0.126
5.909	28.00	0.122
6.029	29.00	0.120
6.147	30.00	0.118

SPR MEMBRANE FILTRATION TEST DATA RUN:BM-26

DATE: 27 FEB 79 PSIG: 6 FILTER:10.0N SS(MG/L):<.001 VOL(L): 126.3

REINJECTION SITE:1UM PREFILTER

LITRES	MINS	L/MIN
2.221	1.00	2.221
4.444	2.00	2.223
6.700	3.00	2.256
8.953	4.00	2.253
11.172	5.00	2.219
13.365	6.00	2.193
15.586	7.00	2.221
17.830	8.00	2.244
20.030	9.00	2.200
22.180	10.00	2.150
24.340	11.00	2.160
26.510	12.00	2.170
28.670	13.00	2.160
30.840	14.00	2.170
33.060	15.00	2.220
35.270	16.00	2.210
37.400	17.00	2.130
39.520	18.00	2.120
41.690	19.00	2.170
43.840	20.00	2.150
45.980	21.00	2.140
48.150	22.00	2.170
50.271	23.00	2.121
52.405	24.00	2.134



REINJECTION SITE:1UM PREFILTER

LITRES	MINS	L/MIN
114.165	54.00	2.016
116.192	55.00	2.027
118.217	56.00	2.025
120.241	57.00	2.024
122.251	58.00	2.010
124.272	59.00	2.021
126.280	60.00	2.008

U.S. Government Printing Office: 1980/5-689-102/8786

REINJECTION SITE:1UM PREFILTER

LITRES	MINS	L/MIN
52.405	24.00	2.134
54.485	25.00	2.080
56.552	26.00	2.067
58.642	27.00	2.090
60.739	28.00	2.097
62.839	29.00	2.100
64.902	30.00	2.063
66.965	31.00	2.063
69.013	32.00	2.048
71.075	33.00	2.062
73.190	34.00	2.115
75.253	35.00	2.063
77.301	36.00	2.048
79.362	37.00	2.061
81.414	38.00	2.052
83.448	39.00	2.034
85.158	40.00	1.710
87.553	41.00	2.395
89.635	42.00	2.082
91.697	43.00	2.062
93.739	44.00	2.042
95.781	45.00	2.042
97.849	46.00	2.068
99.876	47.00	2.027
101.919	48.00	2.043
103.923	49.00	2.004
106.028	50.00	2.105
108.078	51.00	2.050
110.114	52.00	2.036
112.149	53.00	2.035
114.165	54.00	2.016

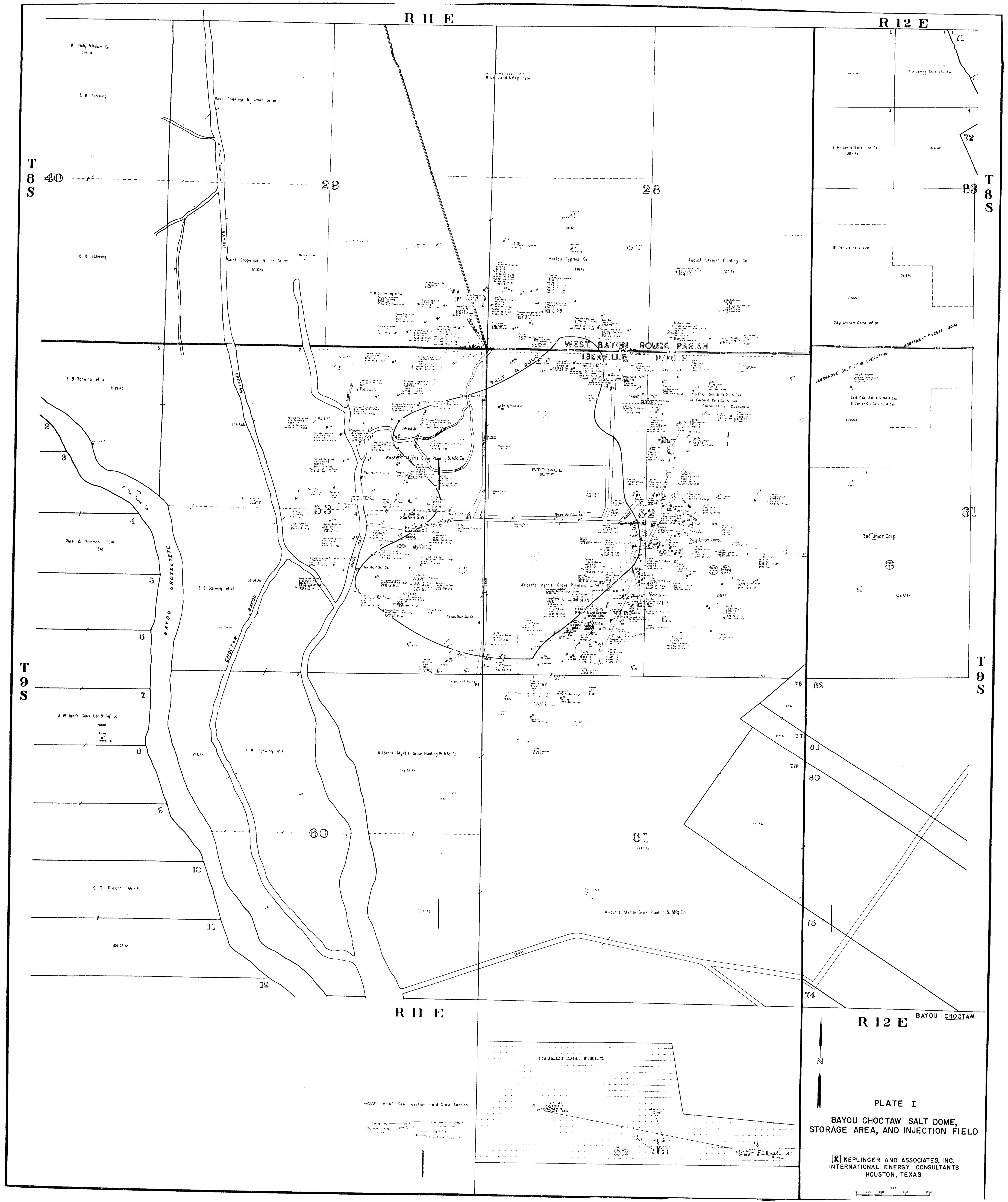


PLATE I

BAYOU CHOCTAW SALT DOME, STORAGE AREA, AND INJECTION FIELD

KEPLINGER AND ASSOCIATES, INC.
INTERNATIONAL ENERGY CONSULTANTS
HOUSTON, TEXAS

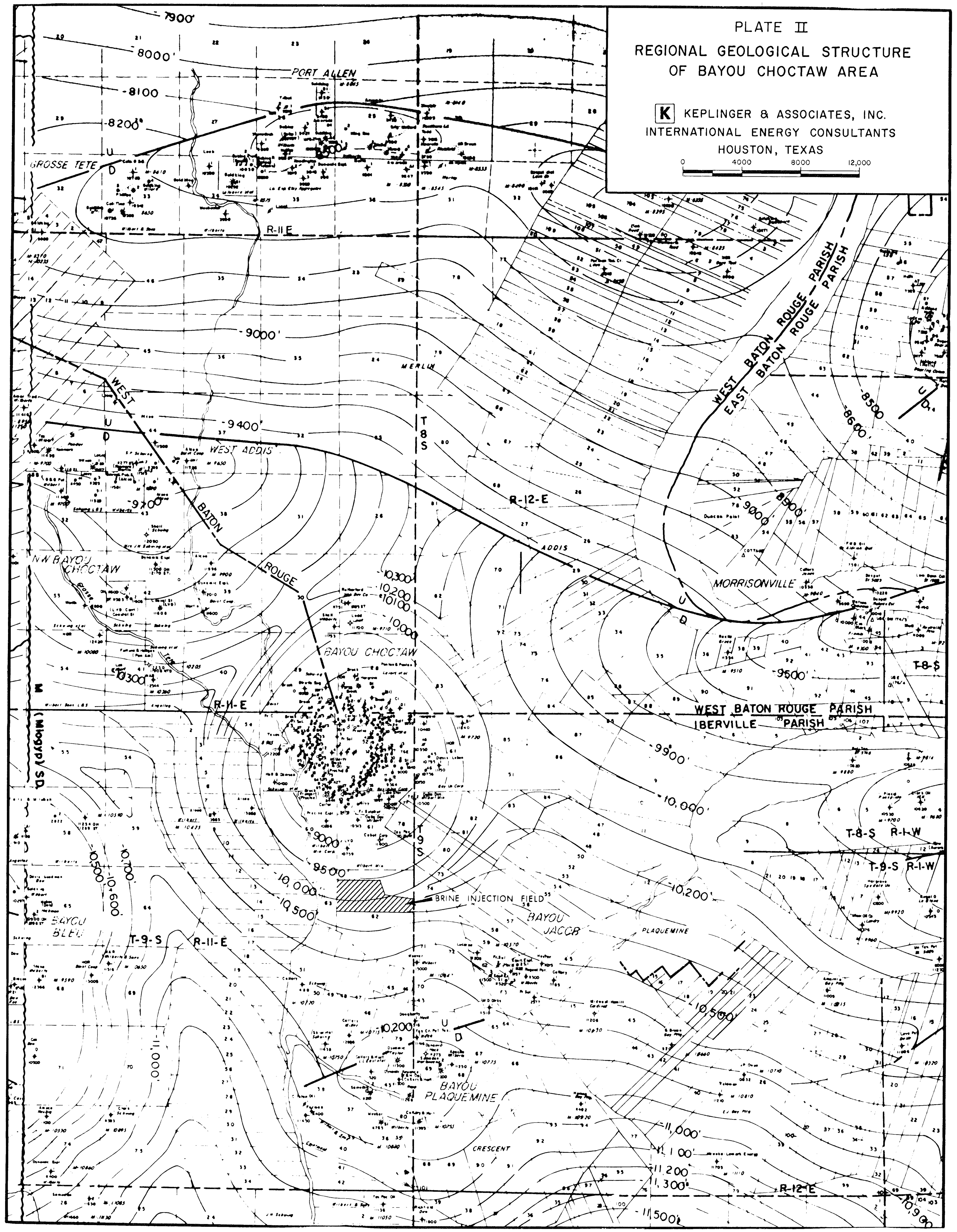


PLATE II
REGIONAL GEOLOGICAL STRUCTURE
OF BAYOU CHOCTAW AREA
K KEPLINGER & ASSOCIATES, INC.
INTERNATIONAL ENERGY CONSULTANTS
HOUSTON, TEXAS
0
4000
8000
12,000
PORT ALLEN
GROSSE TETE
WEST ADDIS
NW BAYOU CHOCTAW
BAYOU CHOCTAW
MORRISONVILLE
WEST BATON ROUGE PARISH
EAST BATON ROUGE PARISH
IBERVILLE PARISH
BRINE INJECTION FIELD
BAYOU JACOB
PLAQUEMINE
BAYOU PLAQUEMINE
BAYOU BLEU
CRESCENT
ADDIS
MERLIN
R-11-E
R-12-E
T-8-S
T-9-S
R-1-W
-7900'
-8000'
-8100
-8200'
-9000'
-9400'
-9700
-9500'
-9900
-10,000'
-10,200'
-10,500'
-11,000'
-11,500'

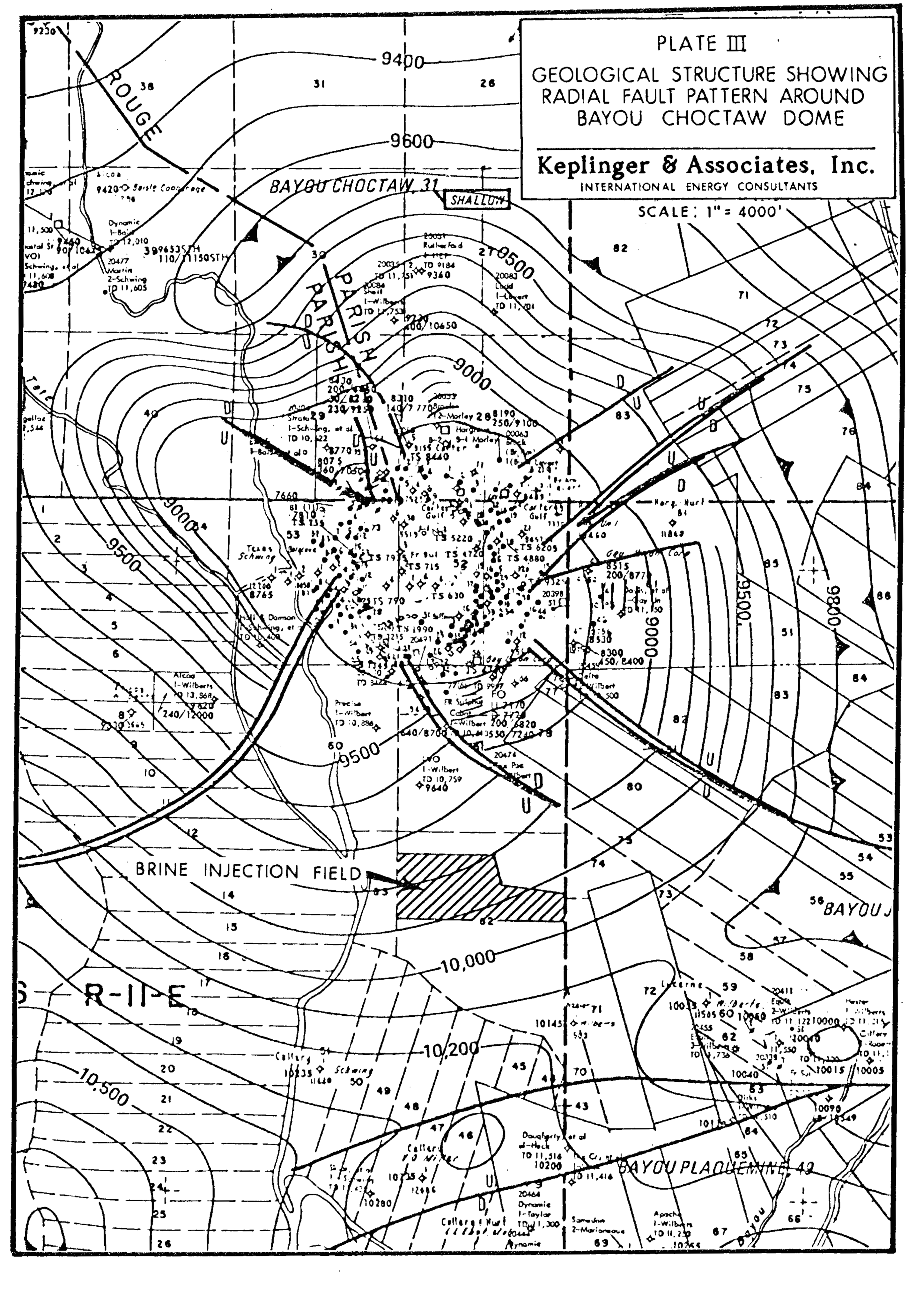


PLATE III
GEOLOGICAL STRUCTURE SHOWING
RADIAL FAULT PATTERN AROUND
BAYOU CHOCTAW DOME
Keplinger & Associates, Inc.
INTERNATIONAL ENERGY CONSULTANTS
SCALE: 1" = 4000'
BAYOU CHOCTAW 31
BRINE INJECTION FIELD
R-11-E
ROUGE
BAYOU PLAQUEMINE 42
9400
9600
9500
9000
10,000
10,200
10,500

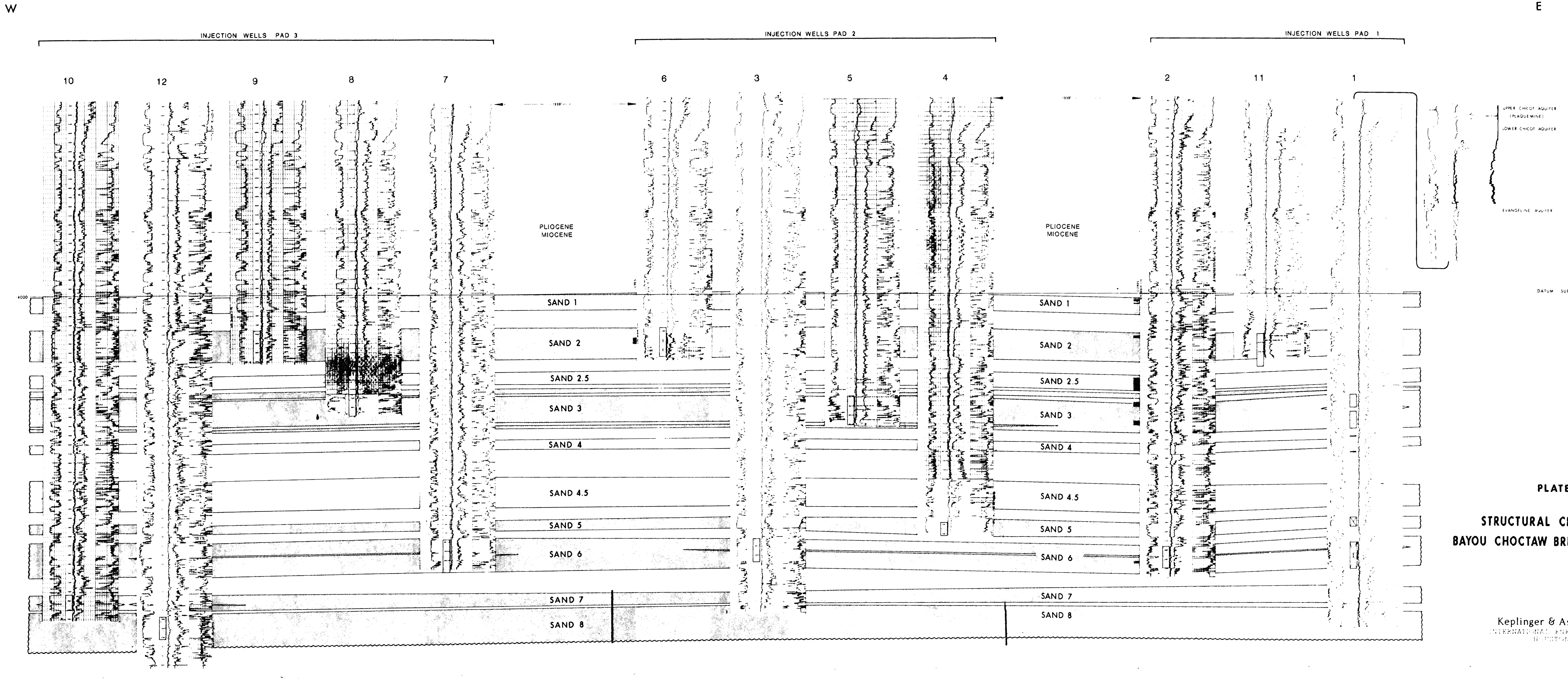


PLATE IV

STRUCTURAL CROSS-SECTION
BAYOU CHOCTAW BRINE INJECTION FIELD

Keplinger & Associates, Inc.