AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

mm

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

DOE/MC/11076--3847
(DE94012279)
Distribution Category UC-107

Development of the CROW™ Process

Topical Report

Lyle A. Johnson, Jr.

Work Performed Under Cooperative Agreement No.: DE-FC21-86MC11076

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Western Research Institute
365 North 9th Street
Laramie, Wyoming 82071

May 1994

TABLE OF CONTENTS

LIST OF TABLES

SUMMARY

The Contained Recovery of Oily Waste (CROW^{TM}) technology has been successfully tested in the laboratory and presently is being implemented at field sites contaminated with wood treating wastes and byproducts of town gas production. These field demonstrations will utilize only hot-water displacement without any chemical additives because the use of chemicals to enhance the hot-water flushing process has only been tested on a preliminary basis. Preliminary testing has shown that low concentrations of chemicals could reduce the contaminant content by an additional 10 to 20 wt %. Western Research Institute (WRI) research, plus research at Carnegie Mellon University, on surfactant enhancement of solubility of polynuclear aromatic hydrocarbons in water and water-soil systems indicate the potential of chemical enhancement of the CROW process. Chemicals that have been tested and that were used in these tests are totally biodegradable.

The objective of this task was to obtain sufficient baseline data to show the effectiveness and environmentally safe use of chemicals, primarily surfactants, to enhance the CROW process. To met this objective, 14 one-dimensional displacement tests were conducted. Eleven tests were conducted on a material from a former manufactured gas plant (MGP) site and four tests were conducted with a contaminated soil from a former wood treatment facility. The tests investigated the effect of three chemical concentrations (0, 0.5, and 1.0 vol %) at three temperatures (ambient, the projected optimum temperature, and one 40°F [22°C] below the optimum temperature).

The MGP soil, instead of being a sand contaminated with some coke and coal tars, was essentially coal tar contaminated coke particles with some sand. This mixture produced a system with dual porosity, intergranular porosity, and porosity within the coke particles. The tests using this material showed only a slight increasing trend of organic removal with increasing temperature and chemical addition for approximately 40 pore volumes (PV) of flushing water. Removals were in the range of 15 to 20 wt % of the initial organic saturation. However, the use of 40 PV of chemical-enhanced flush water followed by an additional 40 PV of flush water without chemical increased the removal to 36 to 40 wt %. This indicates that the chemical is assisting with the removal of the organic from the pores of the coke, but requires additional time and flushing volumes.

The response from the wood treatment soil tests was more in-line with what the original hypothesis was. The tests showed only a slight increase in removal with the increase in the flushing temperature, 44 to 46 wt %. However, the addition of chemical to the flushing water increased the removal to 58 and 70 wt % for the ambient and elevated temperature flushes, respectively. These results, in conjunction with the extended flushing tests using the MGP soil, demonstrate the advantage of incorporating a chemical in the flushing water for removal of organic contaminants.

BACKGROUND

The Contained Recovery of Oily Wastes (CROW™) process removes organic contaminants from the subsurface by adaptation of technology used for secondary and heavy oil recovery. The CROW technology has been successfully tested in the laboratory (Johnson and Guffey 1990). Presently the process is being prepared for field demonstration in areas contaminated with wood treating wastes and byproducts of town gas production. These demonstrations will use hot-water displacement without chemical additives. The use of chemicals with the hot water to enhance displacement and solubilization of the wastes has been tested on a preliminary basis. This chemical additive testing to identify the potential of chemical addition was conducted as part of a project for the U.S. Environmental Protection Agency (EPA) SITE Program's Emerging Technology Program (Johnson and Guffey 1990). The preliminary testing has shown that less than 1 vol % of chemical in the initial pore volumes of hot-water flush could reduce the contaminant content by an additional 10 to 20 wt %. This level of testing has shown the potential of chemical addition, but additional testing needs to be conducted to demonstrate to regulatory personnel the full benefit of the chemical addition. The chemicals tested are totally biodegradable and pose little if any environmental threat. However, the fate of the added chemicals will be considered in all testing.

The use of surfactants to enhance the solubility of polynuclear aromatic hydrocarbons (PAH) has been tested in the laboratory by researchers at Carnegie Mellon University for PAHs in water and soil-water systems (Edward et al. 1991, 1992; Liu et al. 1991; Laha and Luthy 1992). In these studies, researchers have found that solubility enhancements as great as a factor of two can be attained when commercially available nonionic surfactants such as alkyl or alkylphenol polyoxethylene are added to the water in concentrations between 0.1 and 1.0% by volume. This solubility enhancement resulted in 70 to 90% solubilization of the PAH. Noted in these studies was the linear decrease in the surface tension between the PAH phase and the aqueous phase as the surfactant concentration increased from the onset of surfactant micelle formation (~0.1% by volume) to the critical micelle concentration (~1% by volume). The researchers also found that partitioning of the surfactant between the soil and solution phases increased as the degree of solubility increased. The combined effects of lowering of the surface tension and the enhancement of the PAH solubility should significantly increase the removal efficiency of the CROW process.

Western Research Institute (WRI) has also conducted a limited number of other CROW screening tests with chemical enhancement. The chemicals in these tests ranged from commercial surfactants to pH modifiers for the injected water. In these tests, the surfactants performed more effectively than the pH modifiers. Results of these tests are not available for public dissemination because of the proprietary nature of the work.

The objective of this task was to obtain sufficient baseline data to show the effectiveness of surfactants to enhance the CROW process. To met this objective, 11 one-dimensional displacement tests were proposed. However, 14 tests were conducted. The tests investigated the effect of chemical addition to the flush water, increased flush water temperature, and the combination of added chemical and elevated temperature flushing to remove organic contaminants from soils. The soils used in the tests were from a former manufactured gas plant (MGP) site and a former wood treatment site and the two soils were significantly different from each other.

EXPERIMENTAL APPARATUS AND PROCEDURES

To begin testing, a characterization sample is prepared from each contaminated material. The bulk sample is homogenized and composite samples taken for determination of the fluid saturations. The soluble organic material collected during the saturation determinations are combined to provide a sample for initial organic characterization, if a free phase organic is not available. The viscosity and density are determined for the soluble organic material. The viscosity and density determinations are conducted at three temperatures, ambient and two elevated temperatures, for estimation of the optimum water injection temperature.

The reactor system used for the one-dimensional displacement tests is the tube reactor system shown in Figure 1 (Figures are located in the Appendix). A disposable chlorinated polyvinyl chloride reactor tube (4-inch i.d. x 36-inch long [10.2 cm x 91.4 cm]) is uniformly packed with approximately 25 to 30 lb (11.3 to 13.6 kg) of contaminated soil and is vertically oriented within a series of insulated shield heaters. Auxiliary equipment includes inlet water injection and metering devices, a water heater, and product collection equipment. The entire system is instrumented and interfaced to a data acquisition computer that records temperatures and pressures every 5 minutes. Flow rates are preset on a calibrated metering pump.

Six internal reactor thermocouples are spaced approximately every 6 inches within the center of the soil pack to monitor the reactor/process temperatures. These thermocouples are also electronically paired with six wall-mounted thermocouples. Each pair is connected to an individual temperature controller and shield heaters. This arrangement allows the reactor tube to be operated either isothermally or adiabatically.

Water is injected into the bottom of the reactor by a positive displacement metering pump. The injected water passes through a heater to generate steam or hot water. Chemical, when used, is metered into the water stream by a high-pressure syringe pump upstream of the heater.

Produced fluids are collected from the top of the reactor through an automatic sampling valve system. Sampling intervals can be held constant or changed throughout the progress of the test. The reactor back pressure is maintained near atmospheric pressure by venting the product collection vessels to the atmosphere through a gas collection system.

All experiments are conducted in a similar manner with only the temperature and chemical concentration varied between tests. To initiate the tests, a homogenized bulk sample of the contaminated material is packed into the reactor tube. During packing of the tube, a composite sample of the material placed in the tube is collected for determination of the initial organic saturation of each tube. The weight of the packed material is recorded in the laboratory notebook. The tube is instrumented with the appropriate thermocouples and placed into the reactor shell.

Following placement of the tube, water injection at 100 cc/min and the predetermined temperature is initiated and continued until approximately 40 pore volumes (PV) of water have been injected. The PV of the packed tube is determined from the physical dimensions and weight of the tube and the density, weight, and saturation of the contaminated soil. During the displacement phase, produced fluids are sampled every 2 to 4 PV for total organic carbon (TOC) determinations. TOC measurements were conducted immediately following the collection of the sample.

After completion of the injection phase, the injection and production ports are closed, the reactor shell opened, and the tube allowed to cool before removal. The tube is then removed from the reactor shell and the weight of the contents determined and recorded. The flushed material is then extruded from the tube and divided into five even increments from the top to the bottom of the tube. Each increment is homogenized and a composite sample is analyzed to determine the posttest organic saturation distribution and track surfactant partitioning during the test.

SAMPLING AND ANALYTICAL PROCEDURES

Initial Material

The materials as received from the suppliers, Midwest Gas and Union Pacific Railroad, were removed from the containers and homogenized to produce as uniform a sample as possible. For the Midwest Gas's MGP sample, seven aliquots of the homogenized sample were prepared, one for initial characterization and six for the displacement tests. Three aliquots of the homogenized wood treatment contaminated soil from Union Pacific Railroad were prepared, one for initial characterization and two for the displacement tests. All aliquots not for immediate use were placed in cold storage until needed.

The characterization samples were submitted for determination of the fluid saturations. The soluble organic material collected during the saturation determination provided the sample for initial organic characterization. The viscosity and density were determined for the soluble organic material at three temperatures. The temperatures for the MGP organic were ambient, 100, and 140°F (38 and 60°C) and for the wood treatment organic; ambient, 140, and 185°F (60 and 85°C). These data were used to estimate the optimum water injection temperature.

Posttest Material

Following each test, the flushed material was extruded, partitioned into five increments, homogenized, and a composite sample taken of each increment. Fluid saturations of the five samples were determined and the extracted organic material saved for further testing, if needed.

The extracted material from the ambient temperature, no-chemical tests and all the chemical-added tests were analyzed to determine the retention of the chemical in the flushed samples. The tests without chemicals provided baseline data for the procedure. Gas chromatography/mass spectrometry analysis was used to determine the percentage of the chemical in the extracted organic, thus showing the partitioning of the surfactant between the aqueous and the residual organic-soil phases.

All posttest material not consumed in analysis and all initial material not used in testing were returned to the site of origin. This was agreed to by the suppliers, Midwest Gas and Union Pacific Railroad.

Produced Material

The fluids produced during the tests were sampled every 2 to 4 PV during the tests. The collected samples were analyzed for TOC content. At the end of each test, a 2-liter sample of the produced fluid was collected, labeled, and placed in cold storage until completion of the project. The purpose of these large samples was to provide material for assisting in the determination of the surfactant partitioning if the posttest materials were not sufficient.

Analytical Procedures

The samples were analyzed using WRI standard operating procedures. The organic saturation of the solid samples was determined using standard operating procedure WRI-204. This procedure is a modified Soxhlet extraction combined with azeotropic distillation to remove water and organics from the sample. For the process, 120 to 140 grams of accurately weighed, contaminated soil sample is placed in a thimble. The thimble is then inserted into the extractor and the apparatus is assembled. The difference between this procedure and conventional Soxhlet extractions is that a Dean-Stark trap is inserted between the extractor and the condenser. The toluene is allowed to reflux through the extractor for 12 hours. The extractor is allowed to cool, and the water is drained from the Dean-Stark trap into a tared container and weighed. The toluene solution containing the extracted organic component is distilled under vacuum to remove the toluene until a constant weight is achieved. The weight of the organic component and the extracted soil matrix are determined. The weight data of the sample before extraction and the data for the three products are used to determine a mass balance closure around the extraction. The organic saturation is calculated as the weight percentage of the organic in the contaminated soil. Duplicate and blank analyses are performed once in every ten samples analyzed by the method.

The concentrations of selected compounds in the extracted organic material are measured using standard operating procedure WRI-083. This procedure is a gas chromatography/mass spectrometry-based method using an internal standard for analysis of the selected compounds. Compounds of interest to the process are selected based on their relevancy to the project. Standard solutions are prepared and analyzed to determine sensitivity factors. The samples are analyzed and the sensitivity factors are used to calculate the concentration of each selected compound.

Strict adherence to the procedure is followed that includes validation of the instrument performance and verification of the calibration after every ten analyses or every 24 hours. Duplicate and blank analyses are performed once for every ten samples analyzed by the method.

The TOC, viscosity, and density determinations are routine analytical tests conducted according to WRI standard operating procedures.

RESULTS AND DISCUSSION

The contaminated soils used in these tests were obtained from a former MGP site and an inactive wood treatment site. The MGP site material, the initial material, was to be a sandy soil contaminated with coal tars and coal cinders and was provided by Midwest Gas of Iowa. The soil from the wood treatment site was a sand contaminated with creosote and petroleum based hydrocarbons. This material was obtained from the Baxter Tie Plant Site in Laramie, Wyoming and was provided by Union Pacific Railroad.

The MGP soil contained 10 to 12.5 wt % organic contaminant. The extracted organic was composed of two phases that separated during removal of the solvent used to extract the organic. Both organic phases were heavier than water, Table 1, with the majority designated as waxy phase because of its appearance. There was insufficient quantity of the minor phase to conduct individual testing. The viscosity for the waxy phase could be obtained only at elevated temperature since the material was semi-solid at room temperature, Table 1. The organic from the wood treatment soil was lighter than water with both the specific gravity and the viscosity rapidly decreasing at elevated temperatures, Table 1.

Table 1. Properties of the Organic Contaminants

	MGP Organic		Wood Treatment Organic
	Total	Waxy Portion	
Viscosity, cP			
77°F	---	---	41.4
100°F	---	14.9	---
140°F	---	6.7	1.65
185°F	---	---	1.16
Specific Gravity,			
60°F	1.124	1.035	---
77°F	---	---	0.9744
100°F	1.114	1.021	---
140°F	1.097	1.010	0.9469
185°F	---	---	0.9263

The use of two soils in the testing program was based on the results of the initial 11 one-dimensional displacement tests using the MGP site sample. The results of these first 11 tests indicated that a second sample would assist in interpretation of the results. The initial 11 tests were conducted as three sets of experiments: three tests without chemical addition; six tests with chemical addition; and two essentially duplicate tests. In each set of tests, three temperatures were used for the flushing water. These temperatures were based on the reduction in the viscosity and density of the organic contaminate as determined during initial characterization.

Tests with the wood treatment contaminated material consisted of four tests. A single test was conducted at ambient temperature and the predicted optimum temperature with and without chemical addition. The chemical addition was at the highest concentration used in the first 11 tests.

The chemicals selected for use were Triton X-100 and Igepal CA-720, marketed by Aldrich Chemicals, and Hyonic NP-90, produced by Henkel Corporation. All three chemicals are nonionic, aerobically biodegradable surfactants. To evaluate which chemical to use, a known amount of the MGP contaminated material was placed in a 1% by volume chemical in water mixture and agitated for several hours. The resultant surfactant and organic mixture was decanted and the organic reduction determined. Based on these simple tests, Igepal CA-720 was chosen as the chemical to be used in subsequent flushing tests. The chemical concentrations chosen for use in the flushing tests were 0.5 and 1.0% by volume. These concentrations and the initial three selected chemicals were based on the studies at Carnegie Mellon University previously referenced.

During the packing of the tube with the MGP soil, it was noted that the packed weights were significantly lower than with prior tested materials, 12 to 15 lb (5.4 to 6.8 kg) compared to the usual 25 to 30 lb (11.3 to 13.6 kg). The material instead of being a sand matrix contaminated with coke and coal tars was determined to be mainly coal tar contaminated coke like material with some sand. The individual coke particles were porous and the contaminant appeared to reside on and within the particle. The porous nature of the particles can also be noted in the higher porosity for the individual tubes in the MGP tests compared to the wood treatment tests, Table 2. The MGP soil packed tubes were dual porosity systems consisting of primary porosity between the coke and sand particles and secondary porosity within the individual coke particle, therefore a higher overall porosity for the tube. It was decided that further testing of the material would increase the knowledge base for the CROW process.

Table 2. Test Parameters and Results

Test No.	Initial Organic[1] Sat., wt%	Porosity %	Temperature °F	% Chemical Added	Injection Rate cc/min	Total Injected Water, PV	Residual Organic[1] Sat., wt%	Organic Reduction, %	% Chem in Residual Organic
Midwest (MGP soil)									
128	10.27	41.74	67	0	109	33.3	8.9	13.34	0
129	11.11	33.62	135	0	89	44.1	9.01	18.9	0
130	12.55	44.71	175	0	93	33	9.67	22.95	0
133	11.77	43.84	63	0.46	107	33	9.78	16.91	0
136	9.85	46.51	134	0.5	92	31.3	8.16	17.16	9
134	11.75	45.61	174	0.49	102	35.4	9.58	18.47	17
131	10.62	38.04	65	0.8	99	38.7	10.01	5.74	0
132	12.14	41.99	139	0.9	96	36.5	9.27	23.64	1
135	12.23	46.03	178	0.92	100	34.1	9.79	19.95	42
137[2]	11.78	39.75	141	1.00[2]	98	76.3[2]	7.55	35.91[2]	3
138[2]	11	45.04	173	0.93[2]	99	64.0[2]	6	45.45[2]	42
Baxter (wood treatment soil)									
139	1.97	27.15	67	0	86	47.6	1.1	44.16	0
140	1.25	25.35	64	0.95	101	47.2	0.52	58.4	23
141	1.16	29.98	149	1.09	87	41.3	0.35	69.83	32
142	1.97	33.93	152	0	98	36.9	1.07	45.69	0

[1] Saturations are given on a water free basis
[2] First half of the flush volume contained chemical, second half contained no chemical

The initial nine MGP tests, test numbers 128 through 136, consisted of one each at approximate flushing temperatures of 65, 135, and 175°F (18, 57, and 79°C) with 0, 0.5, and 1.0% by volume chemical added to the flushing water, Table 2. For all tests, the targeted injection rate was 100 cc/min with a total injected volume of approximately 40 PV. The temperature profiles of the six inner thermocouples for all the tests, Figures 2 to 10, show that the desired flushing temperature was rapidly obtained and remained fairly constant throughout the tests. The minor fluctuations are caused by tuning of the temperature control units and were not enough to adversely effect the tests.

The results of these initial nine tests showed a slight increase in the reduction of the organic contaminant with increasing flushing temperature, but no definite effect from the chemical addition, solid symbols Figure 11a. The slight increase in organic removal is believed to be caused by the location of the contamination in the secondary porosity where only a minor contact with the flushing water occurs. However, the TOC analyses of the produced fluids, Figures 12 through 20, and determinations of the chemical remaining in the residual organics (organics remaining on or in the matrix following flushing), Table 2, indicated that a portion of the chemical was partitioning into the contaminant. The TOC content of the injected water because of the chemical addition would be 5,000 and 10,000 ppm for the 0.5 and 1.0% chemical addition tests, respectively. This would also be the TOC for the produced fluid if no partitioning were to occur.

To assist in determining the effect of the chemical addition, two tests, 137 and 138, were conducted at the two higher temperatures with 1.0% chemical addition, replication of the conditions in tests 132 and 135, respectively. The difference between these tests and the previous tests was the incorporation of an additional 40 PV of elevated temperature flush without chemical addition following the initial 40 PV of elevated temperature flush with chemical addition. The temperature profiles for these tests, Figures 21 and 22, show that the desired flushing temperature was rapidly reached and remained essentially constant. As shown in Figure 11, the additional 40 PV of flushing produced a significant increase in the organic reduction. This data indicates that the chemical additive is modifying the solubility and the surface tension of the contaminate such that the organic material can be removed from the secondary structure, but requires extended flushing following the initial chemical added flush. The extended flushing also removed a portion of the chemical that had partitioned into the organic and onto the matrix as indicated by the TOC

profile in the produced fluid, Figures 23 and 24, and in the lesser amount of chemical remaining in the residual organic compared to the prior tests, Table 2.

Because the results using the MGP soil were not as conclusive as desired, it was decided that a contaminated soil whose matrix was essentially sand may help determine the effect of chemical addition. The soil from the Baxter Tie Plant was selected as such a soil. Only four tests, 139 to 142, were conducted using this material. The tests were conducted with ambient temperature and 150°F (66°C) flush water and chemical concentrations of 0 and 1.0% by volume. As with all prior tests, the desired flushing temperature was rapidly obtained and remained constant throughout the tests, Figures 25 through 28.

Results of these tests show that increased flushing temperature resulted in a slight increase in organic removal while the addition of chemical resulted in a significant increase in organic removal at all temperatures tested, Figure 11b. Also noted was that less chemical partitioned to the residual organic and matrix as indicated by the higher TOC content in the produced water, Figures 29 through 32, and the percentage of chemical remaining in the residual organic, Table 2, than in the MGP tests.

The above results indicate that the surfactant's effect on the contaminant and the partitioning of the surfactant is through a surface area phenomena. Since the MGP soil is a dual porosity system, the surface area would be greater than that for the solid sand particles on the wood treatment soil and one would observe a higher percentage of the surfactant partitioning into the residual organic and onto the matrix. This higher percentage of surfactant was observed, Table 2. If the surface area phenomena is valid, then the use of a lower molecular weight surfactant may increase the removal rate since it could more easily penetrate the secondary pore system.

CONCLUSIONS AND RECOMMENDATIONS

The following observations were made from the chemical assisted CROW process tests using the two contaminated materials:

- Elevated flushing temperatures increased the removal of the organic contaminate compared to ambient temperature flushing. This holds true for both the no-chemical and chemical flushing series.

- Addition of chemical resulted in increased removal of the contaminate at all temperatures tested for material with primarily a sand matrix.

- Removal of organic contaminants from a material consisting of porous particles can be increased by the addition of a surfactant to the flushing water. The increased removal may require additional nonchemical flushing of the system to permit time for solubilization, surface tension modification, and surface area effects to take effect. That is, time must be allowed for the chemical effected organics to be displaced from the secondary porosity.

- The chemical partitioning between the aqueous and soil phases occurred with a significant concentration remaining in the residual organic. This is especially evident at elevated temperatures and where the soil is comprised of porous particles.

- The use of chemicals in conjunction with elevated temperature water flushing will increase the removal rate and percentage of contaminating organics.

ACKNOWLEDGMENTS

The author expresses appreciation to the U.S. Department of Energy for the funding of this work under Cooperative Agreement DE-FC21-86MC11076

DISCLAIMER

Mention of specific brand names or models of equipment is for information only and does not imply endorsement by Western Research Institute or the United States Department of Energy.

REFERENCES

Edward, D.A., Z. Liu, and R.G. Luthy, 1991, Surfactant Enhanced Solubility of Hydrophobic Organic Compounds in Water and in Soil-Water Systems. In Baker, R.A., ed., Organic Substances and Sediments in Water, Lewis Publishers, 2: 383-405.

Edward, D.A., Z. Liu, and R.G. Luthy, 1992, Interactions Between Nonionic Surfactant Monomers, Hydrophobic Organic Compounds and Soil. Water Science and Technology, 26(1-2): 147-158.

Johnson, L.A., Jr., and F.D. Guffey, 1990, Contained Recovery of Oily Wastes (CROW) - Final Report. U.S. Environmental Protection Agency Assistance Agreement CR-815333, RREL, Cincinnati, OH, 45268.

Laha, S., and R.G. Luthy, 1992, Effects of Nonionic Surfactants on the Solubilization and Mineralization of Phenanthrene in Soil-Water Systems. Biotechnology and Bioengineering, 40: 001-014.

Liu, Z., S. Laha, and R.G. Luthy, 1991, Surfactant Solubilization of Polycyclic Aromatic Hydrocarbon Compounds in Soil-Water Suspensions. Water Science and Technology, 23: 475-485.

APPENDIX

Figures

LIST OF FIGURES

LIST OF FIGURES (continued)

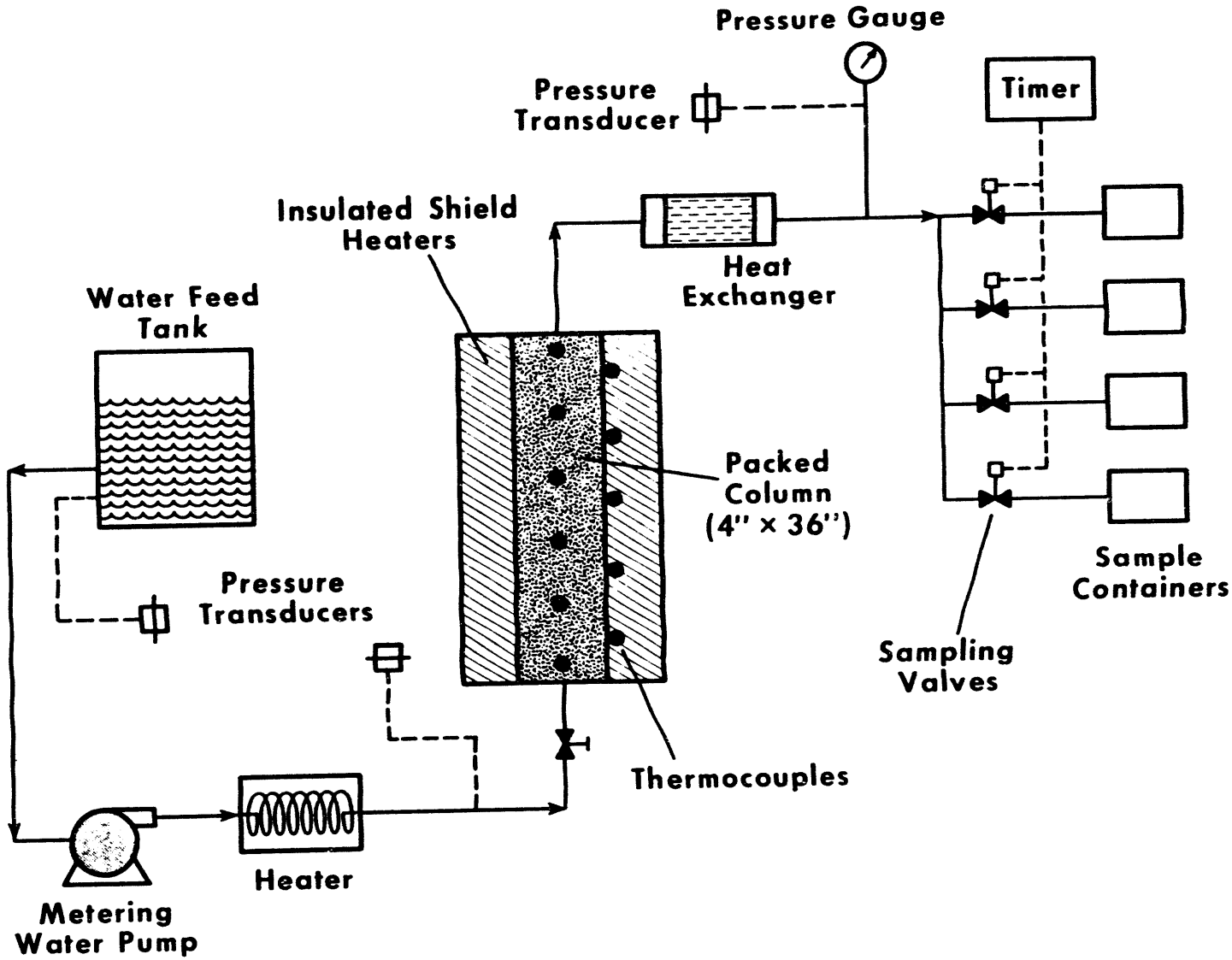

Figure 1. Experimental Apparatus

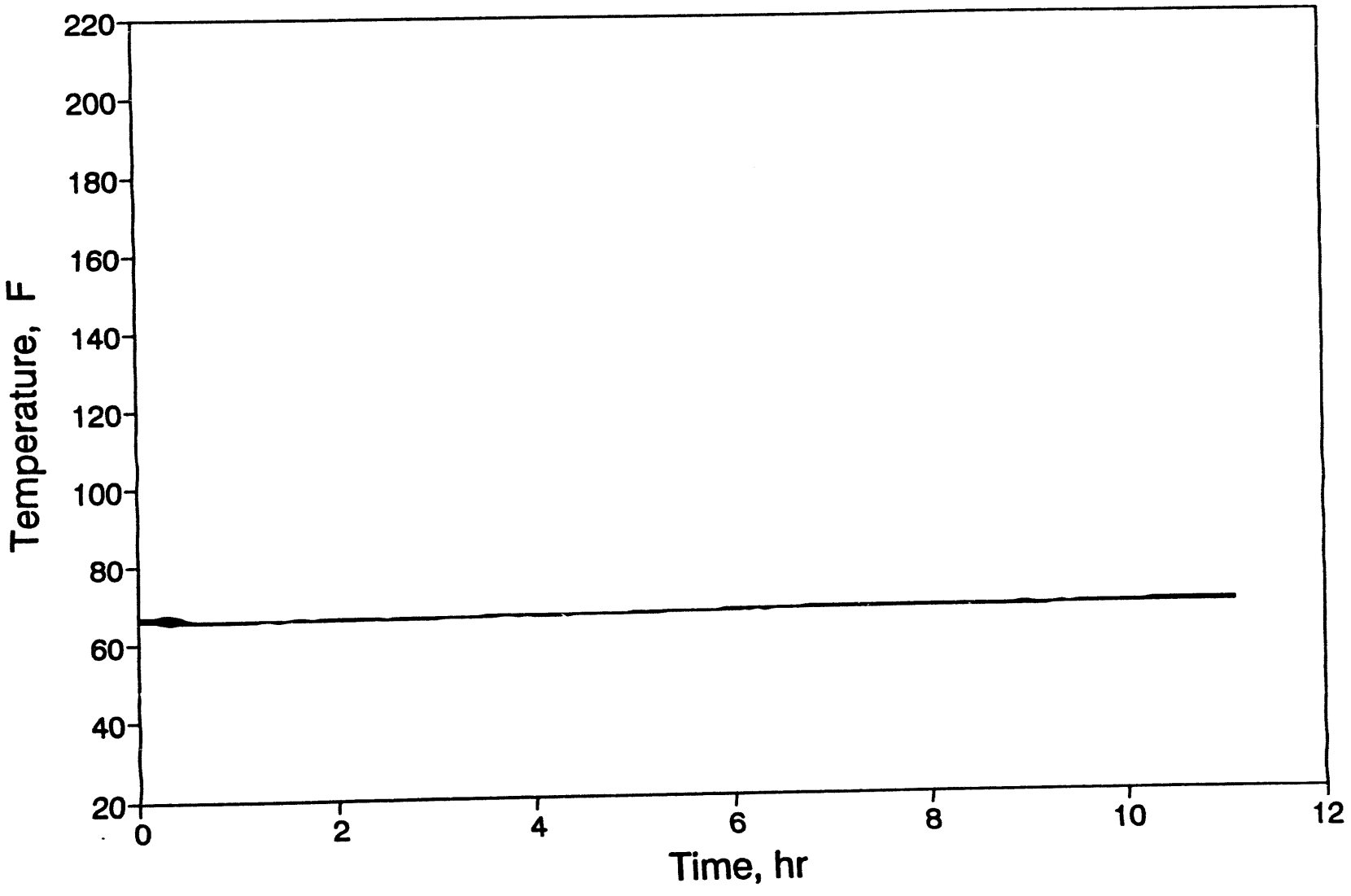

Figure 2. Temperature Profile for CROW Test 128

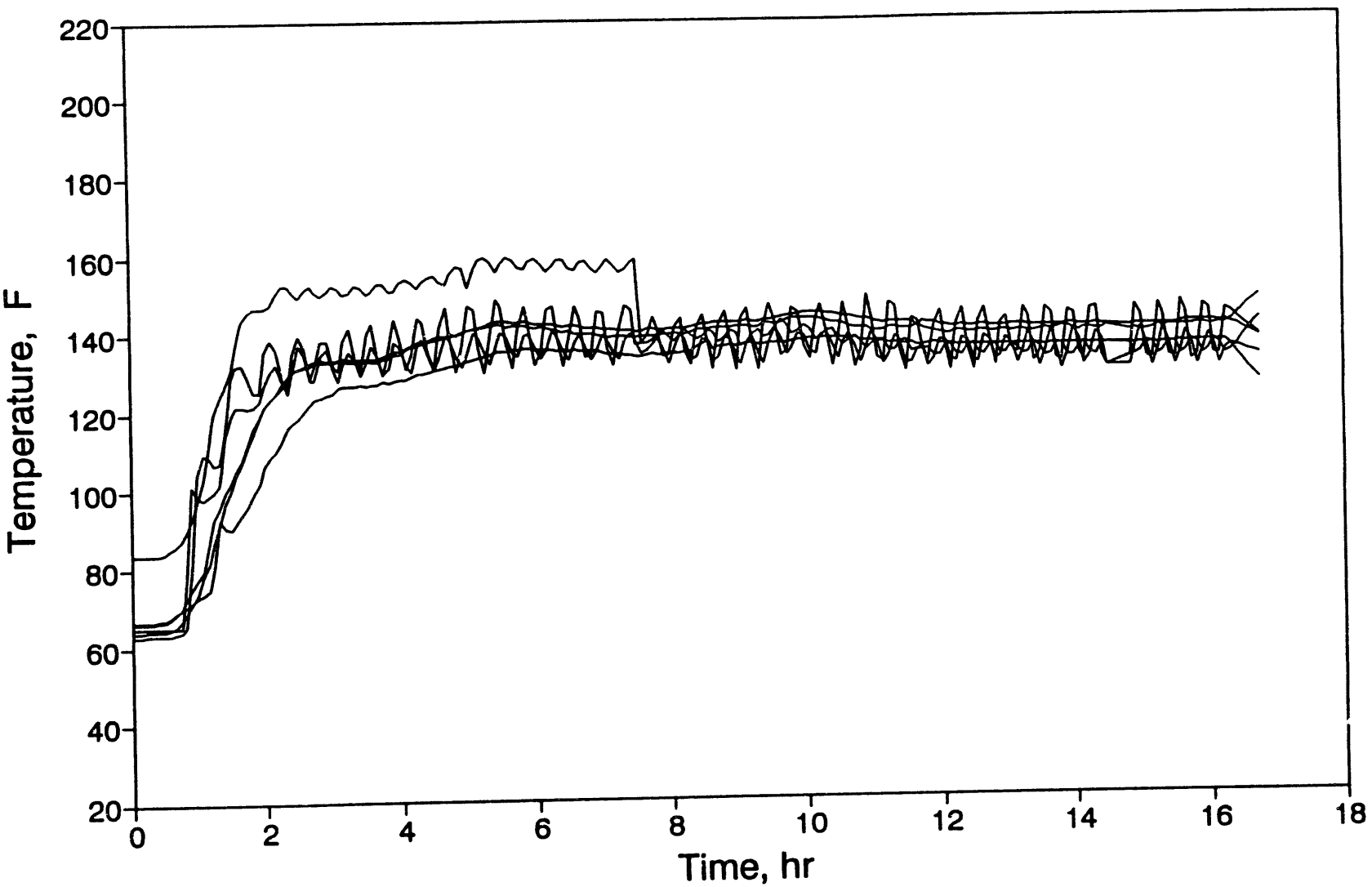

Figure 3. Temperature Profile for CROW Test 129

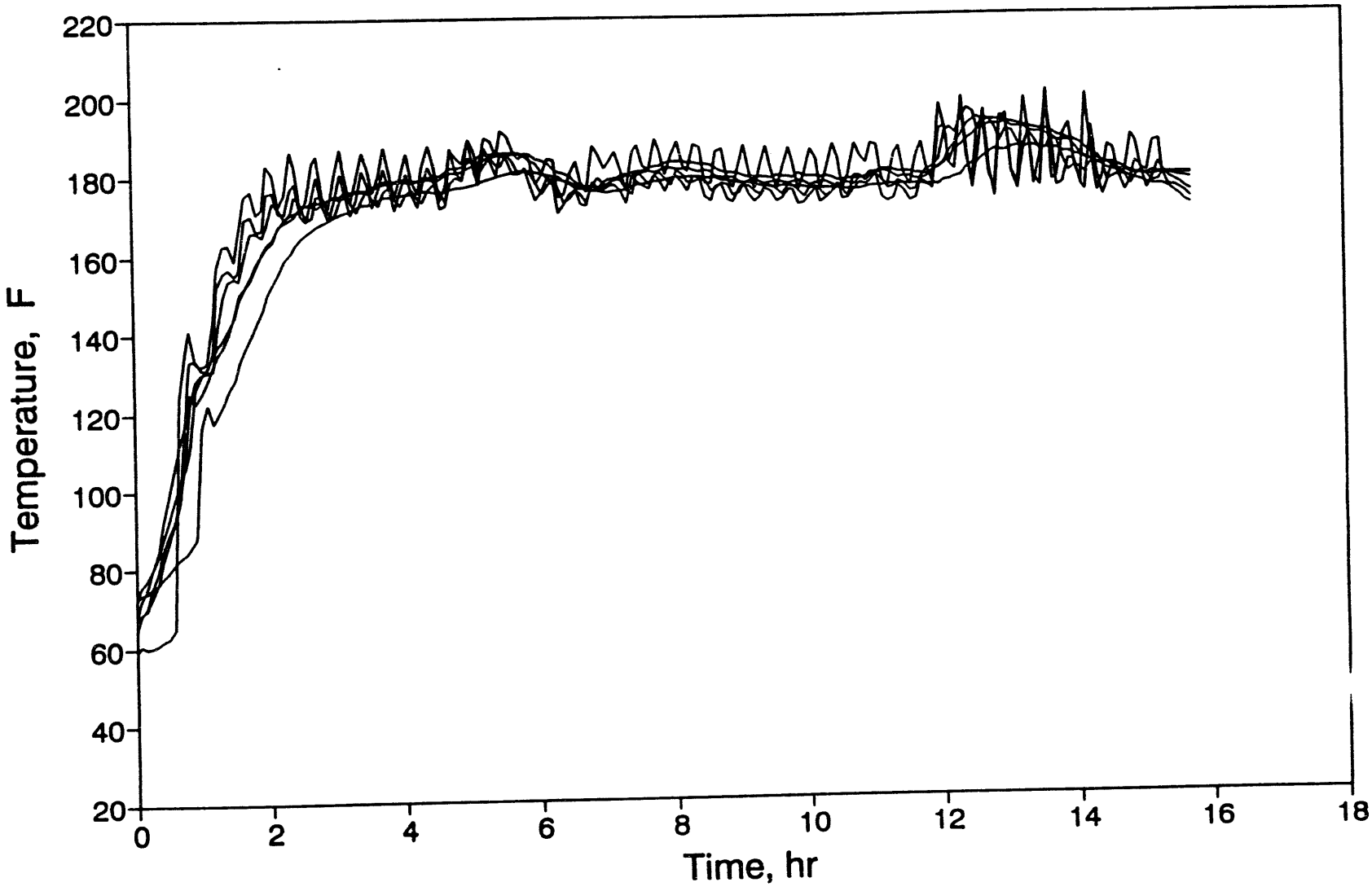

Figure 4. Temperature Profile for CROW Test 130

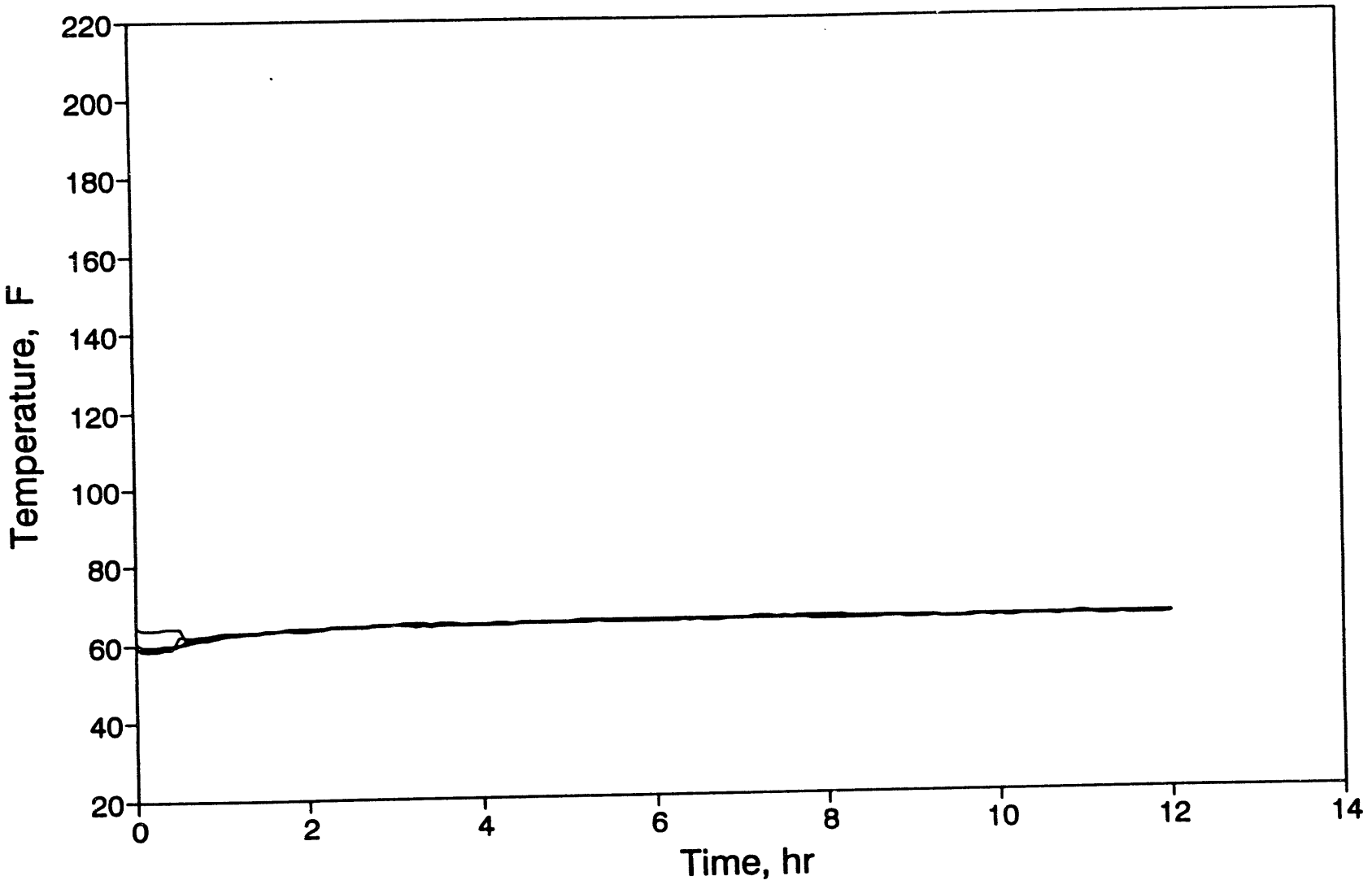

Figure 5. Temperature Profile for CROW Test 131

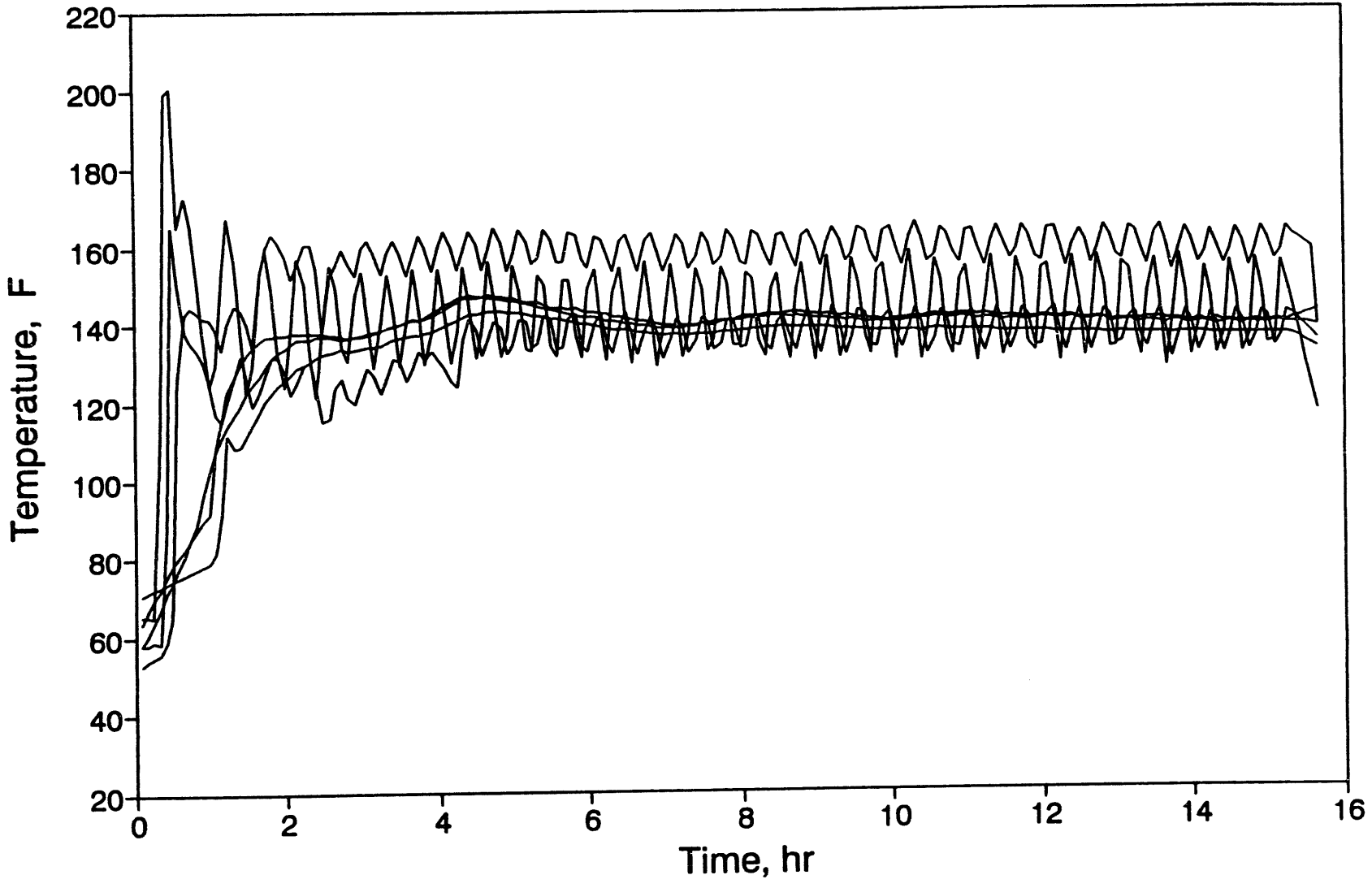

Figure 6. Temperature Profile for CROW Test 132

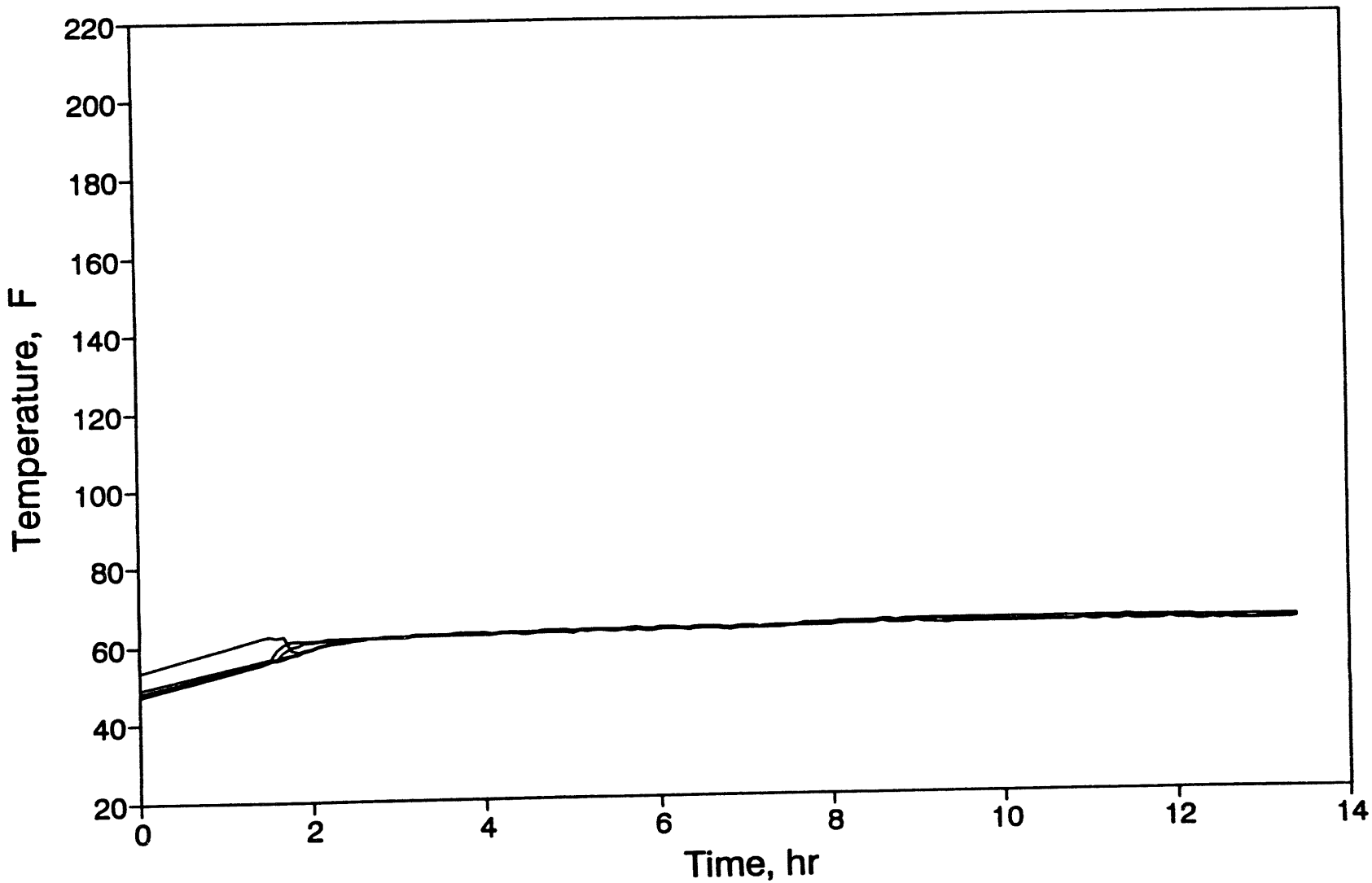

Figure 7. Temperature Profile for CROW Test 133

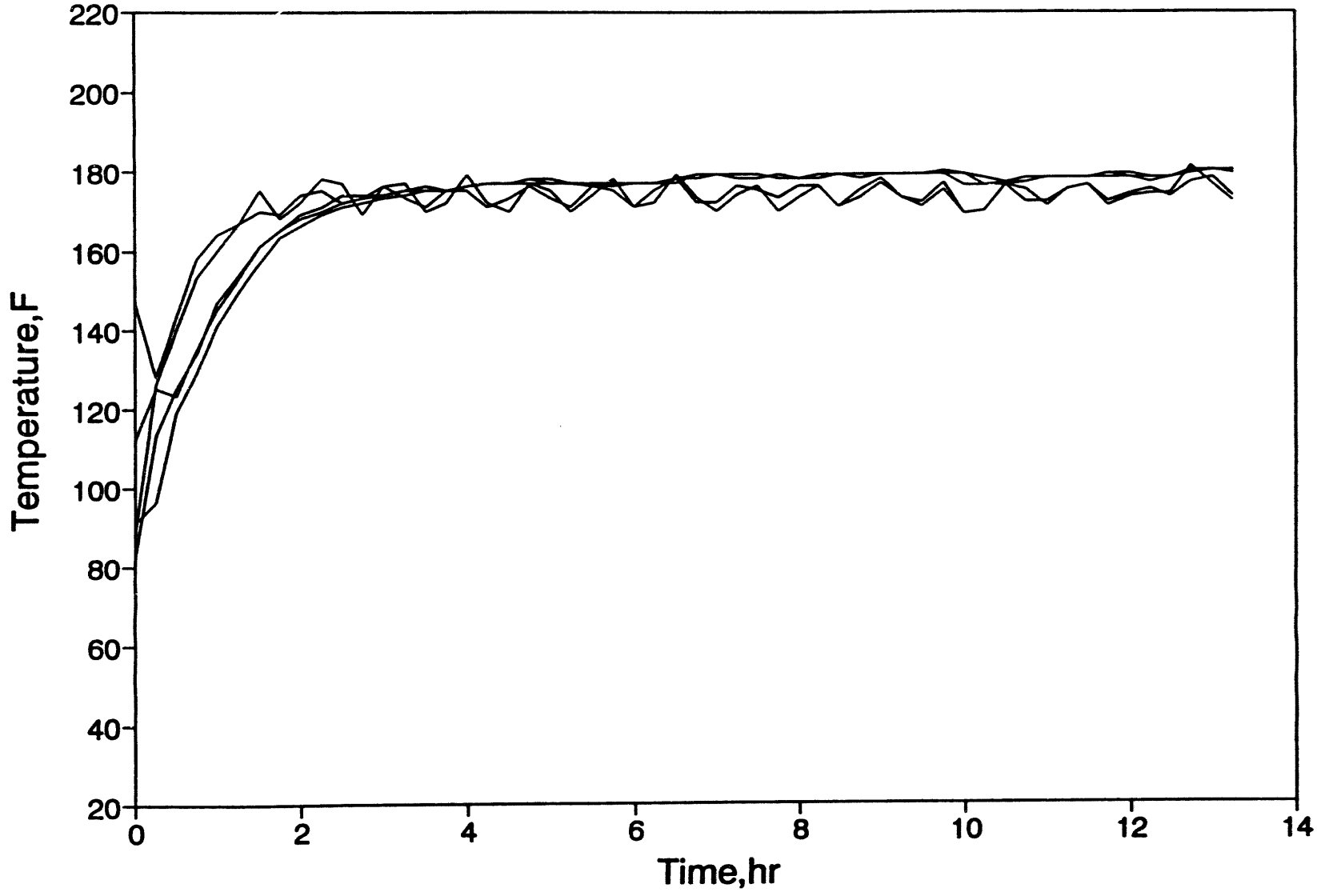

Figure 8. Temperature Profile for CROW Test 134

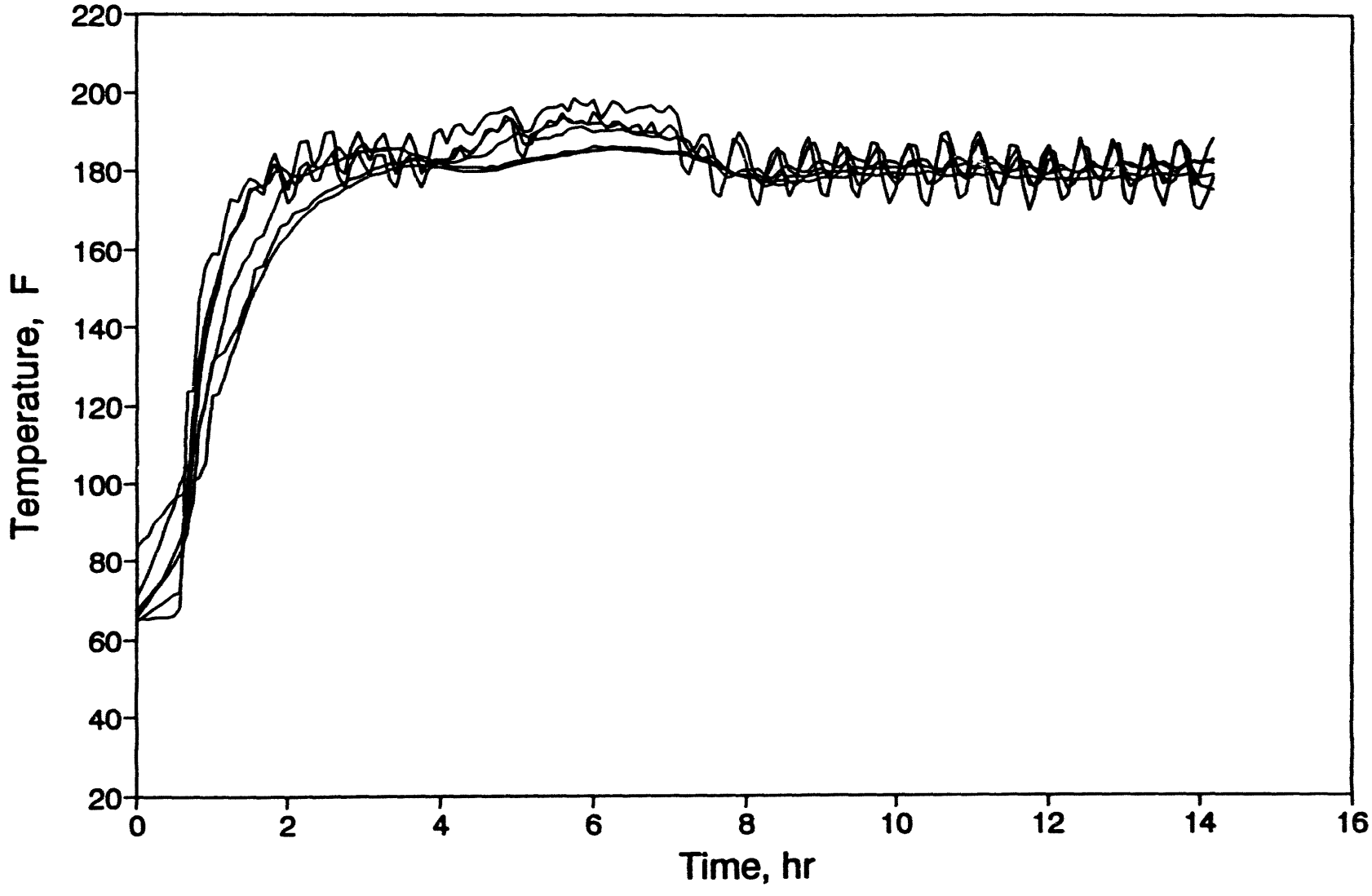

Figure 9. Temperature Profile for CROW Test 135

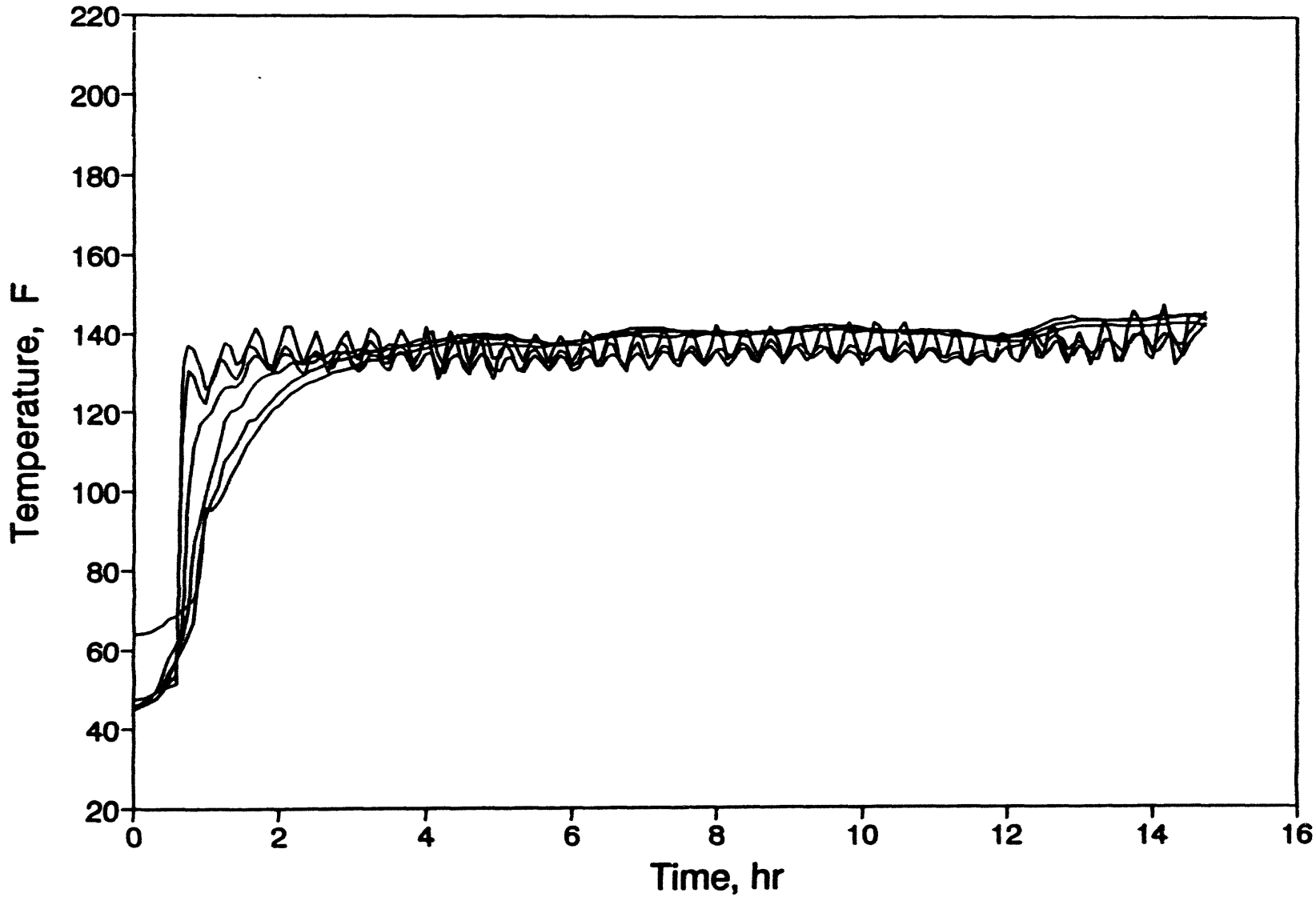

Figure 10. Temperature Profile for CROW Test 136

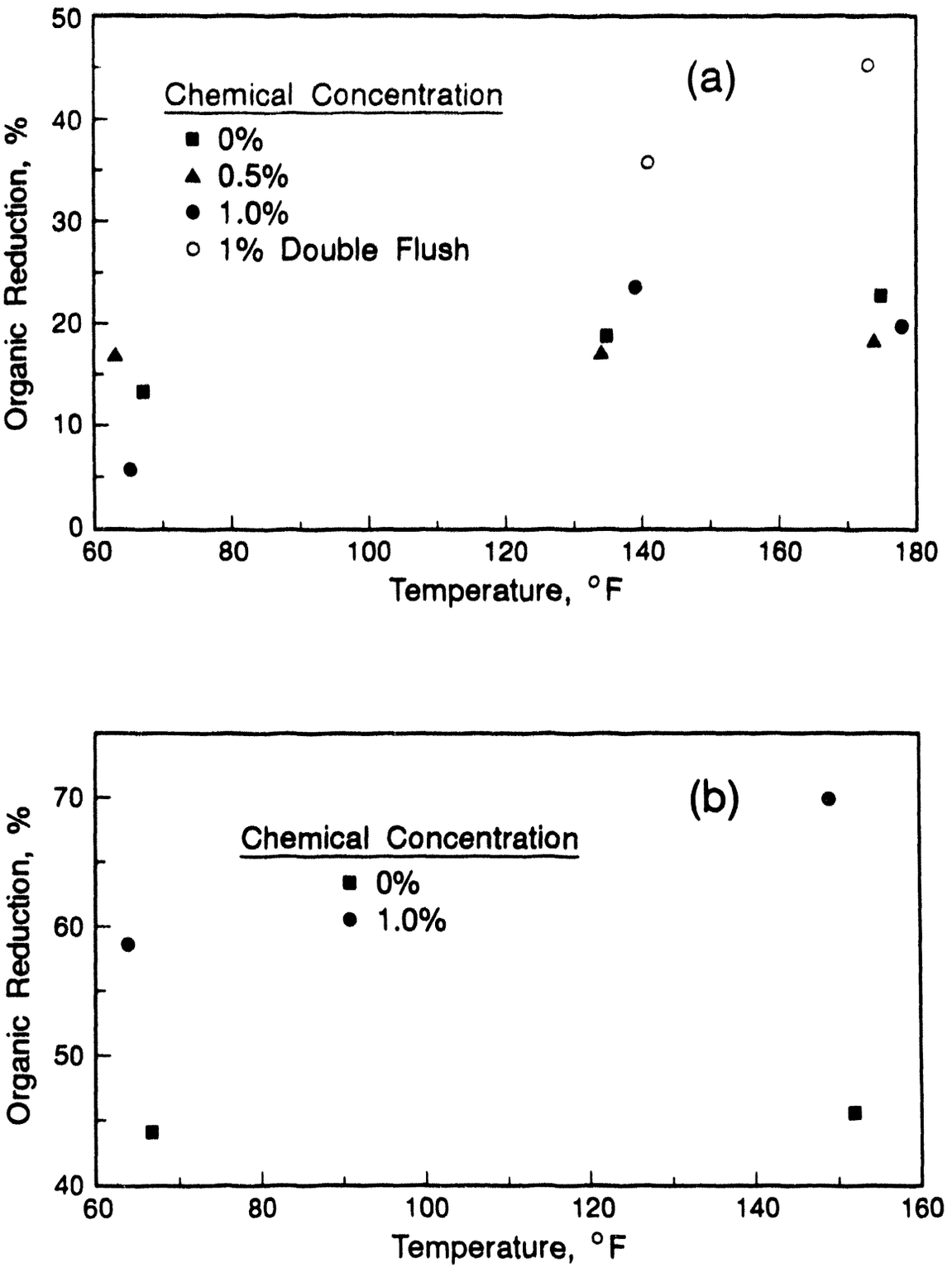

Figure 11. Organic Reduction versus Flush Temperature

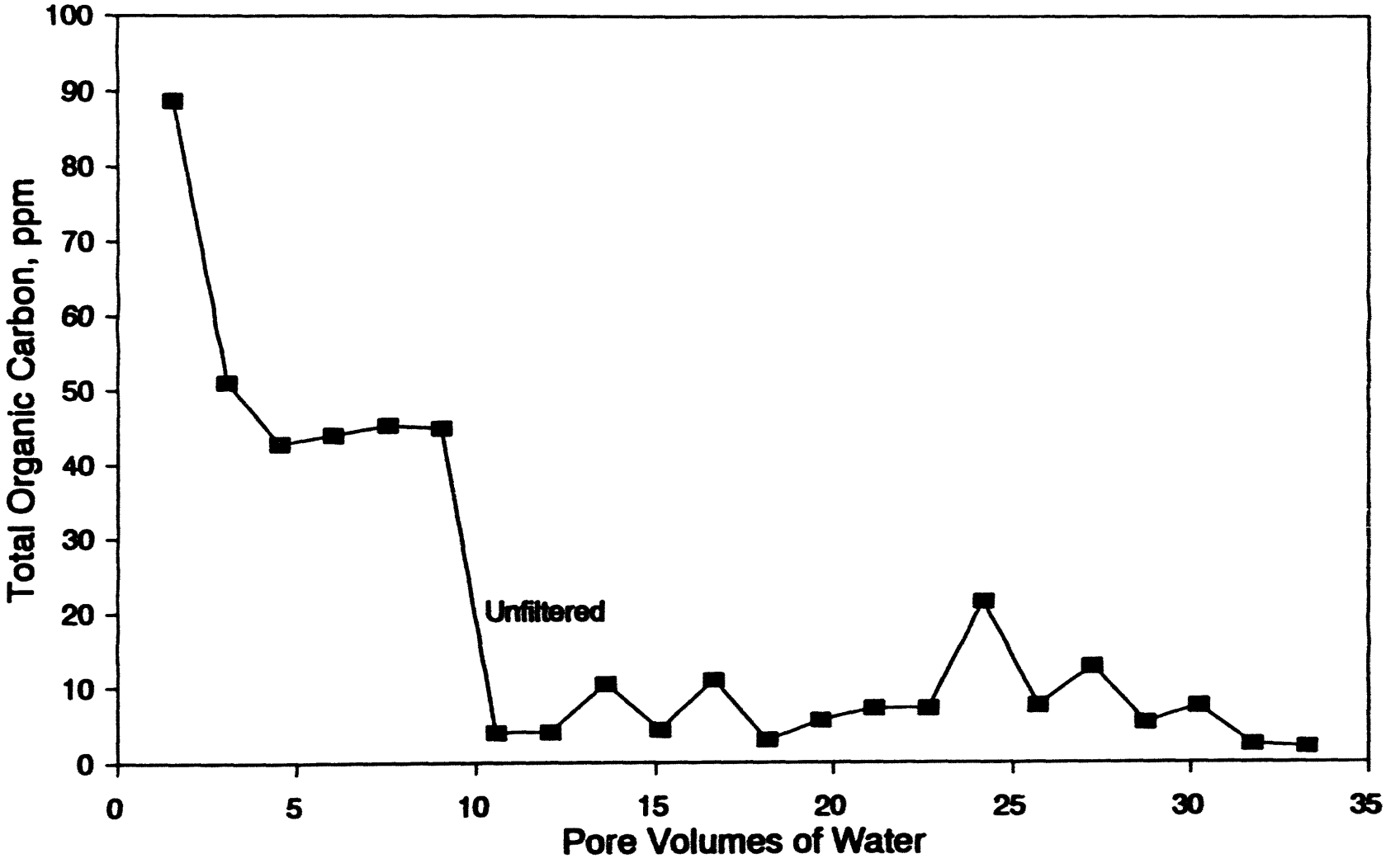

Figure 12. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 128

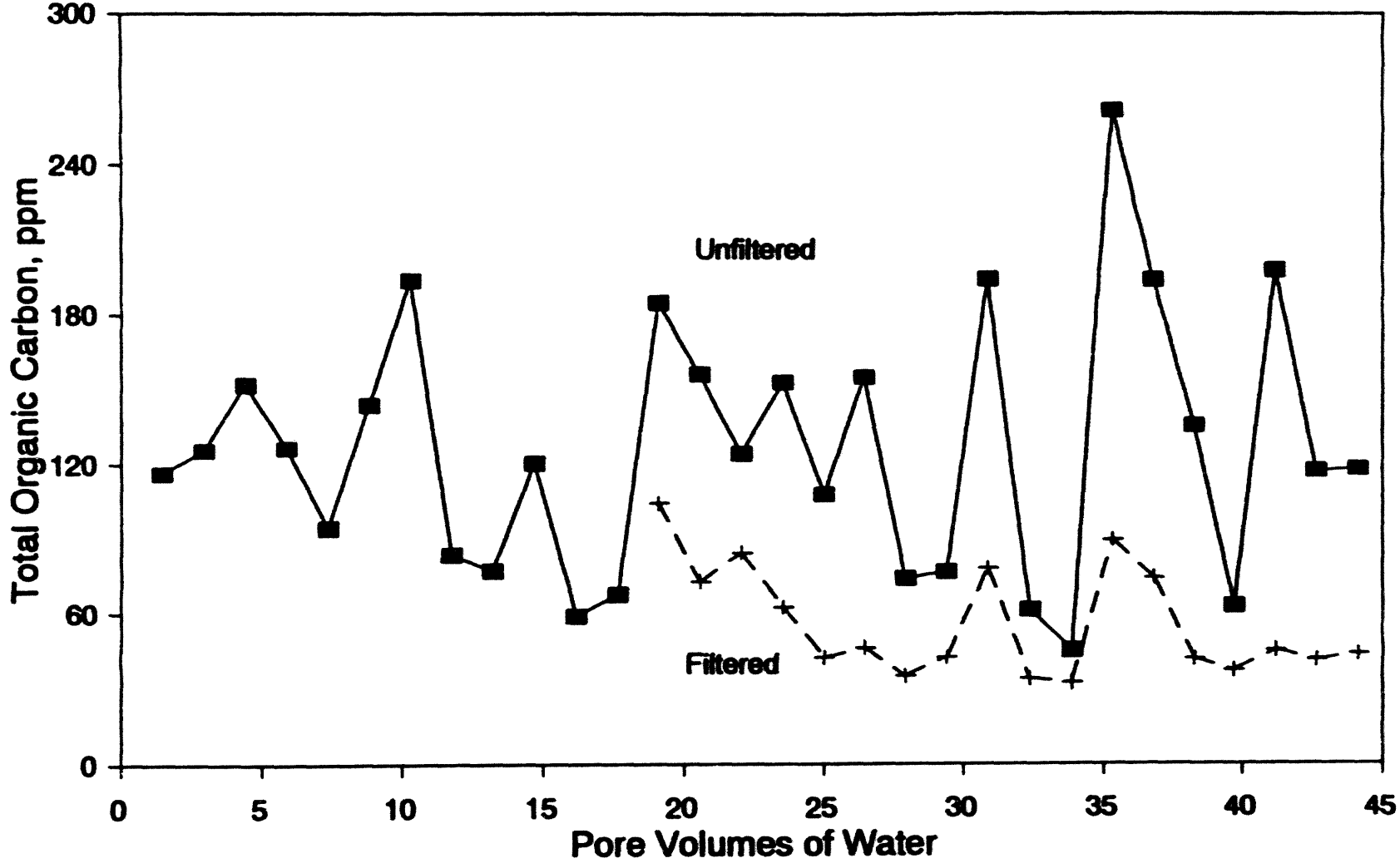

Figure 13. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 129

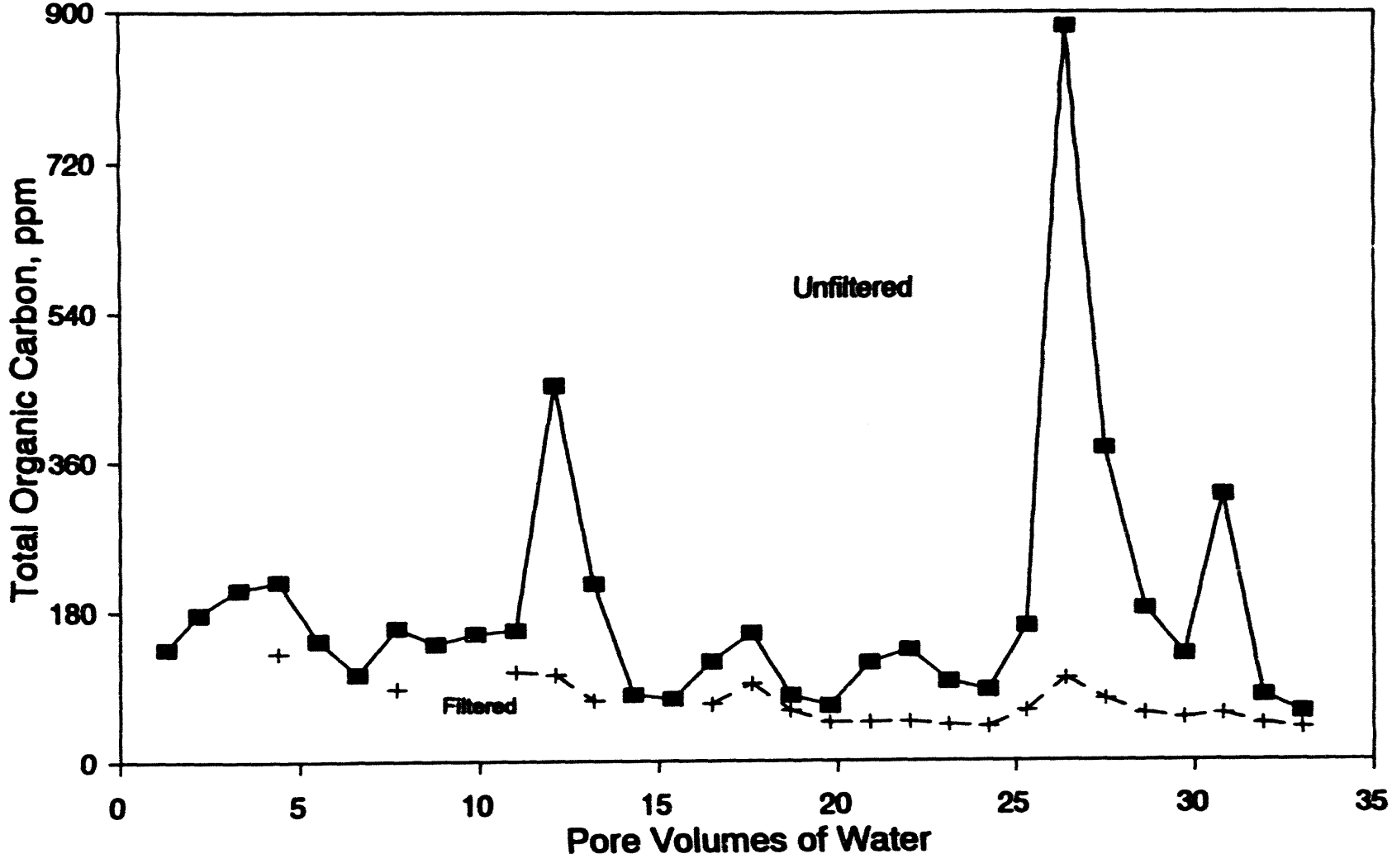

Figure 14. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 130

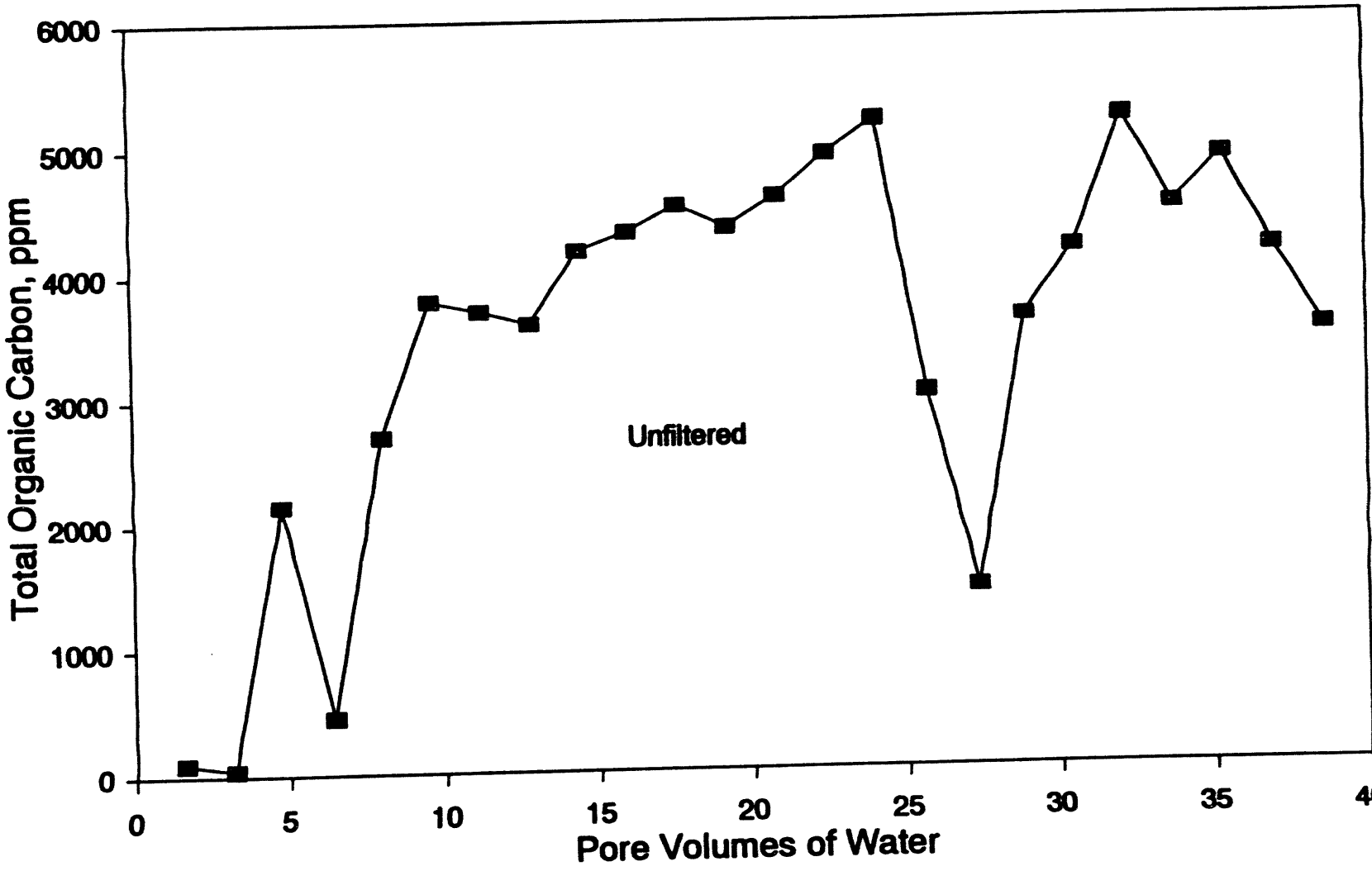

Figure 15. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 131

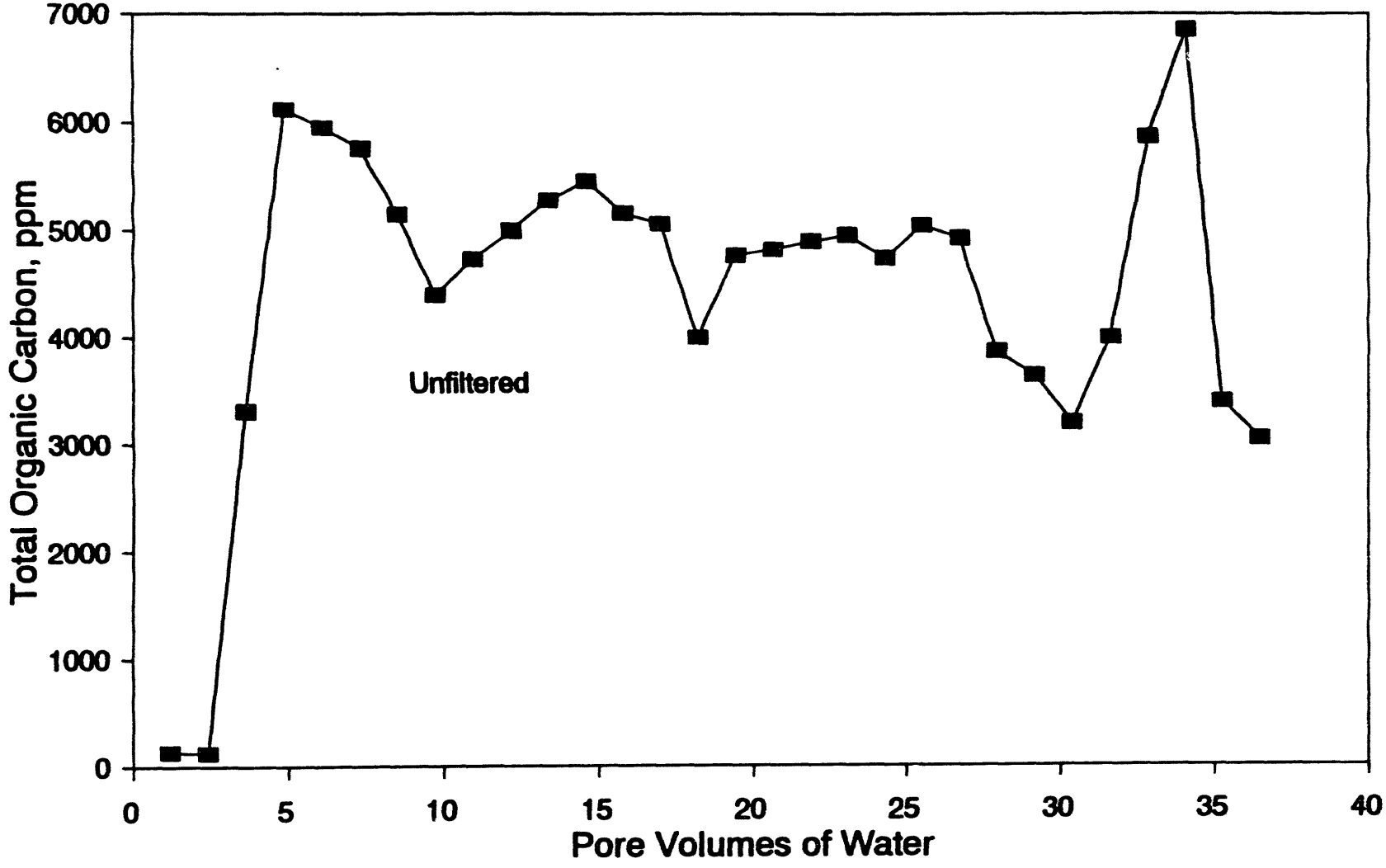

Figure 16. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 132

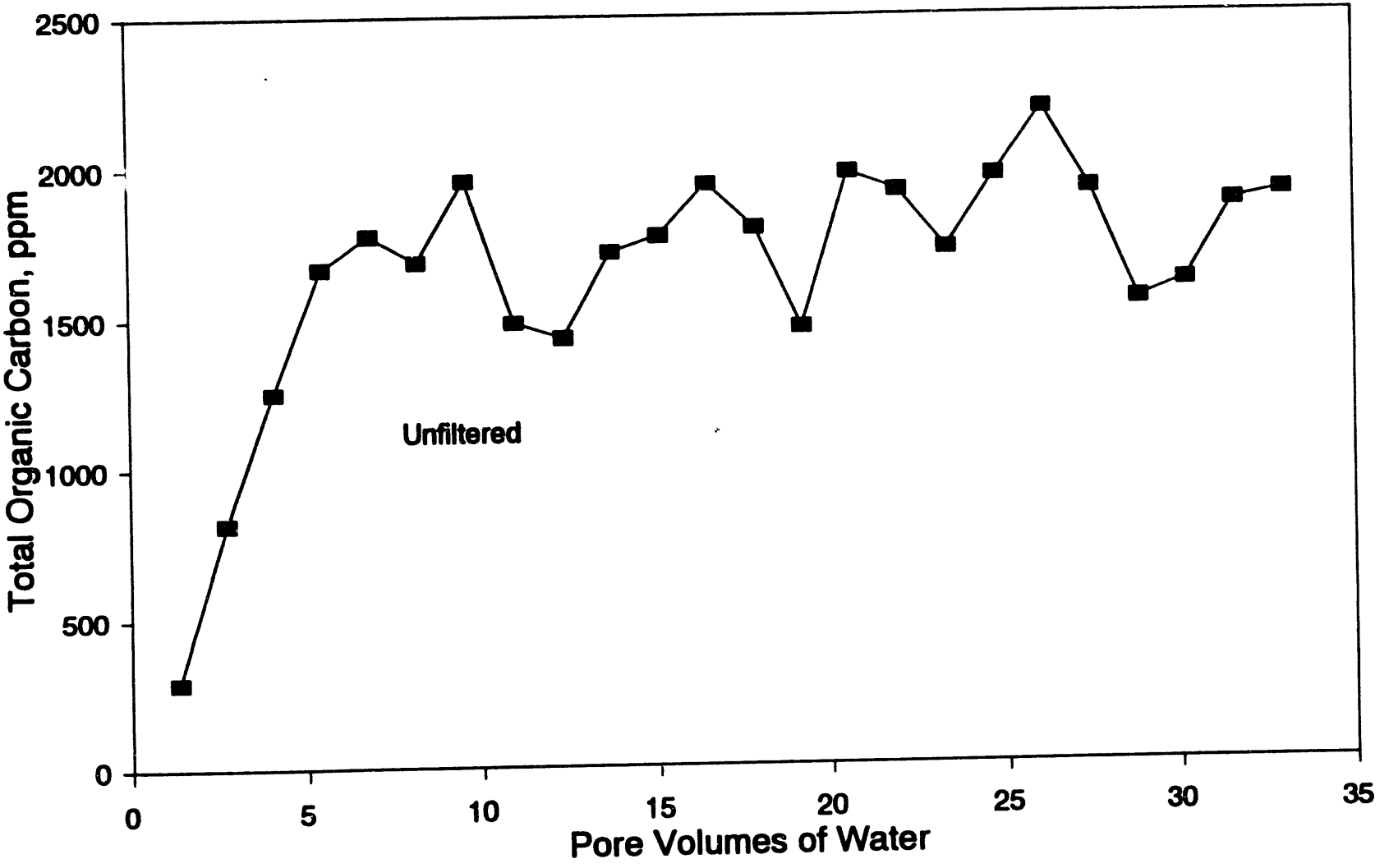

Figure 17. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 133

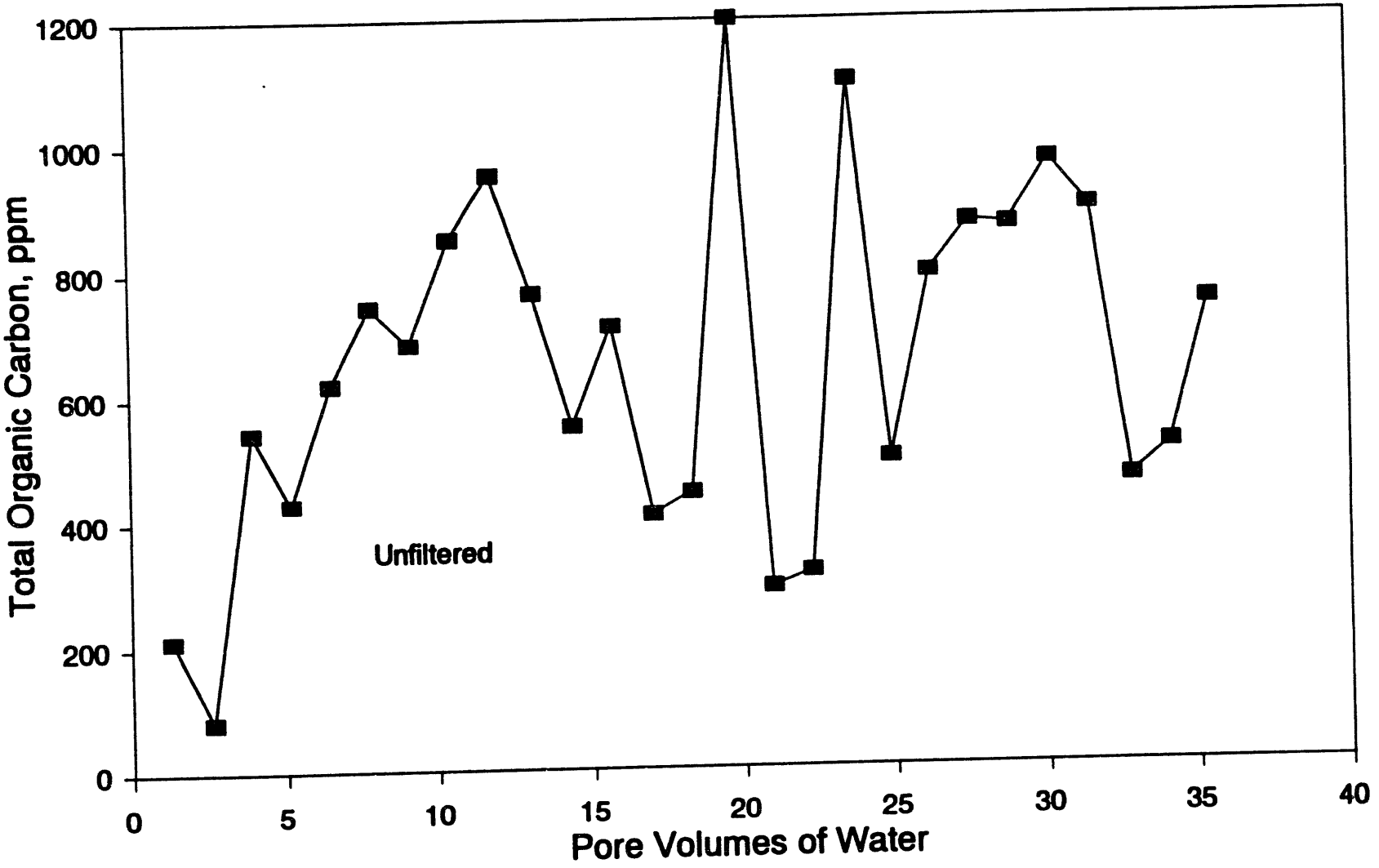

Figure 18. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 134

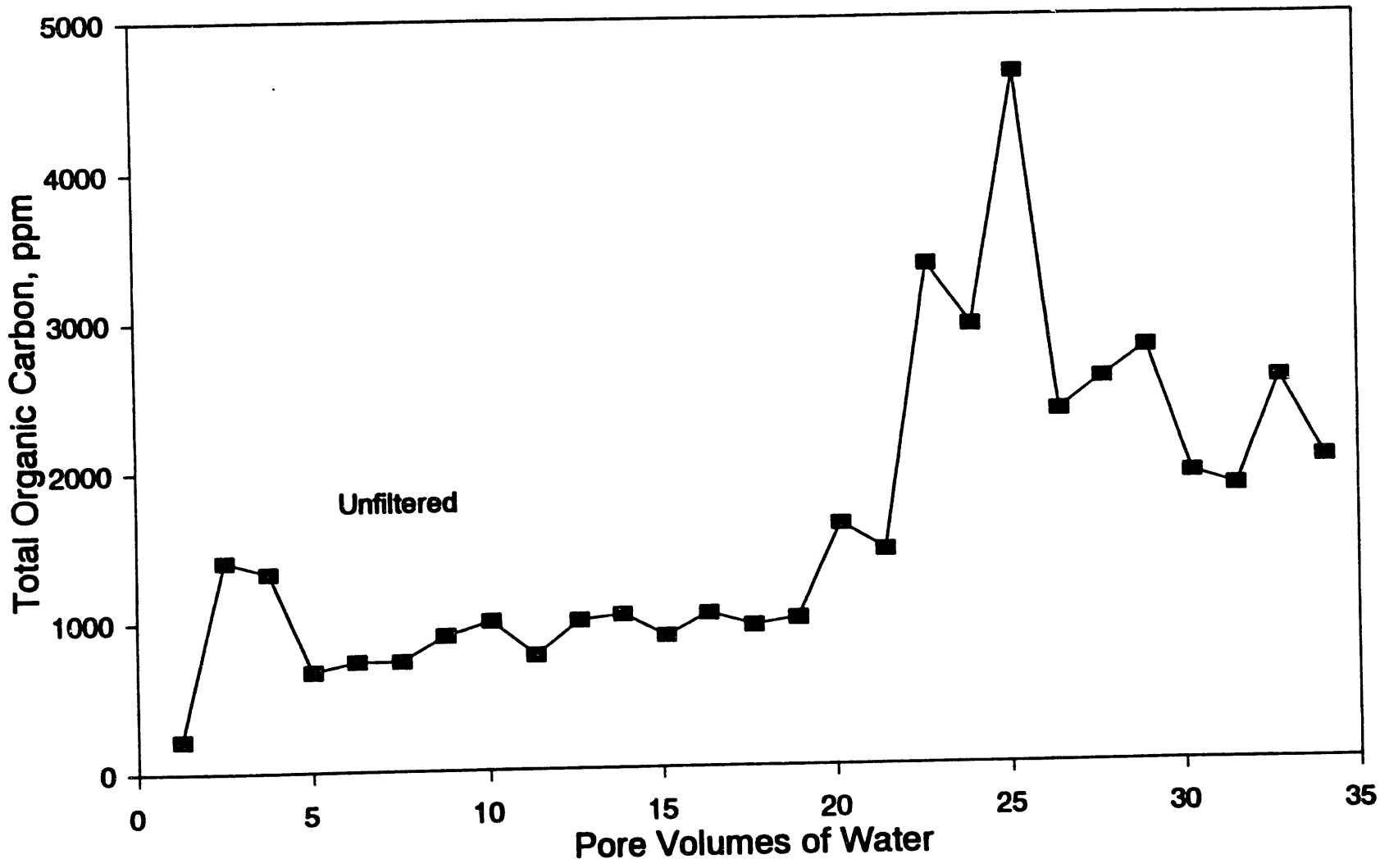

Figure 19. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 135

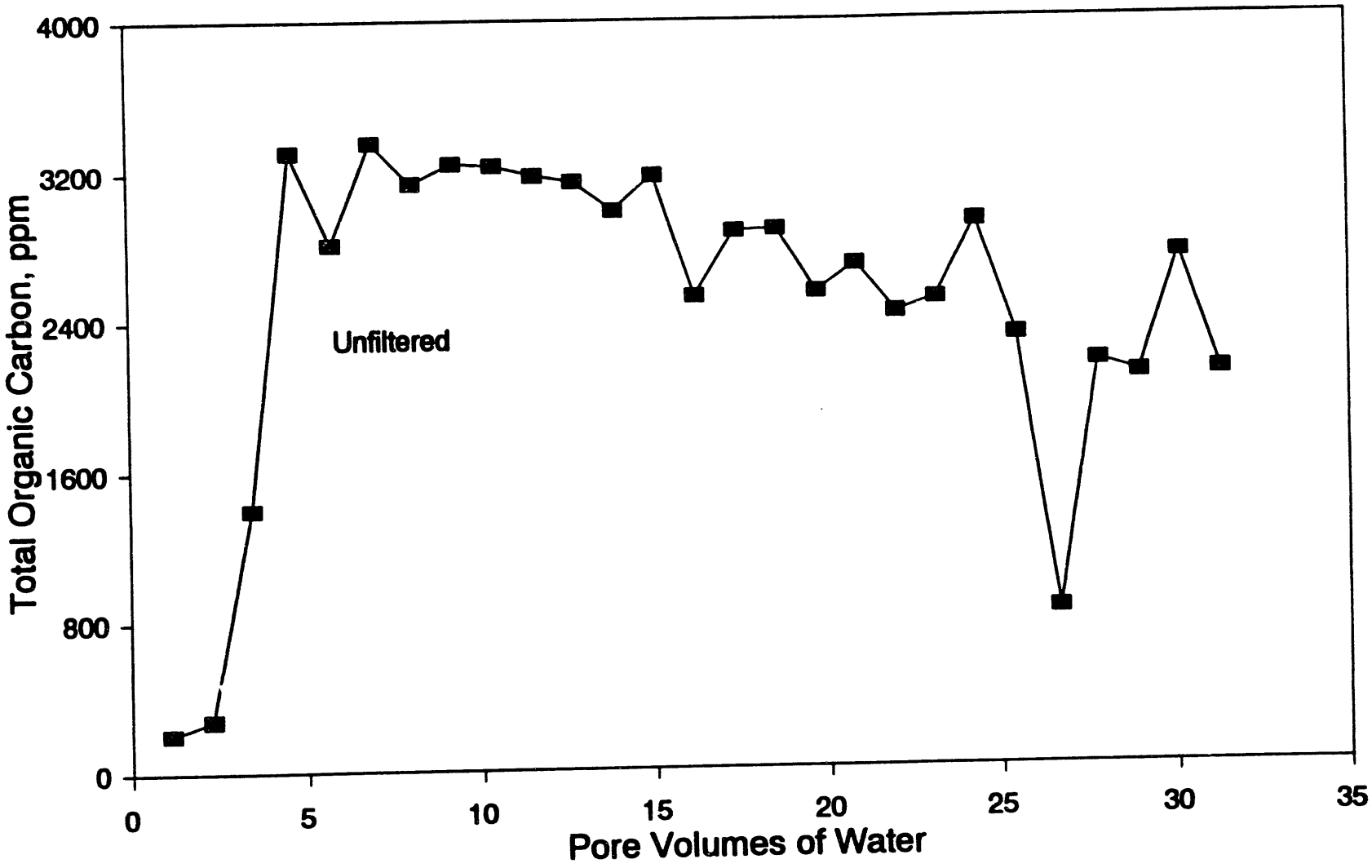

Figure 20. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 136

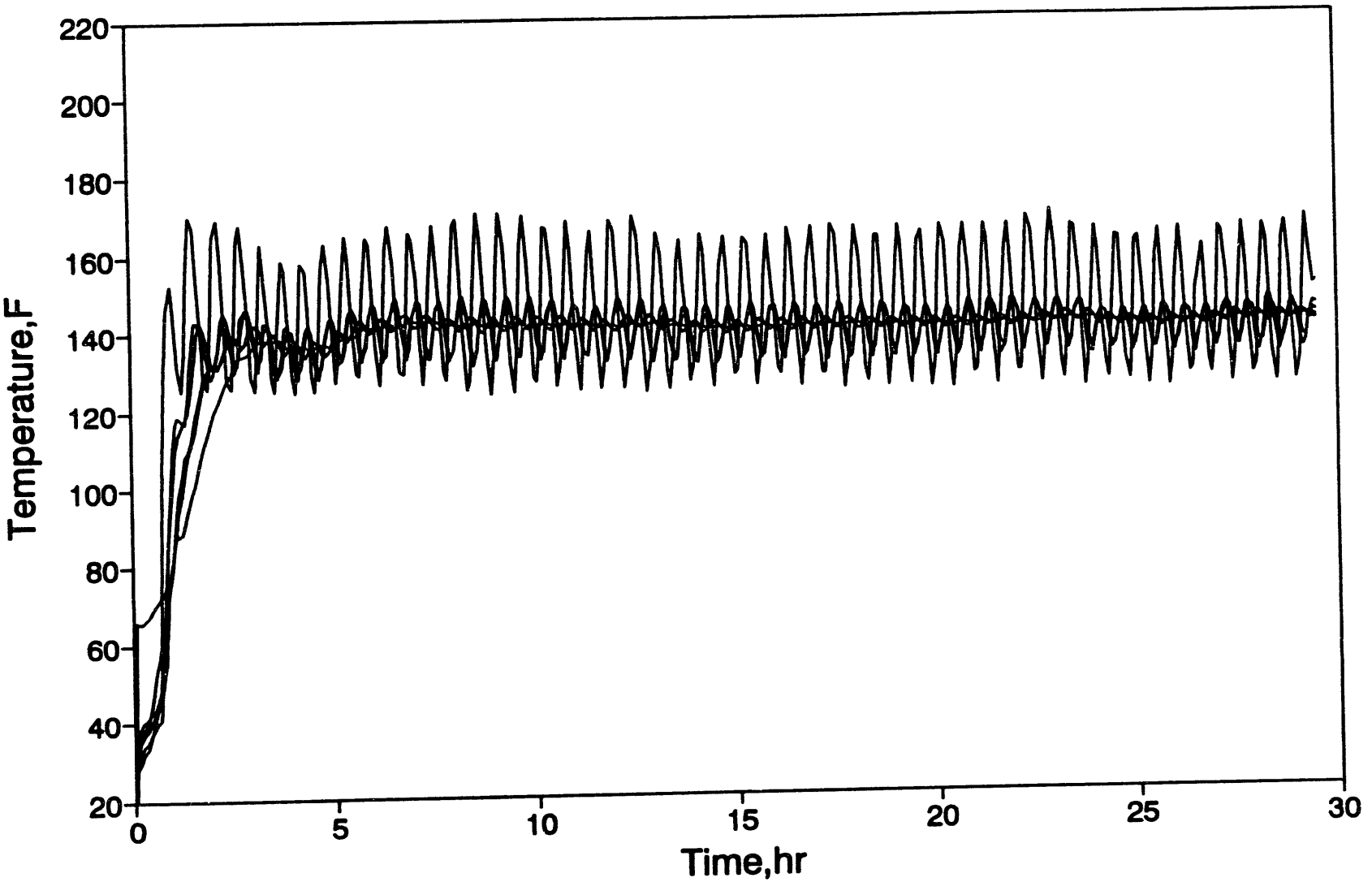

Figure 21. Temperature Profile for CROW Test 137

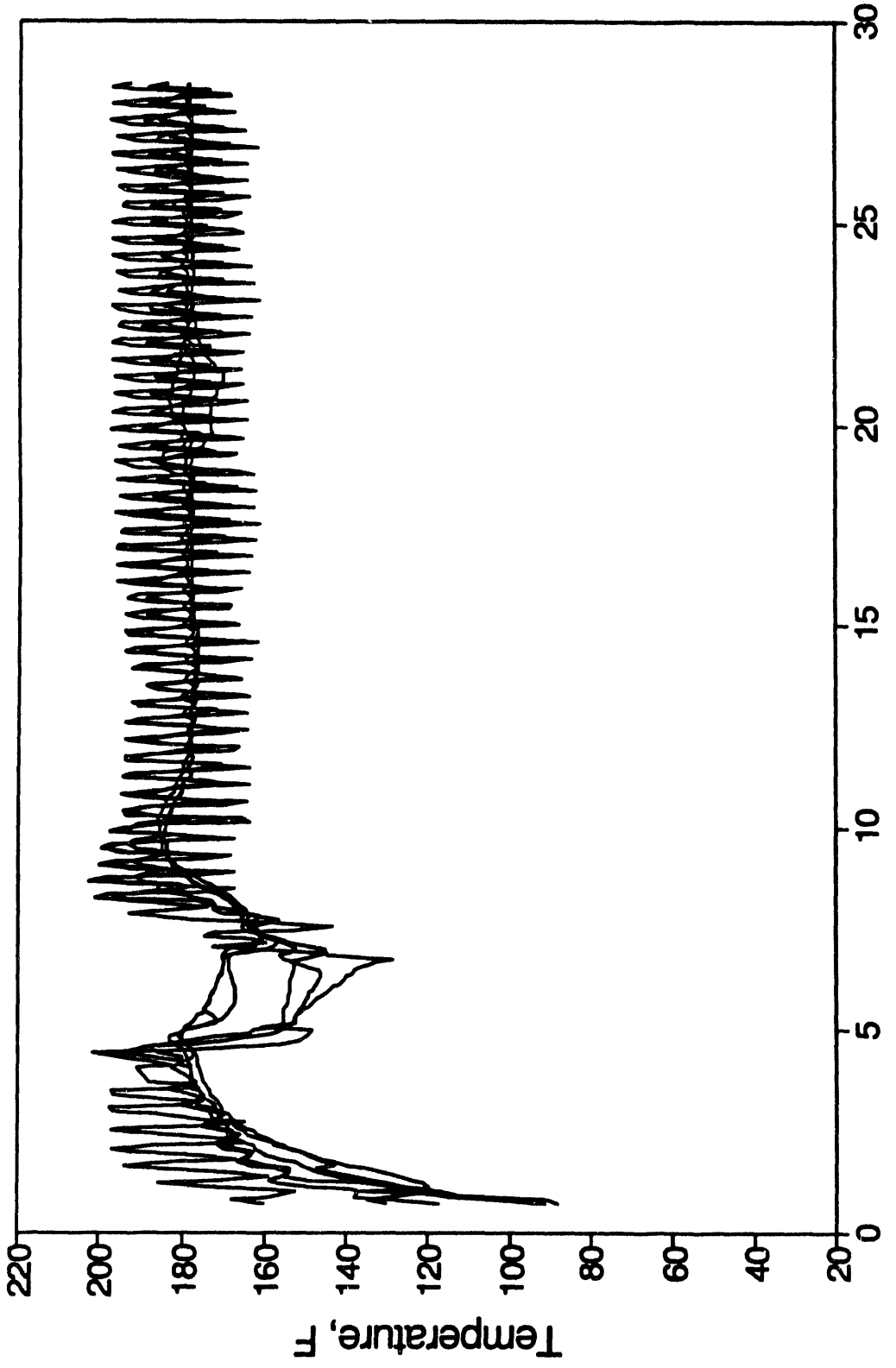

Figure 22. Temperature Profile for CROW Test 138

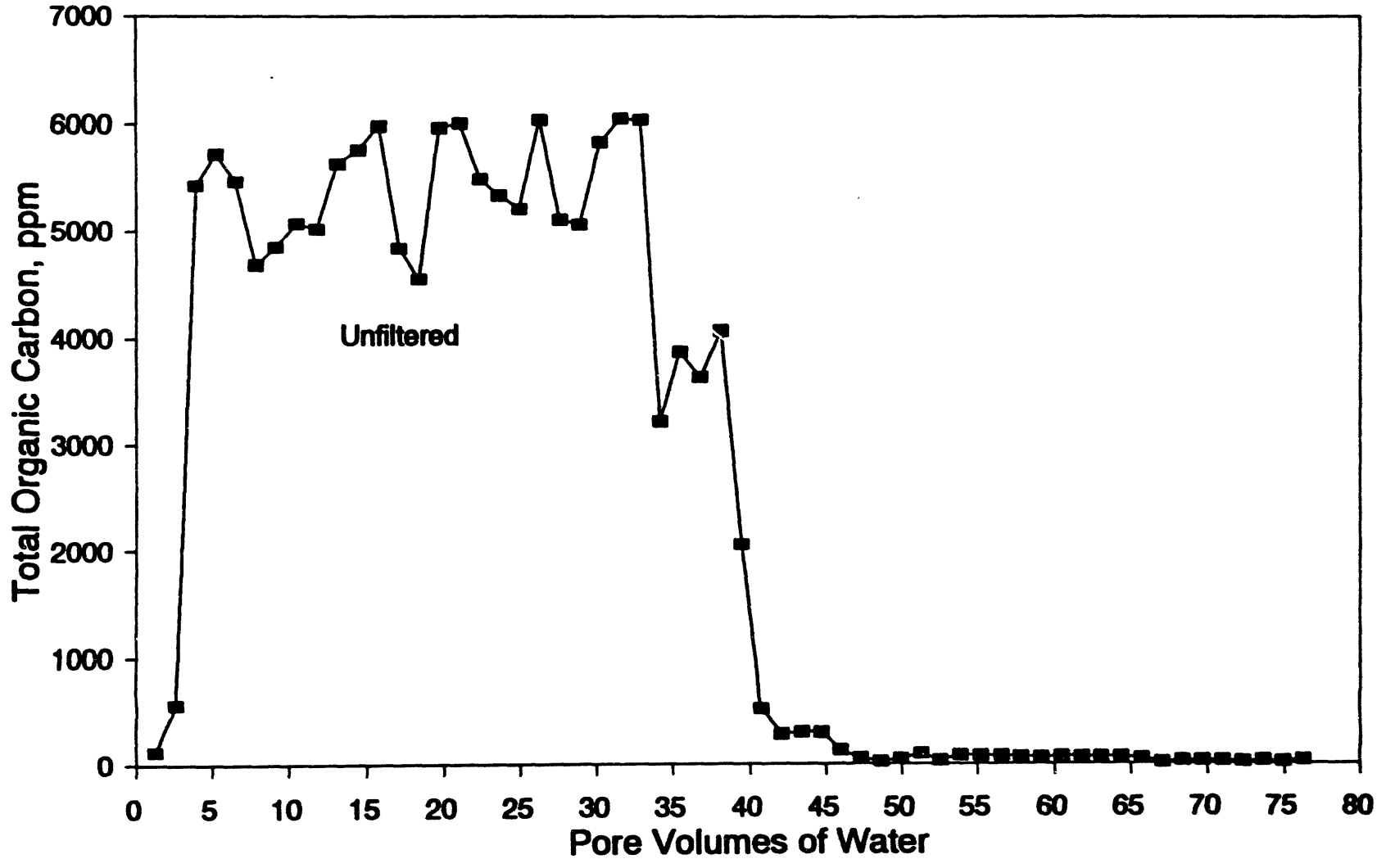

Figure 23. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 137

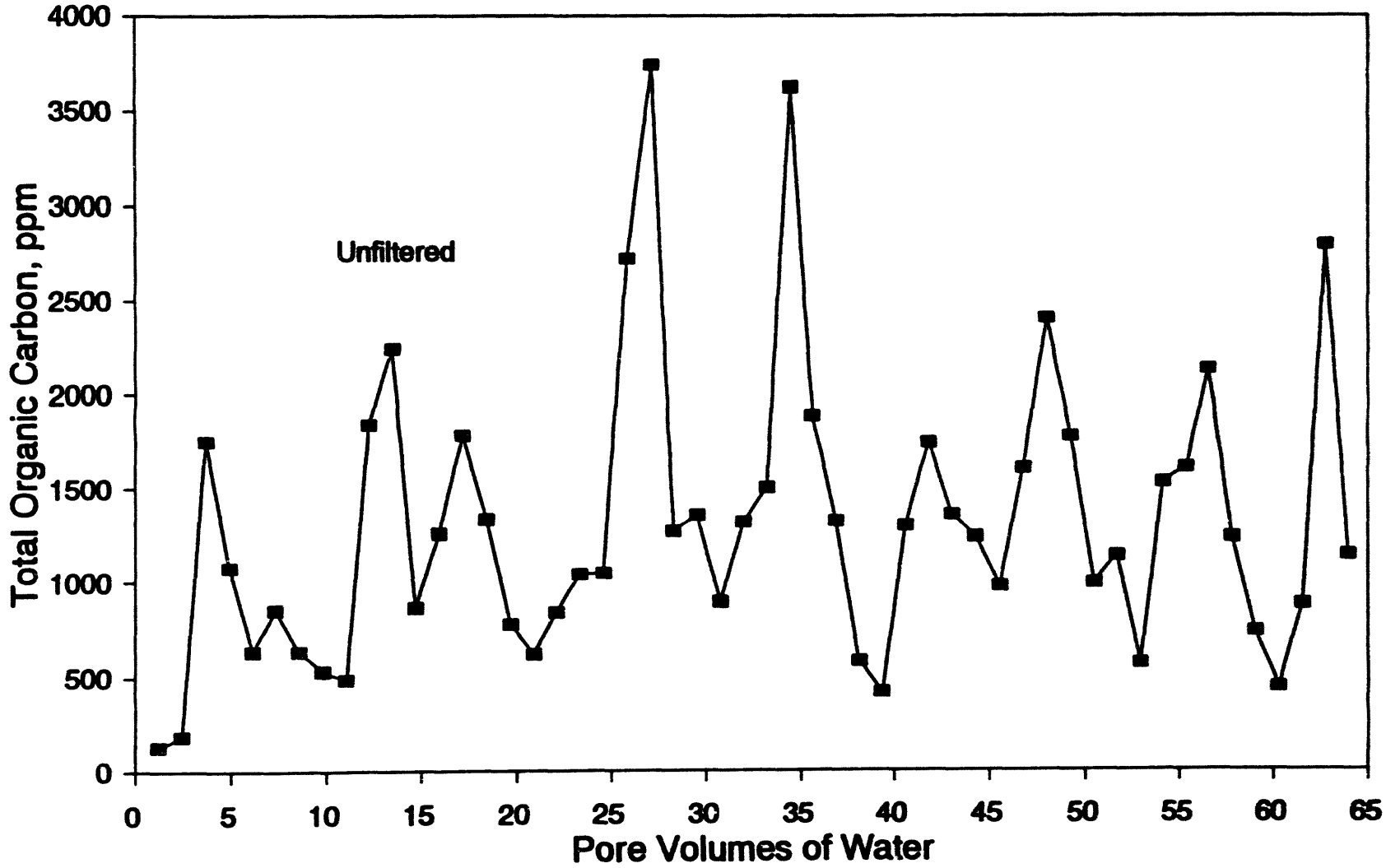

Figure 24. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 138

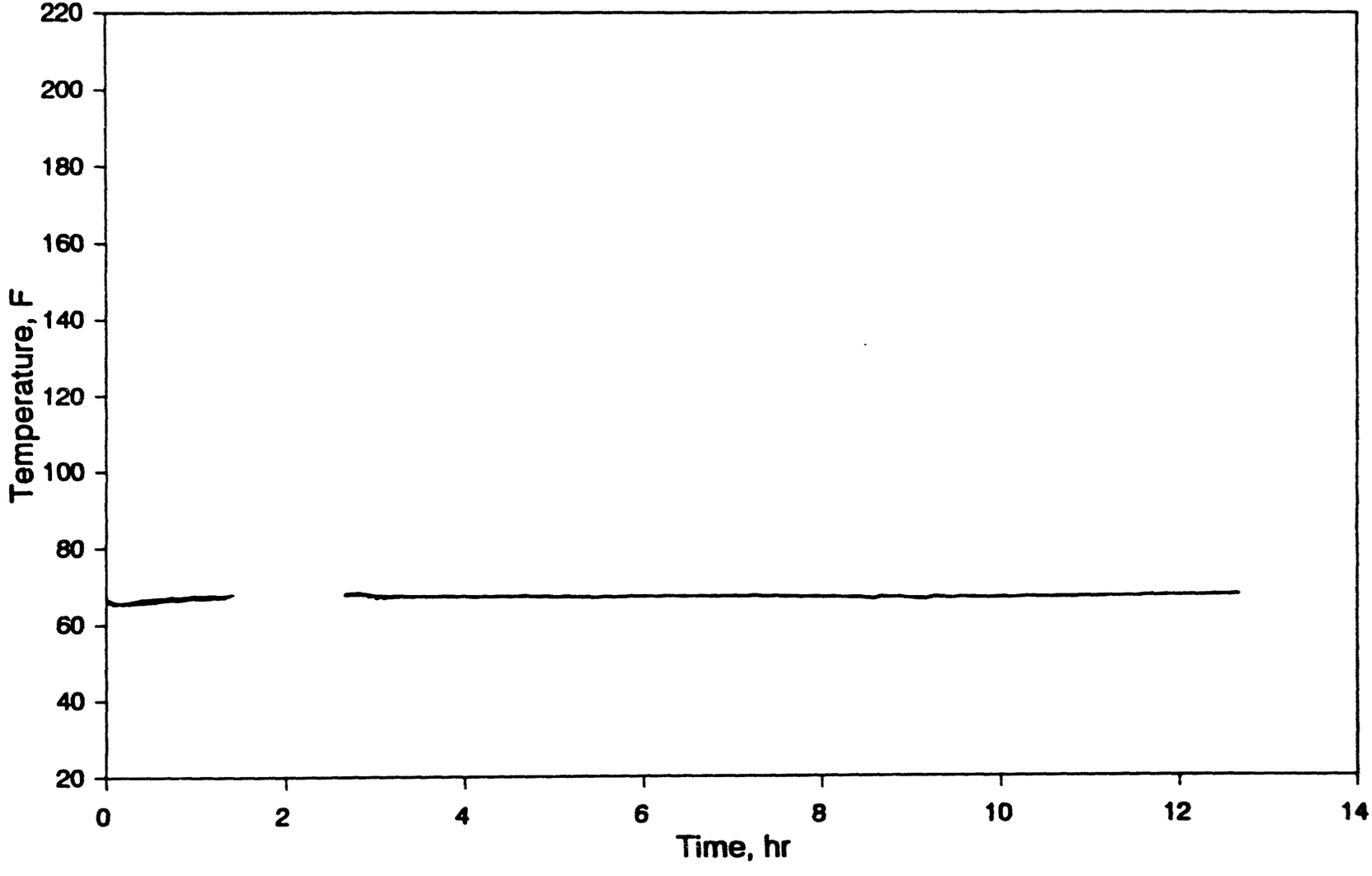

Figure 25. Temperature Profile for CROW Test 139

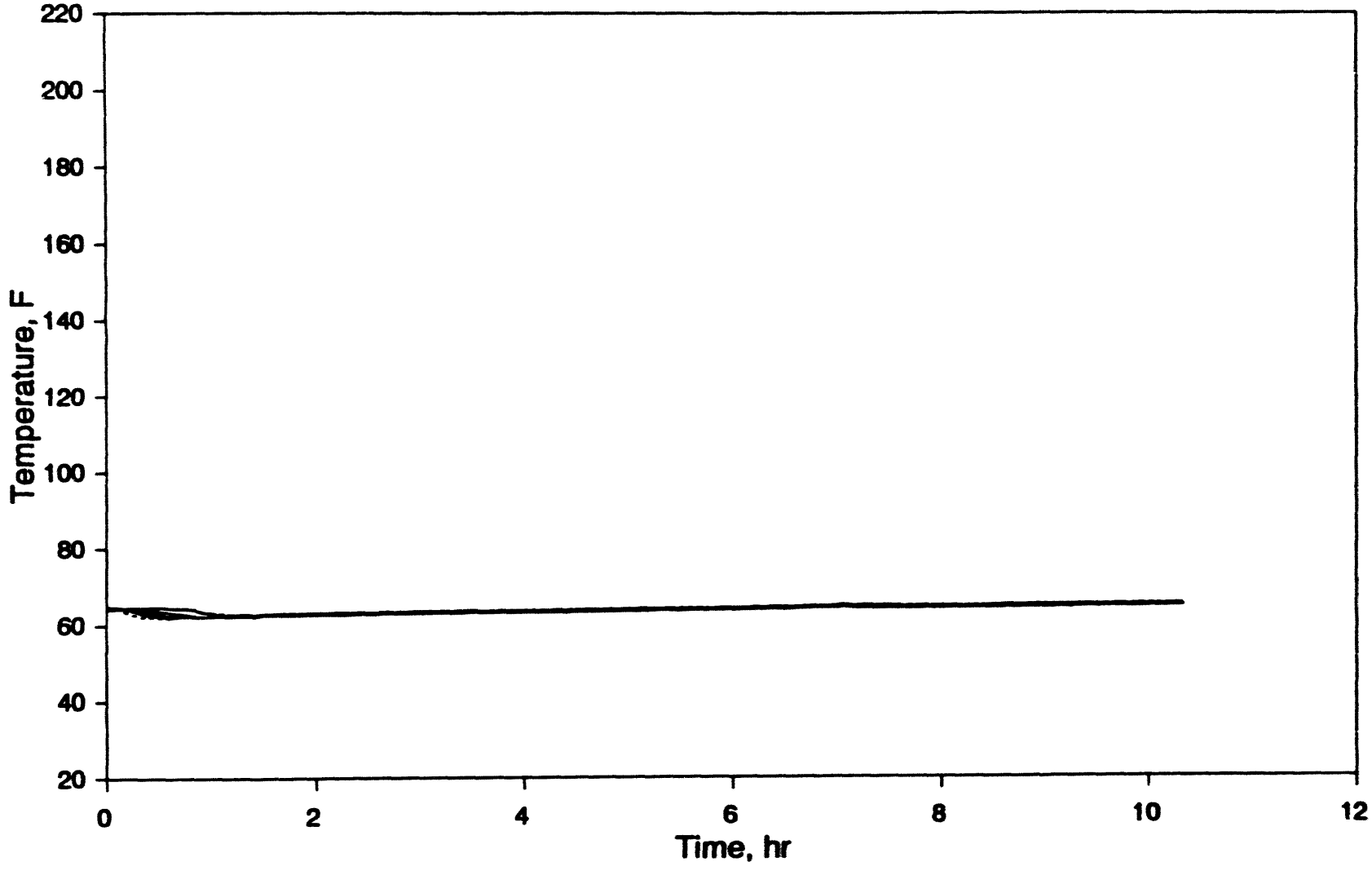

Figure 26. Temperature Profile for CROW Test 140

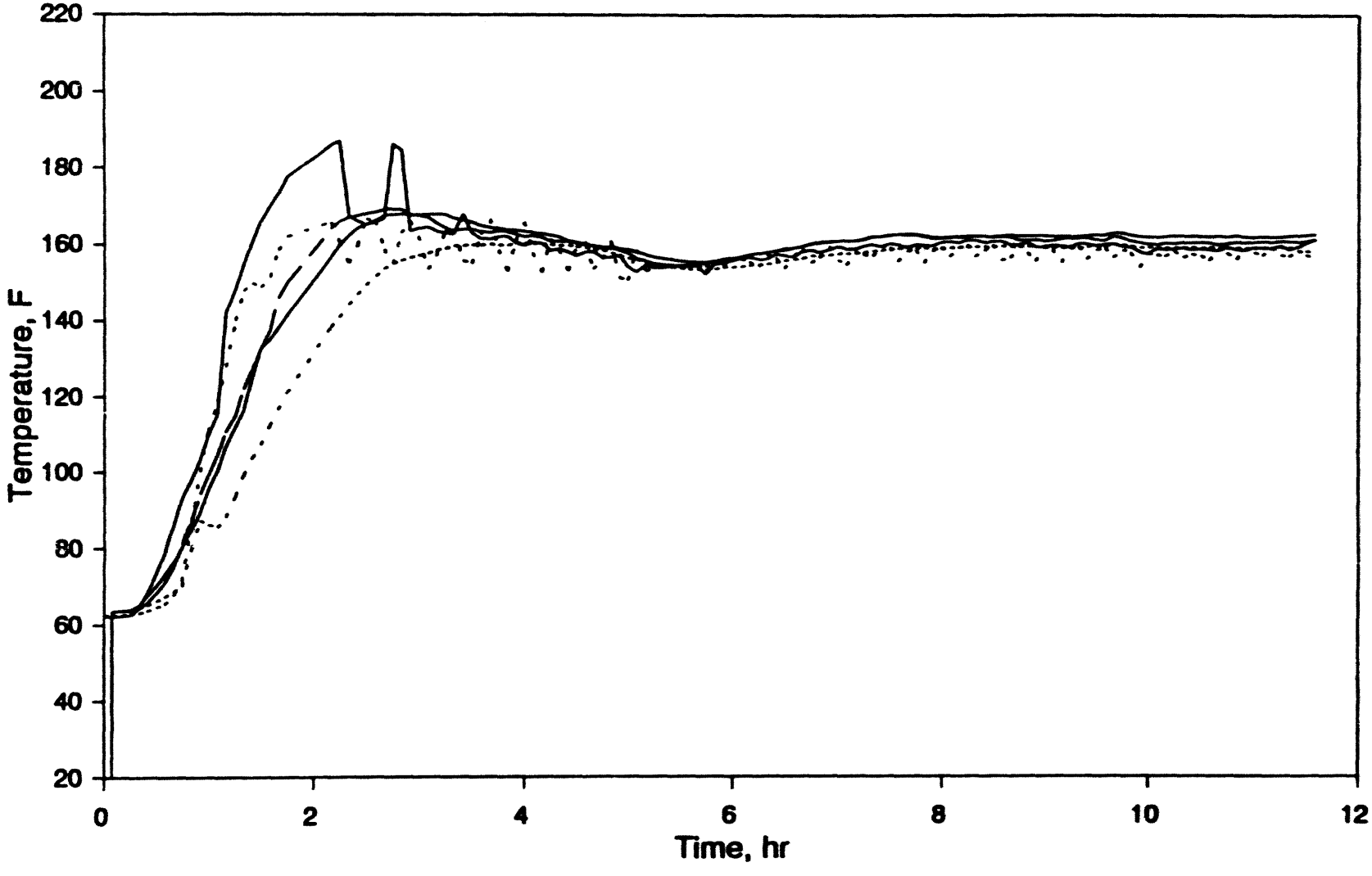

Figure 27. Temperature Profile for CROW Test 141

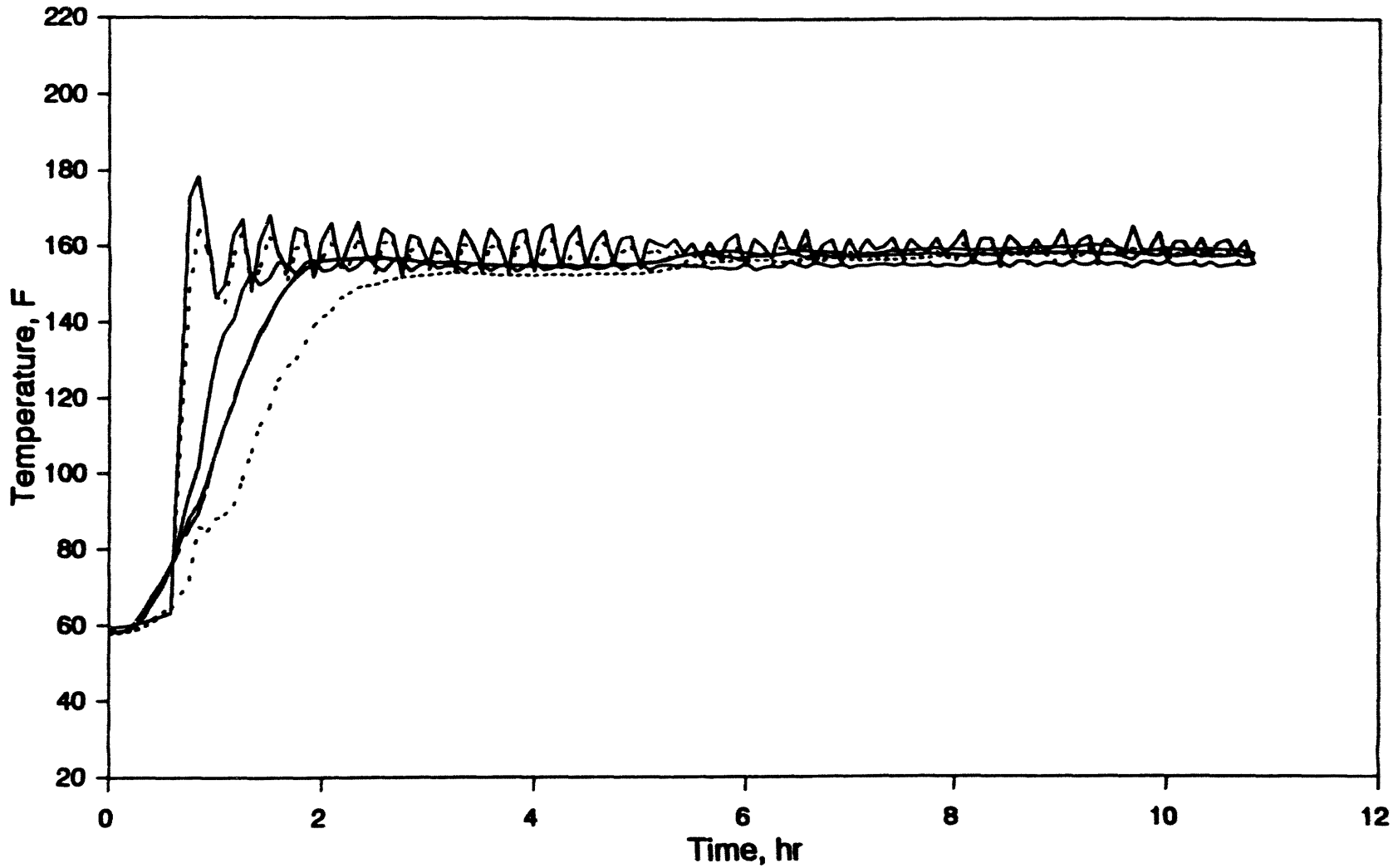

Figure 28. Temperature Profile for CROW Test 142

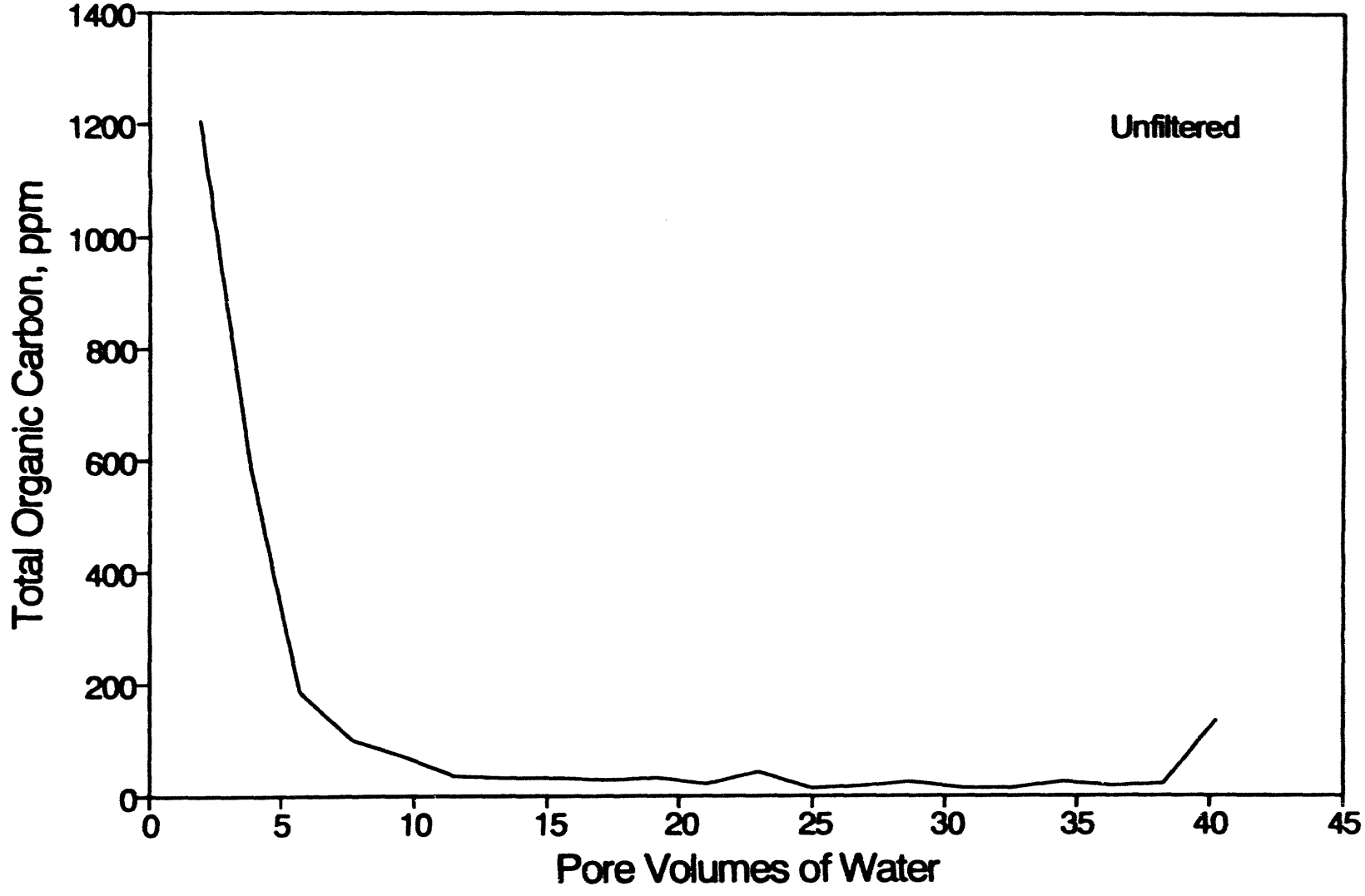

Figure 29. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 139

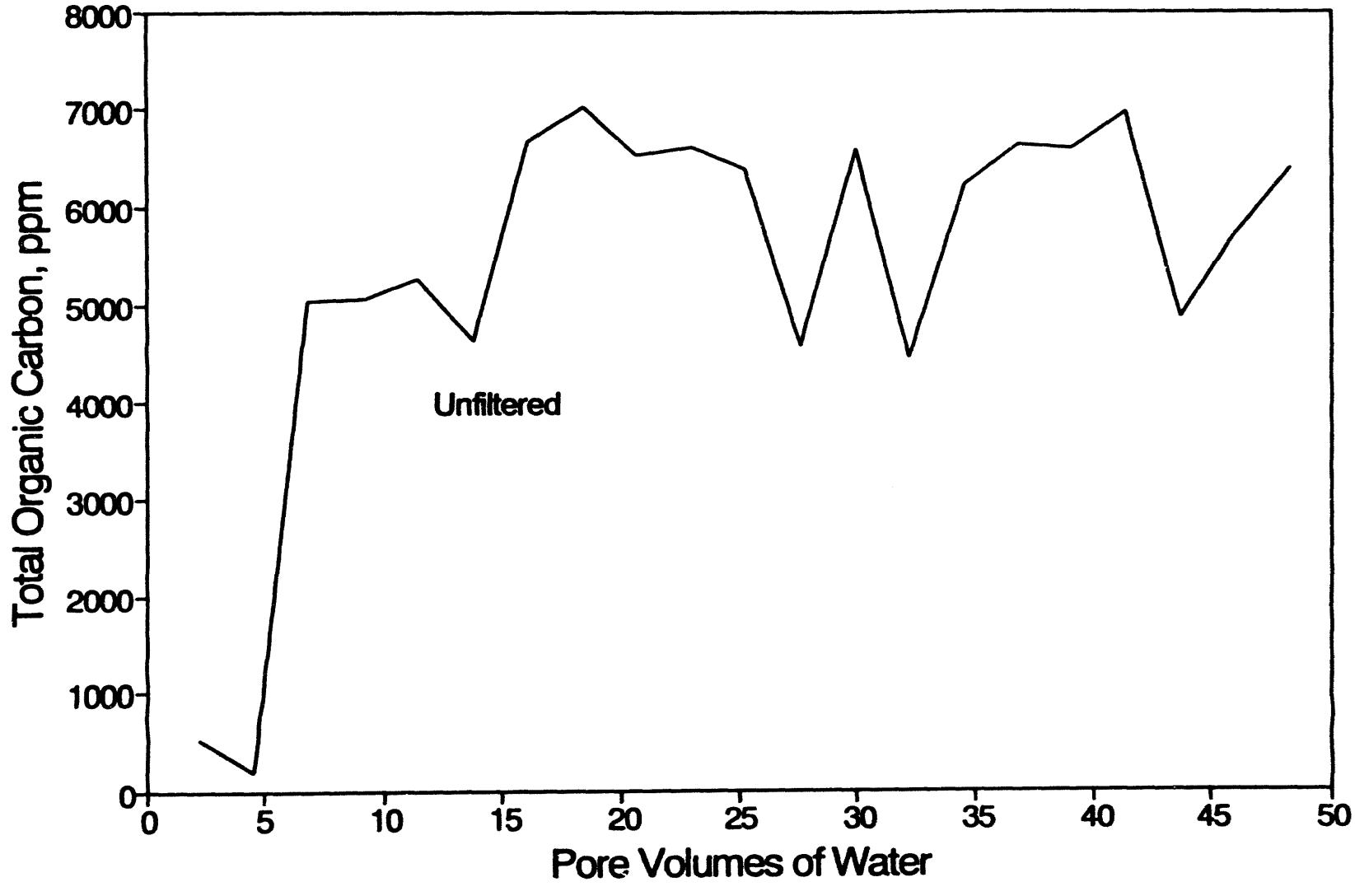

Figure 30. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 140

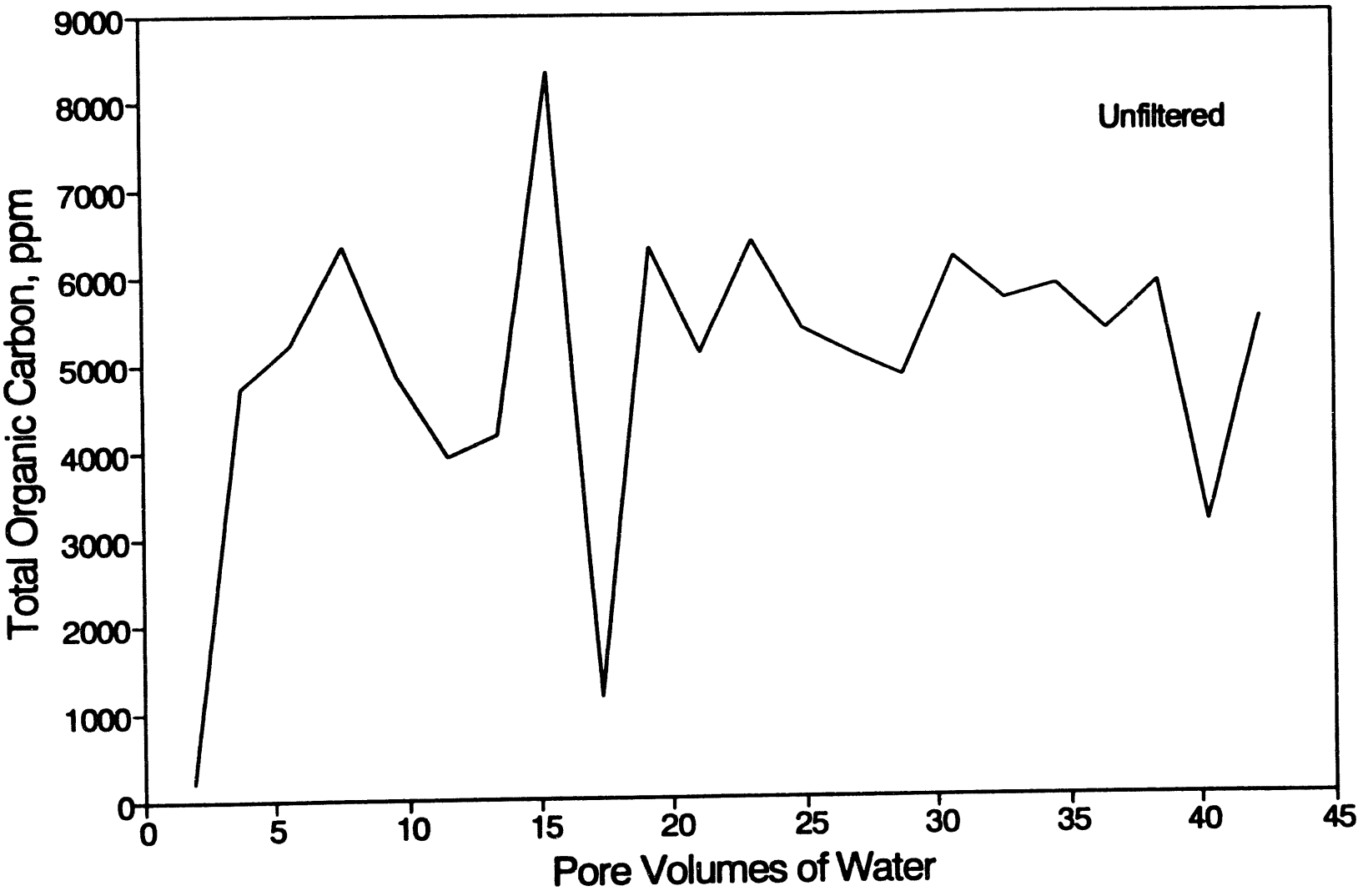

Figure 31. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 141

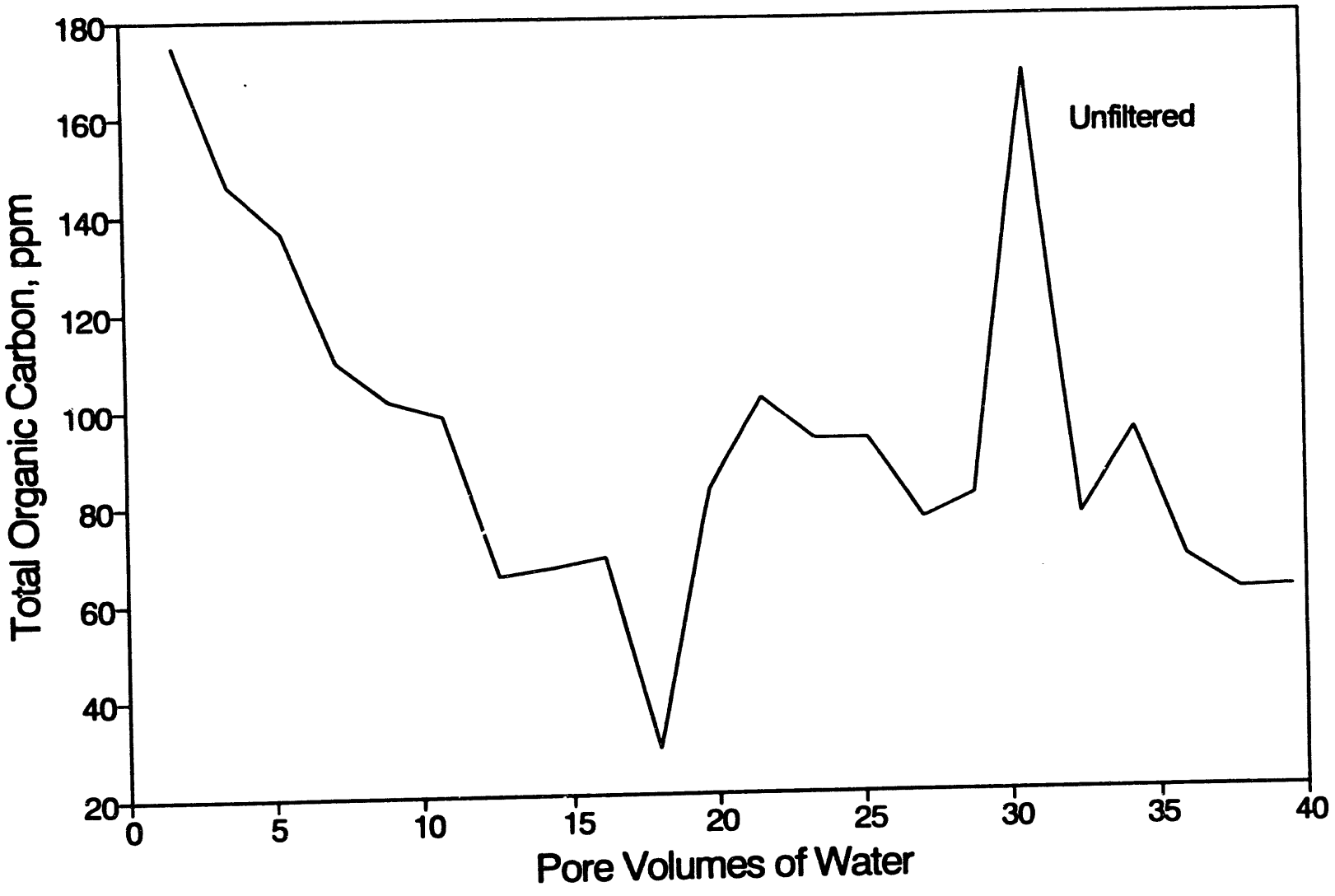

Figure 32. Total Organic Carbon in Produced Fluid versus Pore Volumes of Water Injected for CROW Test 142

DATE
FILMED
10/24/94
END