PILOT-SCALE ENGINEERING STUDY

POLLUTION ABATEMENT SERVICES SITE
OSWEGO, NY

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DRAFT REPORT

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EXECUTIVE SUMMARY

BACKGROUND

The Pollution Abatement Services (PAS) site is a remediated Superfund site in Oswego, N.Y. Remediation consisted of removing thousands of drums and draining lagoons containing hazardous wastes. A bentonite slurry wall and a high density polyethylene cap was placed around and over the site, respectively, to eliminate the migration of hazardous substances remaining in the soil. However, recent hydrogeological evidence suggest that leachate periodically breaches the slurry wall.[1] To avoid this problem, the leachate level within the confines of the slurry wall must be lowered every few months. This necessitates the expenditure of time, money, and manpower to pump, transport, and dispose of the leachate at an off-site treatment facility. This engineering study investigated alternative technologies to reduce or eliminate this expenditure.

The 1986 Superfund Amendments and Reauthorization Act (SARA) mandated the use of innovative and alternative options over existing remediation practices. In accordance with the spirit and letter of the law, the U.S. Environmental Protection Agency (U.S. EPA) Region II requested engineering support from the U.S. EPA Environmental Response Team (ERT) to explore alternative and innovative technologies applicable to the PAS site. The ERT, established in 1978 under the National Contingency Plan, provides to federal, state, and local agencies expertise in, and resources for, engineering studies to test alternative and innovative technologies. Based on previously successful bench-scale studies that have led to full-scale remediation at other sites, the ERT and the Response, Engineering, and Analytical Contractor (REAC) with the support of Environment Canada (EC) explored the feasibility of several alternative and innovative treatment technologies. Using laboratory pilot-scale and field pilot-scale experiments, this project explored the following treatment technologies in two separate tests:

A. Laboratory pilot-scale

- Powdered activated carbon/microfiltration/reverse osmosis.
- Reverse osmosis.

B. Field pilot-scale

- Reverse osmosis.
- Ultraviolet/ozone/hydrogen peroxide oxidation.

In the powdered activated carbon/microfiltration/reverse osmosis (PAC/MF/RO) process, organic contaminants are adsorbed from the leachate to the carbon followed by a microfiltration separation of the carbon from the slurry. The microfiltration effluent (permeate) was further treated by reverse osmosis. In addition, reverse osmosis (RO) alone treated leachate by retaining contaminant compounds behind a semi-permeable membrane while allowing clean water to permeate through the membrane for discharge. The semi-permeable membranes tested were 1001 UOP, DSI B441, Toray SP110, and Filmtec HR. Ultraviolet/ozone/hydrogen peroxide oxidation (UV) treatment oxidized organic contaminants into their basic constituents, carbon dioxide, water, and chlorides (from chlorinated organics).

The objective of this engineering study was to explore the feasibility of several on-site treatment technologies to reduce or eliminate the leachate being sent for off-site treatment.

RESULTS

The laboratory pilot-scale found that PAC/MF/RO and RO alone removed 90 to 100 percent of most organics and heavy metals (see Status Report). However, preliminary economic analysis found PAC/MF/RO more expensive than off-site treatment; hence, it was eliminated from further investigation, the field pilot-scale tests.

Field pilot-scale tests found RO met New York State Department of Environmental Conservation (NYDEC) surface water discharge limits for 12 of the 27 compounds for which the limits were applicable. The discharge limit for a particular contaminant is met when the concentration for a particular contaminant in the treated effluent is lower than the NYDEC standards and guideline values for more than 75% of the technology evaluation trials. RO preceded by UV treatment met this limit for an additional five compounds. Contaminant rejection (the percent of contaminant retained behind the membrane) calculations showed the effectiveness of RO membranes in removing specific compounds from this leachate and other similar wastewaters; however, the ability of compound to meet discharge limits is not totally dependent upon the rejection. RO retained heavy metals best; conversely, organics had mixed results. Heavy metal rejections were excellent (greater than 95 percent) for arsenic, nickel, and acceptable (85 to 95 percent) for antimony and copper, with lead, selenium, and zinc notable exceptions. Even though RO rejected lead poorly (10.0 29.1 percent), lead concentration met discharge limits on all test because of its low concentration in the leachate (less than 59 ug/l) and moderate discharge limits (50 mg/l). Acceptable rejection (85 to 95 percent) was found for the following volatile organics: 1,2-dichloropropane; bromoform; m- and p-xylene; o-xylene; 1,1-dichloroethane; 1,1,1- trichloroethane; bromodichloromethane; methyl isobutyl ketone; and ethylbenzene. Approximately one-half of the semi-volatile organics had greater than 85 percent rejection by RO. Of the organic molecules, the compounds best rejected by RO were relatively high molecular weight and non-polar. The Filmtec membrane met the discharge criteria for more compounds compared with the other membranes tested and this membrane had the highest membrane rejection for most contaminants. To evaluate the performance of RO, a SAS statistical analysis was computed.

Statistical analysis of the data found toluene and naphthalene permeate concentrations (which corresponds to effluent quality) correlated significantly to the feed concentration of these compounds and correlated to the RO process parameters: permeate/concentrate (P/C) ratio, pressure, and cumulative operation time. These 2 contaminants are relatively large and non-polar. The Torey membrane's permeate concentration significantly increased with time, yet the Filmtec membrane's permeate quality remained steady for increasing feed concentrations. An analysis of variance found that membrane type had the most significant effect on the permeate concentration of the nine target compounds analyzed. The other factors, P/C ratio, pressure, and time, showed little effect on the effluent quality. Finally, the analysis developed several models for RO treatment of certain compounds on a per membrane basis.

For batch runs, UV treatment of the leachate and UV treatment of permeate (UV preceded by RO pretreatment) met the NYDEC discharge criteria for all (21) but four published organics of interest. UV batch trials did not achieve effluent quality for 1,1-dichloroethene, benzene, carbon tetrachloride, and bis(2-ethylhexyl)phthalate because of their low effluent concentration limits of 0.7, 4.0, 0.1 and 0.6 ug/l, respectively. Under the same batch operation conditions, UV treatment of RO concentrate feed had fewer compounds achieving dischargeable limits. This is due to the greatly increased organic loading of this feed. Continuous, flow-through UV treatment of either leachate or permeate resulted in substantially less compounds reaching dischargeable concentrations.

An interesting phenomena occurred during the UV treatment trials; acetone appeared as an intermediate of oxidative destruction. It's concentration increased after treatment commenced and slowly declined throughout treatment. This compound must be carefully watched since it is poorly retained by reverse osmosis.

The UV treatment data did not model well. This model's root mean square error and R squared was substantially below the models developed for RO treatment.

CONCLUSIONS

- Revere osmosis alone and ultraviolet/ozone/hydrogen peroxide oxidation pretreatment followed by RO was able to meet the discharge criteria for 13 and 16 compounds, respectively, of the 27 individual compounds of concern; however, no RO effluents achieved the standards and guidance values set by the NYDEC for contaminants. Therefore, RO or UV/RO must be coupled with other technologies for successful leachate treatment at PAS.

- Overall, for the three classes of contaminant compounds in the leachate, reverse osmosis showed excellent removals of heavy metals, acceptable removals for some semi-volatile and volatile organics, and unacceptable removals for the remaining organics.

- Reverse osmosis worked well concentrating heavy metals since rejections were usually above 95 percent, with lead, selenium, and zinc notable exceptions.

- Reverse osmosis may be a feasible technology to remove semi-volatile organics from leachate since six of the thirteen compounds found in the leachate had removals 85 percent or greater.

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- Generally, reverse osmosis did not reject volatile organics.

- In general, reverse osmosis can be successfully used with wastewaters containing heavy metals and used, cautiously, with wastewater containing organics.

- For organic contaminants, the two primary factors affecting rejection are molecular size and polarity; the larger the size and the smaller the polarity, the greater the membrane retention.

- Of the nine target contaminants statistically analyzed, only naphthalene and toluene showed a significant correlation between permeate concentration and feed concentrations and between permeate concentration and process parameters. This correlation may be due to the fact that naphthalene and toluene are relatively large and non-polar molecules; therefore, they exhibit a classical reverse osmosis separation effect. For the other seven compounds, no clear trend was apparent.

- The Torey membrane showed a significant increase in permeate concentration with time. The increase may be the result of membrane deterioration. On the other hand, the Filmtec membrane exhibited an interesting trend; the permeate quality remained constant for increases in feed concentration of certain compounds, a desirable characteristic for any membrane.

- UV treatment of leachate or RO permeate met the discharge limits for most, but not all, published organic compounds. To achieve effluent discharge quality for organics with low NYDEC published standards and guidance values, a longer retention time and/or greater dosage units are required.

- Batch UV treatment achieved the discharge criteria for more organic compounds when compared with continuous, flow-through treatment. The longer retention time in the system, and hence the greater dosage units, are responsible for this result.

- Acetone was formed during UV treatment. It appears to be an intermediate compound during oxidative destruction of complex leachate. This is a serious problem since acetone proved to be refractory to oxidative destruction.

RECOMMENDATIONS

- To meet NYDEC criteria for on-site effluent discharge into White Creek, reverse osmosis is not recommended as a stand-alone technology. Reverse osmosis must be proceeded or followed by additional technologies. One possible technology is ultra-violet/ozone/hydrogen peroxide (UV) oxidation for organic contaminant reduction. A rigorous oxidation should be explored prior to installation of any RO system with careful attention given to compounds recalcitrant to oxidation and inadequately rejected by RO, such as acetone. In addition, to meet the required effluent quality, a staged RO may provide the necessary separation. As another option, an appropriate technology could follow reverse osmosis to polish the effluent. Reverse osmosis is not recommended for water containing a variety of volatile organics because of the low treatment efficiency with this class of contaminants.

- Excellent treatment rejection (greater than 85 percent) make reverse osmosis a viable option for heavy metal laden wastewater; although, RO is not recommended on lead, selenium, and zinc containing waste without additional tests due to the low treatment rejection (less than 85 percent) for these metals. RO is not recommended for many volatile organics and some semi-volatile organics because of the low treatment with these contaminants.

- Since molecular polarity appears to have a strong effect on an organic compound's rejection, the effect of feed pH should be explored in future tests.

- Based on data on discharge criteria, percent rejection, and statistical correlations, the Filmtec HR membrane is the membrane of choice for use with PAS leachate. Compared with the other membranes tested, it met the NYDEC discharge criteria more frequently, had consistently higher percent rejections of contaminants, and exhibited the trend of steady effluent quality at increasing feed concentrations.

- To lower the organic loading in the treated UV effluent and to meet the NYDEC discharge criteria for organics. The UV system must provide more dosage units (mg of oxidizing agent per liter of leachate).

- UV treatment does not treat the heavy metals in the leachate; therefore, another treatment technology should follow UV oxidation, such as a staged RO system or another appropriate technology.

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REVERSE OSMOSIS TREATMENT

1.0 REVERSE OSMOSIS TREATMENT INTRODUCTION

1.1 Background

The Pollution Abatement Services (PAS) site is a remediated Superfund site in Oswego, N.Y. Remediation consisted of removing thousands of drums and draining lagoons containing hazardous wastes. A bentonite slurry wall and a high density polyethylene cap was placed around and over the site, respectively, to eliminate the migration of hazardous substances remaining in the soil. However, recent hydrogeological evidence suggests that leachate periodically breaches the slurry wall [1]. This leachate contains three major classes of contaminants: volatile organics, semi-volatile organics, and heavy metals. To avoid this problem, the leachate level within the confines of the slurry wall must be lowered every few months. This necessitates the expenditure of time, money, and manpower to pump, transport, and dispose of the leachate at an off-site treatment facility. This engineering study was commenced to reduce or eliminate this expenditure.

The 1986 Superfund Amendments and Reauthorization Act (SARA) mandated the use of innovative and alternative options over current remediation practices. In accordance with the spirit and letter of the law, the U.S. Environmental Protection Agency (U.S. EPA) Region II requested engineering support from the U.S. EPA Environmental Response Team (ERT) to explore alternative and innovative technologies. The ERT, established in 1978 under the National Contingency Plan, provides to federal, state, and local agencies expertise in, and resources for, engineering studies to test alternative and innovative technologies. Based on previously successful bench-scale studies that have led to full-scale remediation at other sites, the ERT and the Response Engineering and Analytical Contractor (REAC) with the support of Environment Canada (EC) explored the feasibility of several alternative and innovative treatment technologies [2,3,4,5]. Using field pilot-scale treatment units, this study explored the following treatment technologies:

- Reverse osmosis.
- Ultraviolet/ozone/hydrogen peroxide oxidation.

1.2 Reverse Osmosis

Reverse osmosis is a technology which separates a low molecular weight solvent, like water, from the dissolved solutes using a semi-permeable membrane having characteristics favorable to the permeation of the solvent while rejecting the solutes. In osmosis, transport of a small solvent occurs from the high solvent concentration side of the semi-permeable membrane to the low solvent (high solute) concentration side under the driving force of the chemical potential. The chemical potential is a sum of the hydrostatic (osmotic) pressure, concentration, and electrical potential gradients [6]. To reverse this process, a hydrostatic pressure greater than the osmotic pressure is applied to the high solute side of the membrane. The pressure causes a volumetric solvent flux (the volume of solvent per area of membrane per unit time) through the membrane while retaining the less permeable solutes. This process is called reverse osmosis (RO). The driving force for solvent transport across the RO membrane is the hydrostatic pressure difference minus the osmotic pressure. Therefore, to achieve separation, only pressure is needed, thereby eliminating the costly phase separations found in distillation, evaporation, and crystallization technologies.

Early researchers in the 1920's, Monegold, Michaelis, and McBain, pressurized solutions through cellophane or cellulose-nitrate membranes and discovered the permeates (the liquid which passes through or permeates the membrane) had lower solute concentrations [7]. Additional reverse osmosis research activity did not occur until the 1950s when researchers cast polymeric membranes to desalt water; however, these membranes had low flux [8]. Several years later, Loeb and Sourirajan discovered a method of making asymmetric cellulose acetate membranes containing a thin, solute-rejecting "skin" capable of high solvent flux [7]. Modern membranes, cast of polyamide, polyfurfural, thin-film polyamide-polysulfone composites, and other polymers, have the economically viable characteristics of high solute rejection, high flux, and broad pH operating range.

Modern RO technology has been applied to treat complex wastewaters, chemical spills, and landfill leachates. RO treatment of sanitary landfill leachate, using cellulose acetate and non-cellulose acetate membranes, removed 85 to 99 percent of the total dissolved solids (TDS) and 56 to 94 percent of the total organic carbon (TOC) [9]. Slater et al. treated an industrial landfill leachate with a cellulose acetate membrane reducing chemical oxygen demand (COD) 65 to 68 percent and TOC 59 to 69 percent [10]. Lyandres et al. used polymeric and thin film composite RO membranes to reduce the TOC of a leachate condensate from an evaporative crystallizer in excess of 98 percent [11]. An extensive amount of RO treatment of chemical solutions, chemical spills, and hazardous leachate has been performed by Harry Whittaker of Environmental Canada's Environment Emergency Technology Division (EETD). Tests using four different RO membranes to separate 18 individual chemical solutions generated a useful body of RO separation efficiencies (percent rejection) on a compound specific and membrane specific basis [12]. At two chemical spill sites, EETD used a mobile RO unit to remove 98.9 to 99.99 percent total chlorophenols from contaminated water [13]. This mobile RO unit was also used to treat landfill leachate. For some representative contaminants, engineers reported the following percent rejections: TOC, 76 and 78; benzene, 64 to 90; chlorobenzene, 56 to 78; toluene 67 to 93; trichloroethene, 62 to 77; and acetone, 65 to 70. In addition, during this test, a carbon adsorption polishing step for RO permeate further reduced the effluent concentration of certain organic contaminants [14,15].

The Environment Canada mobile RO unit was used to carry out a separation of PAS leachate. Leachate was fed to the reverse osmosis system under high pressure. Semi-permeable membranes inside the unit allowed the permeation of treated leachate water (permeate) for surface discharge or reinjection to the landfill while retaining and concentrating contaminants into a concentrate stream. It is the intention of this technology to achieve a leachate volume reduction with the concentrate stream containing most contaminants for further treatment (on or off site). The permeate stream consisted of clean water.

The objective of the reverse osmosis study is to test the feasibility of this technology for separating the contaminants from the aqueous leachate.

The reverse osmosis portion of the report has been divided into several sections: methodology, results, and discussion. The methodology section details the sampling and analysis of aqueous samples taken from the process during testing and the various aspects of site preparation necessary for conducting pilot-scale trials on a hazardous waste site. In addition, the methodology section explains the leachate pretreatment process, the arrangement of the reverse osmosis system, the semipermeable membranes types, and the construction of the reverse osmosis unit. The results section contains three major subsections: discharge criteria, contaminant retention and statistics. The discharge criteria subsection details how well the technology met New York State effluent discharge criteria, on a per compound basis. The percent retention of the chemical species measures reverse osmosis effectiveness in separating the contaminants of concern from the leachate. The statistical analysis contains information on correlations, analysis of variance and modeling. The correlation looks for significant trends in the relationship between a contaminant's concentration in the permeate and the feed concentration of the contaminant. Also, correlations analyze the relationship between the permeate concentration and process variables. The analysis of variance calculates the effect of process factors on permeate quality to better explain what occurred during the tests. From the data, models were constructed to assist environmental scientists and engineers in the evaluation and prediction of reverse osmosis performance for this and other hazardous waste sites. The discussion section mirrors the organization of the results section. Finally, for the PAS site and other similar hazardous waste sites, conclusions were drawn from the results of the tests and recommendations were made.

2.0 REVERSE OSMOSIS TREATMENT METHODOLOGY

2.1 Sampling and Analysis

Samples of the RO feed, permeate, and concentrate were taken throughout the study. All sampling, sample storage, and sample shipment was performed in accordance with REAC Standard Operating Procedures (SOP) #2001 to 2005. These SOPs are approved by the ERT and are available on request.

Analyses on the samples generated from the test were performed for the following classes of compounds: volatile organics (VOA), semi-volatile organics known as base neutral/acid extractables (BNA), heavy metals, and pesticides, and miscellaneous analytical parameters. On-site chemists performed VOA analyses by the US EPA methods 601 and 602 using a Hewlett-Packard (HP) 5840 gas chromatograph (GC) equipped with a flame ionization detector and a purge and trap [16]. To check GC VOA analysis performance, a few samples were analyzed by a modified US EPA method 524.2 using a HP 5995C Gas Chromatograph/Mass Spectrometer (GC/MS) equipped with a Tekmar LSC 2000 purge and trap concentrator. The method modification was a reduced sample size of 5 ml [17]. BNA analyses were analyzed according to the separator extraction technique of US EPA method 625 with a HP 5995C GC/MS [18]. Eight samples were analyzed for PCB/pesticides according to US EPA Method 608 using a HP 5890 GC [19].

Priority pollutant metals were analyzed according to US EPA method 7000 series [20]. Beryllium, cadmium, chromium, copper, nickel, silver, zinc, and iron were analyzed by flame atomic absorption using a Varian SpectrAA-300. Mercury analysis was performed on a Varian SpectrAA-300 equipped for cold vapor technique. The following modifications were made to method 7470 for mercury analysis; a 50-ml sample size, a 100-ml final volume, and a Varian VGA-76 vapor gas analyzer. Arsenic, antimony, lead, thallium, and selenium were analyzed by a graphite furnace atomic absorption using either a Varian 400-Z or a Varian SpectrAA-20 both equipped with a GTA-95 graphite furnace unit.

2.2 Site Preparation

Site preparation consisted of landscaping, support equipment, and supplies, utilities, and health and safety planning. Since the site was previously capped with PVC, graded with soil, and seeded, only minor landscaping such as grass clipping was necessary. After landscaping, support equipment and supplies were set up prior to installation of the treatment systems. Figure 1 and Photo 1 show the equipment layout at the site. Trailers were used for office space, for hardware and supply storage, and for on-site sample preparation and VOA analysis. All necessary utilities were installed. City water was distributed from the site perimeter for process and human needs and an existing electrial service was temporarily modified to power equipment,

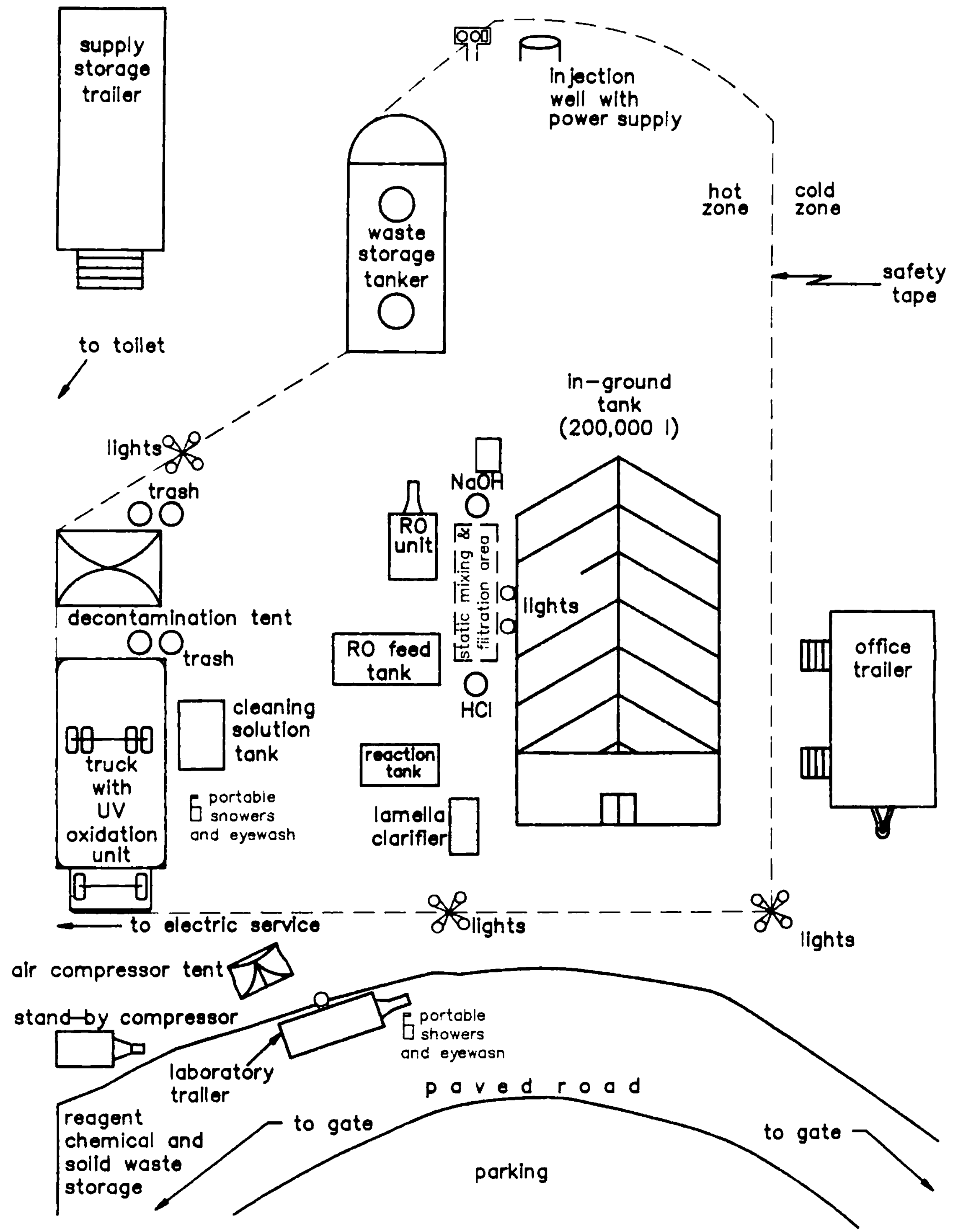


Figure 1. Pollution Abatement Services site plan

PHOTO 1. POLLUTION ABATEMENT SERVICES SITE

trailers, and lights. Additional support equipment included a portable toilet and a diesel fuel tank.

The health and safety of all personnel was of utmost concern. Prior to any site activities, a comprehensive health and safety plan was written which addressed the following items: identification of key personnel, operation safety and health risk analysis, personnel training requirements, personal protective equipment necessary, medical surveillance requirements, air monitoring, site control measures, decontamination plan, emergency response/contingency plan, and confined space entry procedures. To provide adequate personal protection, an ample inventory of protective clothing and gear was accessible and clearly labeled in the storage trailer. To delineate the work area within which protective clothing was required, a zone perimeter was marked with signs and highly visible tape (Figure 1). Along a portion of the perimeter, a decontamination zone was erected and staffed by support personnel. Health and safety equipment, distributed throughout the site at key locations, included fire extinguishers, hospital directions, emergency phone numbers, light towers, emergency horns, and portable eye wash/shower stations.

2.3 Leachate Pretreatment

In this study, all leachate was pretreated prior to treatment by reverse osmosis. The first objective of pretreatment was to reduce the iron content in the leachate by hydroxide precipitation. The second objective was to increase the solubility of the remaining metals by acid addition to reduce or eliminate their precipitation inside the reverse osmosis unit during concentration. Metal precipitation is a major cause of irreversible membrane fouling.

The following details the pretreatment scheme. To deliver the leachate to the pretreatment system, recovery wells at the site pumped raw (untreated) leachate from the site into a 200,000 l in-ground storage tank. This leachate was pumped into the pretreatment system. The leachate pretreatment system consisted of the following sequential steps: 1) 50 percent sodium hydroxide addition, to pH 10, for soluble iron precipitation, 2) an 800-liter reaction tank for metal hydroxide flocculent formation, 3) a slant tube lamella clarifier for metal hydroxide precipitate settling, 4) 5-micron and 0.2 micron cartridge filtration for lamella overflow clarification, 5) concentrated hydrochloric acid addition to pH 5 for increasing solubility of residual metals, 6) a 2000-liter tank for reverse osmosis feed storage, and 7) final 0.2 micron cartridge filtration (see Figure 2 and Photo 2). After pretreatment, the feed to the RO was named basified/acidified leachate. For the final RO test, pretreatment consisted only of cartridge filtration and acid addition which yielded an acidified leachate feed.

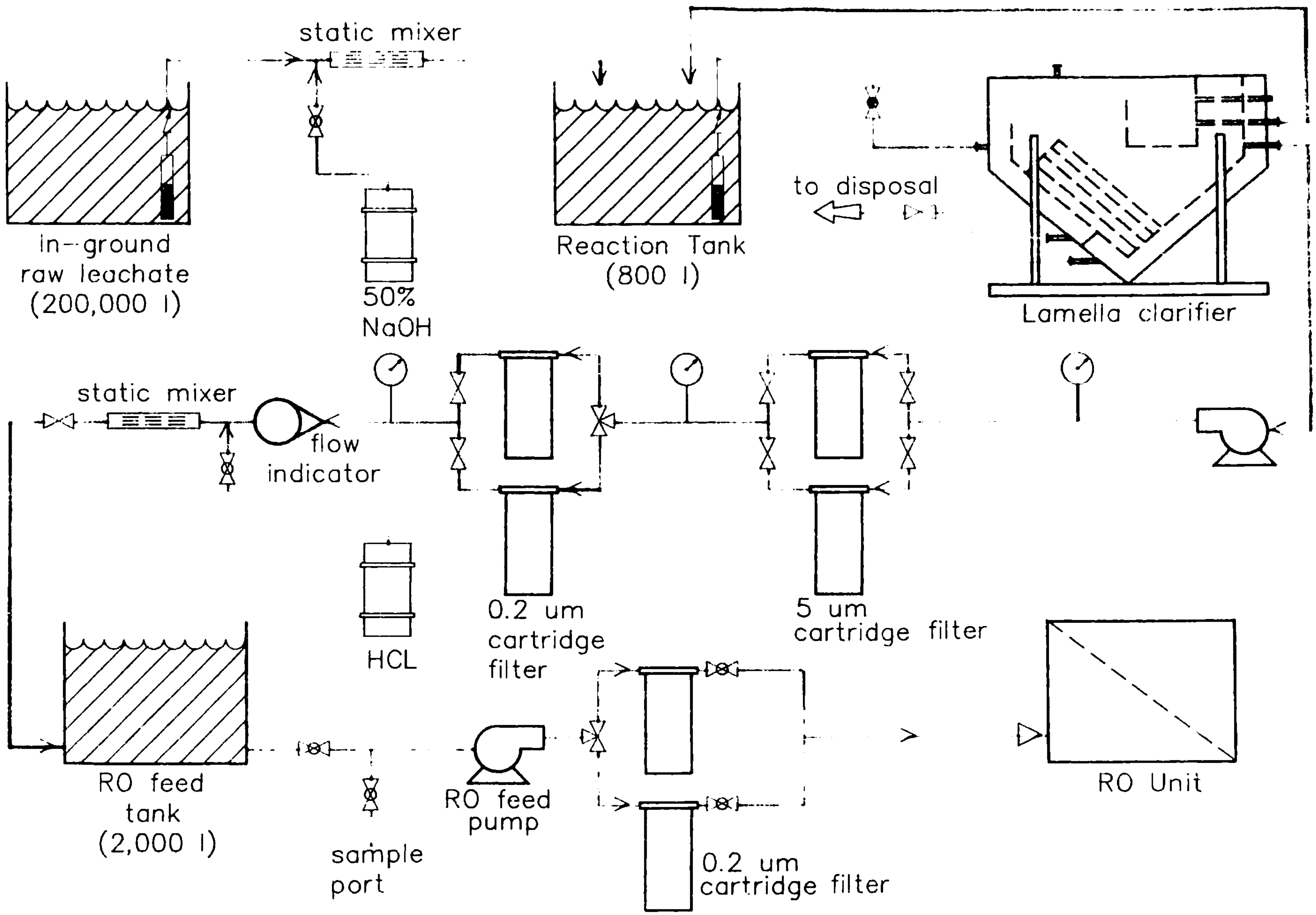


Figure 2. Reverse osmosis (RO) pretreatment system

PHOTO 2. REVERSE OSMOSIS PRETREATMENT SYSTEM

The above details the basic pretreatment scheme. In this study, the RO unit treated three feeds differing only in their pretreatment (Section 2.4).

2.4 Reverse Osmosis

Figure 3 shows the overall reverse osmosis system. Pretreated leachate entered the RO unit from the feed tank and separated into two streams, permeate, and concentrate. These streams were either saved in a hold-up tank for further processing by a ultraviolet oxidation or injected into the landfill. The main part of any reverse osmosis system is the semi-permeable membrane. This test concurrently explores the performance of 4 different types of membranes to retain or "filter" the leachate's contaminants. The membranes were: UOP 1001, DSI B441, Toray SP110, and Filmtec HR. They were chosen based on previous experience with these membranes in hazardous waste applications.

The engineering study used three leachate feeds to the reverse osmosis unit differing only in their pretreatment. Most tests fed the RO with pretreated (sodium hydroxide precipitation and hydrochloric acid addition) leachate called basified/acidified leachate. One test explored membrane separation of pretreated (sodium hydroxide precipitation and hydrochloric acid addition) followed by ultraviolet/ozone/hydrogen peroxide treated leachate called Rayox effluent. On the last test, a partially pretreated leachate, with only hydrochloric acid addition, was separated, called acidified leachate. Rayox effluent and acidified leachate feed were explored to determine the effectiveness of a UV system as the first treatment step and to determine if an abridged pretreatment scheme was feasible, respectively.

Environment Canada (EC) owned the transportable reverse osmosis unit (Photos 3 and 4). The unit contained six fiberglass reinforced plastic pressure vessels that hold two 4-inch diameter by 40-inch long spiral wound membrane elements per vessel, four permeate test ports that allows independent sampling of four different membranes, a internal propane heater that extends operating temperatures, and a structural steel frame that can withstand a three meter drop and roll over (Figures 4 and 5). The 1135 Kg unit is powered by a Lister ST3 air cooled diesel engine which generates 12 volts DC and 100 volts AC power for lighting and controls. The engine is fed by a 60.5 l fuel tank allowing 10 hours of continuous operation. The unit is equipped with basic high pressure, low pressure, and high temperature warning alarms to provide damage control for the hardware and safety for the operating personnel. The RO is also equipped with valving to manipulate hydrostatic pressure and the ratio of permeate to concentrate flow rates.

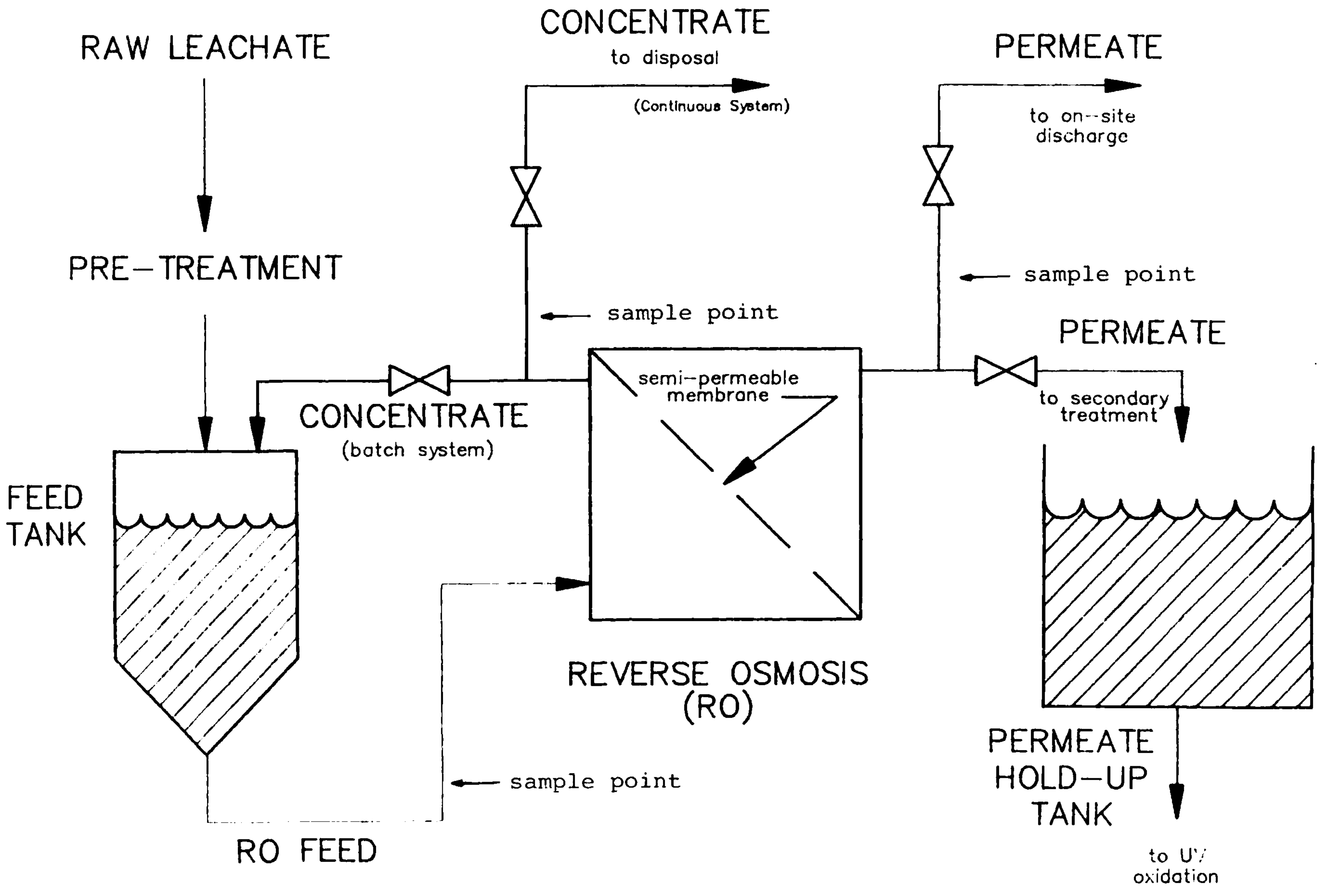


Figure 3. Reverse osmosis (RO) treatment system

PHOTO 3. MOBILE REVERSE OSMOSIS UNIT, FRONT VIEW

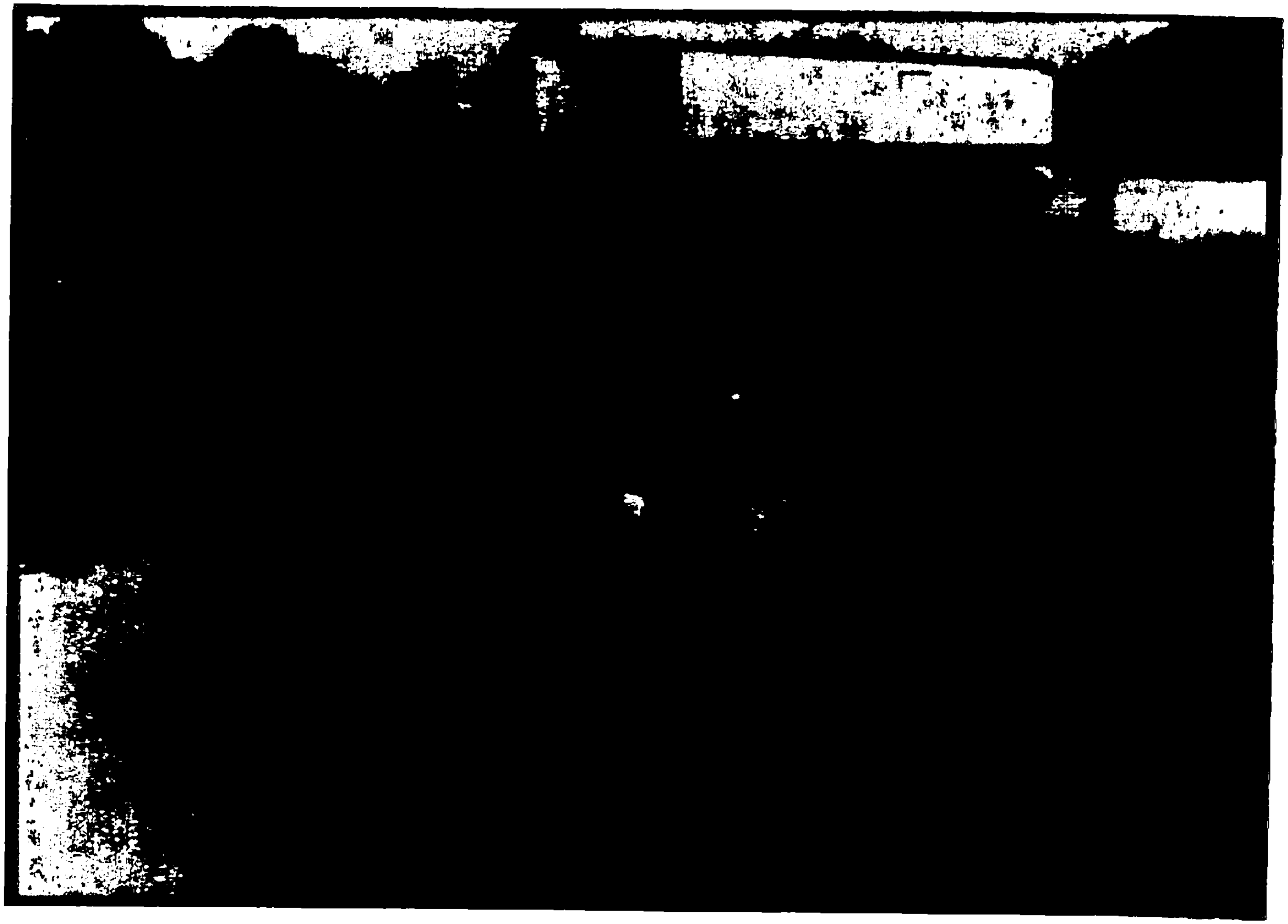
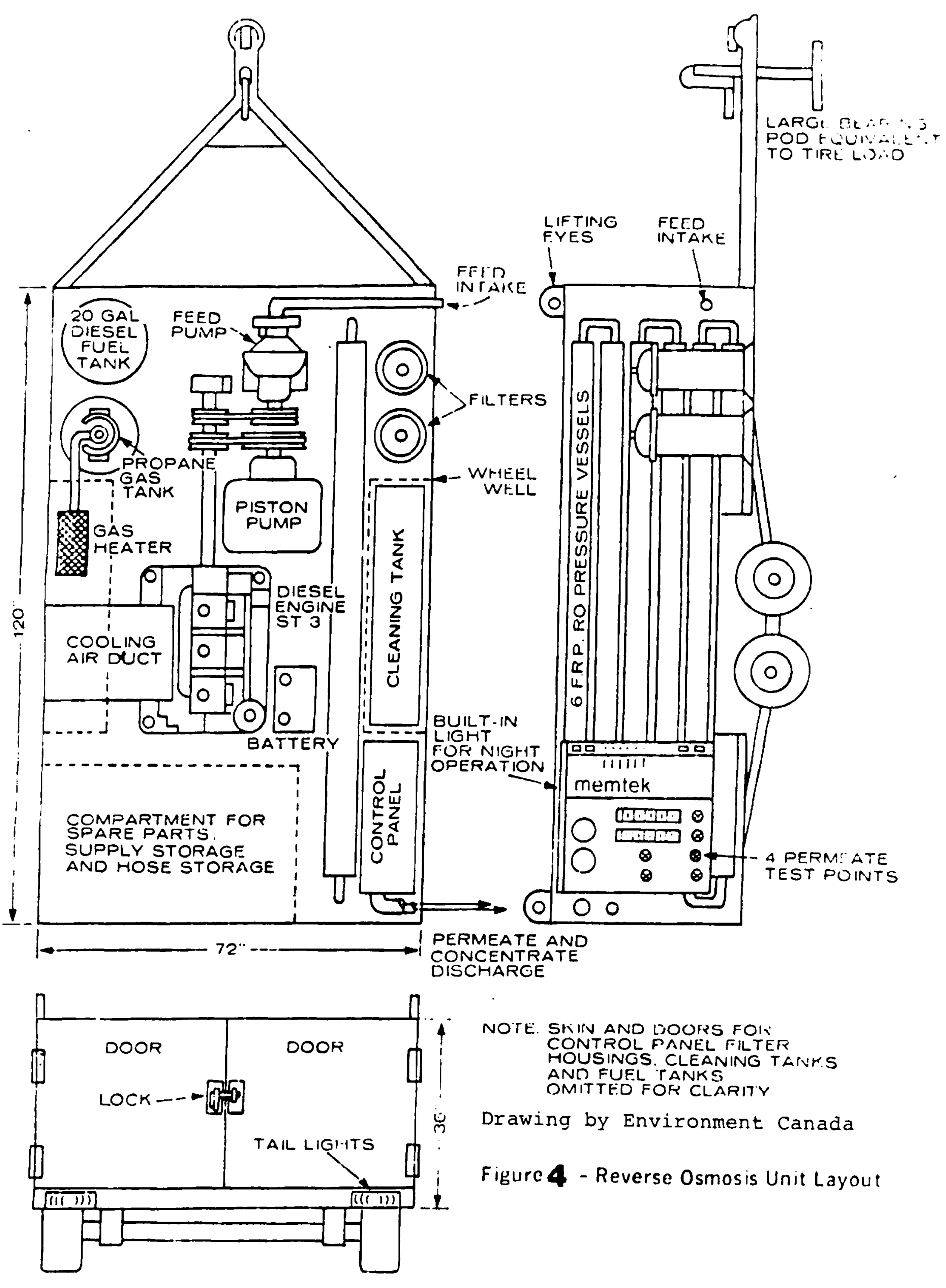


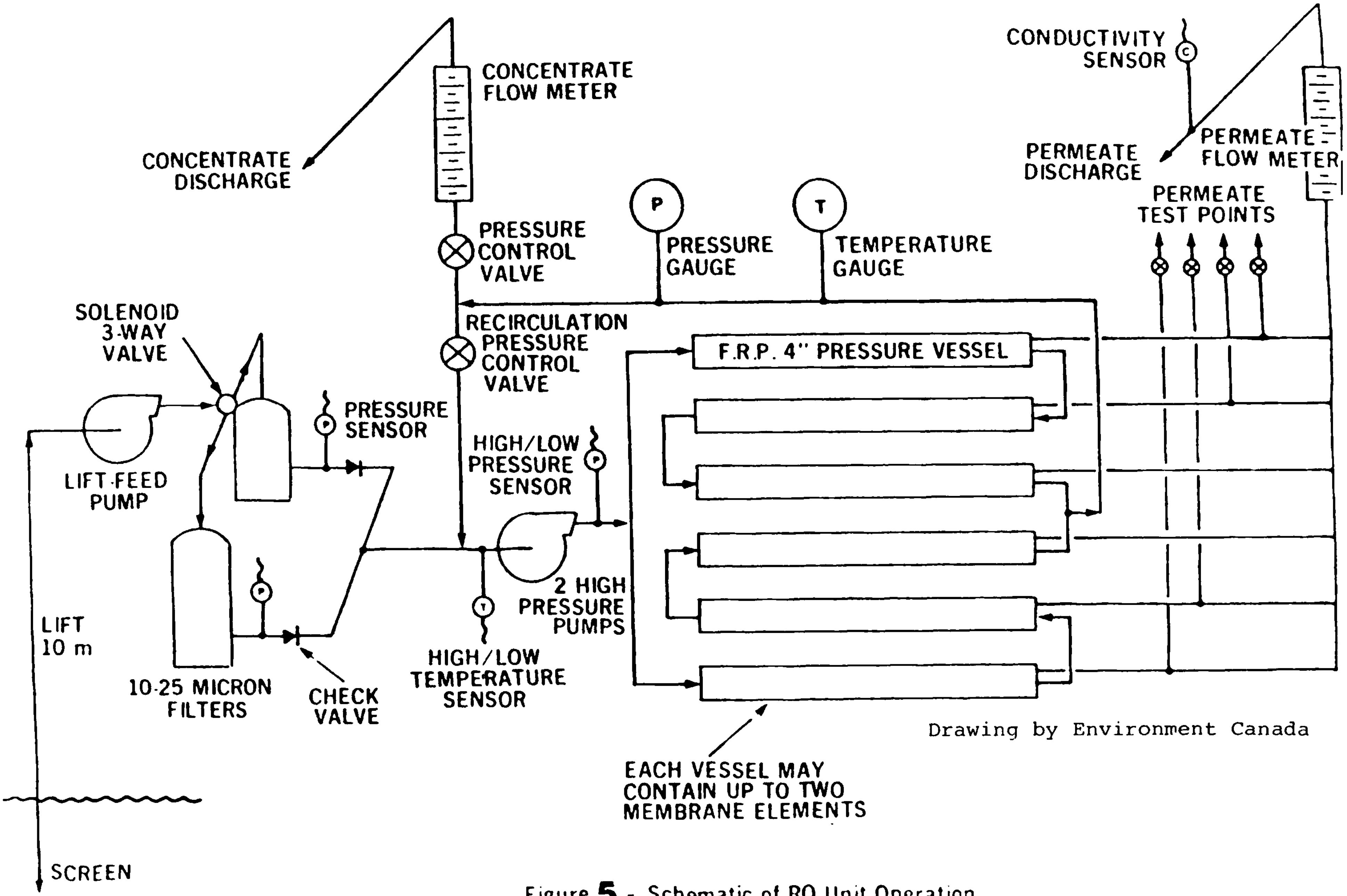
PHOTO 4. MOBILE REVERSE OSMOSIS UNIT, REAR VIEW



NOTE. SKIN AND DOORS FOR
CONTROL PANEL FILTER
HOUSINGS. CLEANING TANKS
AND FUEL TANKS
OMITTED FOR CLARITY

Drawing by Environment Canada

Figure 4 - Reverse Osmosis Unit Layout



Drawing by Environment Canada

Figure 5 - Schematic of RO Unit Operation

2.5 Calculations

2.5.1 Discharge criteria --

The discharge criteria is officially established in a permit provided by the New York Department of Environmental Conservation (NYDEC) Bureau of Water Permits. However, the calculations for the estimated discharge criteria were based on conversations with Daniel B. Halton, Director, NYDEC Bureau of Wastewater Facilities Design in Albany, N.Y. The procedure for calculating these estimates was as follows. Since the treatment technologies used at the PAS site far exceeded the standards provided in Best Professional Judgement Methodologies (publication 1.3.4, April 1, 1987), Revision of Water Technical and Operational Guidance Series (TOG), the evaluation proceeded to TOG publication 1.1.1, Ambient Water Quality Standards and Guidance Values, April 1, 1987. This document stated the surface water classification and their respective standards and guidance values (discharge criteria) for the discharge of treated effluent. These published standards and guidance values are the concentrations of contaminants allowable for discharge into a surface water. The first step in the estimation of appropriate standards and guidance values is the categorization of the surface waters. The stream was classified as a class C receiving water, suitable for fishing and fish propagation but not swimming or bathing. Next, the stream was assumed to be intermittent, one that goes dry once in 10 years; therefore, no dilution factor was allowed. Finally, since the creek flowed approximately 0.5 miles into Lake Ontario, the discharge criteria was evaluated for the lake with a 10:1 dilution factor. The most stringent of either Class B or Class C receiving water value was used for the discharge criteria.

The discharge limit for a particular contaminant is met when the concentration for a particular contaminant in the treated effluent is lower than the NYDEC standards and guideline values for more than 75 percent of the technology evaluation trials.

2.5.2 Contaminant rejection --

The percent rejection for each contaminant was calculated for each membrane and each test by the formula:

$$\frac{C_F - C_P}{C_F} \times 100$$

where C_F and C_P represented the concentration of a particular compound in the feed and permeate, respectively. For each contaminant, the mean of the rejections from all the tests for each membrane was then calculated. In other words, a compound's retention was calculated for each test by membrane, and the mean was calculated from these retentions.

In the above rejection calculations, an assigned value was given for any non-detectable (ND) analysis. The value was either one-half of the detection limit or on-half of the lowest detectable value (J value) below the detection limit. A J value was any detectable value below the official detection limit. Same compounds had several assigned values because their detection limit varied between samples. This was prevalent for the semi-volatile organic (BNA).

The minimum rejection values for any compound was zero. All negative rejections were set to zero; these zero values are the result of negative rejection where a compound's permeate concentration exceeds its feed concentration during a test. This phenomena occurs because a portion of the concentrate stream is recycled back to the incoming feed; therefore, the concentration of contaminants that contacts the membrane is greater than the feed concentration.

3.0 REVERSE OSMOSIS TREATMENT RESULTS

The results of the reverse osmosis tests are based on the analyses of samples taken during the trials for several analyte classes: volatile organics, base neutral/acid extractables, heavy metals, and miscellaneous parameters. The first three classes, all priority pollutants, are compounds of interest to the U.S. EPA because of their impact on human health and the environment. The miscellaneous parameters included total organic carbon (TOC), flash point, alkalinity, biological oxygen demand (BOD), turbidity, total suspended solids (TS), total dissolved solids (TDS), dissolved silica, and cyanide. All data from the reverse osmosis field pilot-scale tests are located in Appendix 1, and all data from the reverse osmosis lab pilot-scale test are located in the Status Report (Appendix C). The Appendix 1 data is grouped by analyte class: VOA, BNA, or heavy metals; and, within each class, arranged by test numbers. Within each test, the Appendix 1 data can stand alone because it contains the process parameters of that test.

In addition, Appendix 1 contains some pesticide analysis and several miscellaneous parameters that were explored for process and effluent (concentrate) disposal consideration. No pesticides were found in the leachate. This corresponds to the lack of PCB's and pesticides in leachate samples during preliminary sampling (see Status Report, Appendix C). TOC was reduced from a mean of 541.7 mg/l in the raw (unpretreated) leachate to a mean of 37.3 mg/l in the Filmtec membrane permeate, a 93.1 percent reduction. Other membranes had higher TOC values in their permeates. For the analysis of results, there was no obvious difference in RO performance between basified/acidified leachate, and acidified leachate. So the results of this test (#12) was lumped with the other tests.

To obtain a broad overview of the RO experiments and to assist in navigating through the raw data for all the tests, two tables summarize all the reverse osmosis tests and organize all the samples by test. Table 1 lists the various reverse osmosis tests and includes the operational parameters of each test. Table 1-A, in Appendix 1, coordinates the samples taken during each test with the test number, with the sampling location, with the analytes for each sample, and with the time of sampling.

3.1 Discharge Criteria

Table 2 lists the results of reverse osmosis technology in meeting discharge criteria while Table 3 lists the results of leachate treated by UV followed by RO. For each contaminant, Table 2 shows the number of tests that a particular membrane's permeate was equal to or lower than the discharge standard or guidance value. The table also includes the total number of tests for which data was available. Compounds for which the discharge limit was met for any membrane were: 1,1-dichloroethane; 1,1,1-trichloroethane; bromodichloromethane; bromoform; 1,2-dichlorobenzene; ethylbenzene; naphthalene; di-n-octylphthalate; di-n-butylphthalate; antimony; arsenic; lead; and zinc. The Filmtec membrane met or exceeded the discharge criteria more often than the other membranes tested. Reverse osmosis did not meet discharge limits for the other compounds because either the discharge limits were very stringent or the membrane rejection was not adequate.

An additional test was explored to pretreat the leachate with ultraviolet/ozone/hydrogen peroxide oxidation (not to be confused with basidification/acidification pretreatment which was done for all leachate) before treatment by reverse osmosis. The feed to the RO unit had reduced concentrations after UV pretreatment (Appendix 1, Test #4). The ability of this UV-RO configuration to meet discharge criteria is listed in Table 3. In addition to the compounds listed above which met NYDEC standards, toluene, chlorobenzene, and xylenes also achieved dischargeability. Hence, the addition of the UV system helped in the RO treatment.

The discharge criteria was not met for several compounds because either the discharge limits were very stringent or the membrane rejection of contaminants was not adequate. The next section addresses membrane rejection of contaminants. This value, usually expressed as the percent of a compound's feed concentration retained by the membrane, is useful for a

TABLE 1. REVERSE OSMOSIS OPERATION CHRONOLOGY AT THE POLLUTION ABATEMENT SERVICES SITE, OSWEGO, NY

Test/ Date	Reverse Osmosis Feed	Leachate Pretreatment Scheme	Pressure (psi)	Permeate to Concentrate Ratio	Oper. Time (min)	Cum. Oper. (hrs)
Shake down/ 8-13-88	acidified Rayox^R effluent	raw leachate -- pH 10 -- UV oxid. -- pH 6 -- RO	600	1:1	30	0.5
Shake down/ 8-13	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 4 -- RO	600	1:1	30	1.0
Shake down/ 8-18	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	200 600	1:1 1:1	60 210	2.0 5.5
1/ 8-31	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	600	5:1	210	9.0
2/ 9-2	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	600	5:1	60	10.0
3/ 9-7	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	800	8:1	150	12.5
4/ 9-8	acidified Rayox^R effluent	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- UV oxid. -- pH 5 -- RO	600	5:1	150	15.0
5/ 9-9	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	600	5:1	270	19.5
6/ 9-10	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	600	10:1	110	21.3
7/ 9-12	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	800	8:1	700	33.0

TABLE 1. REVERSE OSMOSIS OPERATION CHRONOLOGY AT THE POLLUTION ABATEMENT SERVICES SITE, OSWEGO, NY (CONT'D)

Test/ Date	Reverse Osmosis Feed	Leachate Pretreatment Scheme	Pressure (psi)	Permeate to Concentrate Ratio	Oper. Time (min)	Cum. Oper. (hrs)
8/ 9-13	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	800	10:1	300	38.0
9/ 9-13	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	800	8:1	600	48.0
10/ 9-14	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	800	10:1	570	57.5
11/ 9-14	basified/ acidified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- RO	800	5:1	380	63.8
12/ 9-15	acidified/ leachate	raw leachate -- filter (5& 0.2 um) -- pH 5 -- RO	800	10:1	322	69.2

TABLE 2. NUMBER OF TESTS USING REVERSE OSMOSIS TREATMENT WHICH MET NEW YORK STATE DISCHARGE CRITERIA

Contaminant	Discharge Criteria (ug/l)	Membrane Type			
		UOP	DSI	TOREY	FILMTEC
<u>Volatile Organics</u>*					
Methylene Chloride	500	2 (11)	1 (9)	1 (9)	2 (11)
1,1-Dichloroethene	0.7	0 (9)	0 (8)	0 (9)	3 (10)
1,1-Dichloroethane	500	10 (11)	9 (10)	(4)(10)	11 (11)
t-1,2-Dichloroethene	500	0 (11)	0 (9)	0 (10)	1 (11)
1,2-Dichloroethane	80	0 (11)	1 (11)	1 (11)	0 (11)
1,1,1-Trichloroethane	500	10 (11)	11 (11)	10 (11)	11 (11)
Carbon Tetrachloride	4	0 (3)	1 (3)	0 (3)	3 (3)
Bromodichloromethane	500	9 (10)	9 (10)	9 (10)	10 (10)
Trichloroethene	11	1 (11)	2 (11)	2 (11)	2 (11)
Benzene	0.1	1 (11)	1 (11)	1 (11)	1 (11)
Bromoform	500	7 (10)	7 (10)	8 (10)	9 (10)
Toluene	500	0 (11)	3 (11)	4 (11)	8 (11)
Chlorobenzene	5	0 (11)	2 (11)	1 (11)	1 (11)
Ethylbenzene	500	2 (11)	4 (11)	4 (11)	11 (11)
Xylenes	500	0 (11)	0 (10)	0 (11)	3 (10)
<u>Semi-Volatile Organics</u>*					
Phenol	5	0 (9)	0 (9)	0 (9)	1 (9)
1,2-Dichlorobenzene	5	0 (9)	3 (9)	2 (9)	9 (9)
Naphthalene	100	9 (9)	9 (9)	9 (9)	9 (9)
bis(2-ethylhexyl) phthalate	0.6	2 (9)	5 (9)	4 (9)	1 (9)
di-n-octylphthalate	500	9 (9)	9 (9)	9 (9)	9 (9)
di-n-butylphthalate	500	9 (9)	9 (9)	9 (9)	9 (9)
<u>Heavy Metals</u>*					
Antimony	30	9 (9)	9 (9)	9 (9)	9 (9)
Arsenic	190	9 (9)	9 (9)	9 (9)	9 (9)
Copper	2000	1 (1)	1 (1)	1 (1)	1 (1)
Lead	50	9 (9)	9 (9)	9 (9)	9 (9)
Selenium	1	0 (3)	0 (3)	0 (3)	0 (3)
Zinc	30	8 (9)	7 (9)	5 (9)	9 (9)

* Number on left is the number of tests meeting discharge criteria compared with the total number of tests (in parenthesis).

rd:eh/EVNGLSTA/FR-1083

TABLE 3. THE RESULTS OF REVERSE OSMOSIS TREATMENT COUPLED WITH ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE OXIDATION PRETREATMENT TO MEET NEW YORK STATE DISCHARGE CRITERIA

Contaminant	Discharge Criteria (ug/l)	Membrane Type UOP	 DSI	 TOREY	 FILMTEC
Volatile Organics*					
Methylene Chloride	500	NO	NO	NO	NO
1,1-Dichloroethene	0.7	NO	NO	NO	NO
1,1-Dichloroethane	500	YES	YES	YES	YES
t-1,2-Dichloroethene	500	NO	NO	NO	NO
1,2-Dichloroethane	80	NO	NO	NO	NO
1,1,1-Trichloroethane	500	YES	YES	YES	YES
Carbon Tetrachloride	4	NO	NO	NO	NO
Bromodichloromethane	500	YES	YES	YES	YES
Trichloroethene	11	NO	NO	NO	NO
Benzene	0.1	NO	NO	NO	NO
Bromoform	500	NO	YES	YES	YES
Toluene	500	YES	YES	YES	YES
Chlorobenzene	5	YES	NO	NO	NO
Ethylbenzene	500	YES	YES	YES	YES
Xylenes	500	NO	NO	NO	NO
Semi-Volatile Organics					
Phenol	5	NO	NO	NO	NO
1,2-Dichlorobenzene	5	NO	YES	YES	YES
Naphthalene	100	YES	YES	YES	YES
bis(2-ethylhexyl) phthalate	0.6	NO	NO	NO	NO
di-n-octylphthalate	500	YES	YES	YES	YES
di-n-butylphthalate	500	YES	YES	YES	YES
Heavy Metals					
Antimony	30	YES	YES	YES	YES
Arsenic	190	YES	YES	YES	YES
Copper	2000	YES	YES	YES	YES
Lead	50	YES	YES	YES	YES
Selenium	1	NO	NO	NO	NO
Zinc	30	YES	YES	YES	YES

* Note: Only one test using the configuration of ultraviolet/ozone/hydrogen peroxide oxidation followed by reverse osmosis was performed. "Yes" indicates that the compound met discharge criteria for the membrane's effluent.

rd:eh/EVNGLSTA/FR-1083

situation where the feed concentration varies (as did the PAS leachate), where the discharge criteria could be flexible and where reinjection of the treated leachate into the landfill could be acceptable.

3.2 Contaminant Rejection

The ability of RO to reject contaminants behind the membrane barrier varied between compound and between membranes. The mean RO membrane rejection was calculated for all analytes by membrane type (Section 2.5.2). Table 4 contains the mean of the retentions for all tests listed by compound organized according to analyte class, and by membrane.

Generally, for the three classes of contaminants, the membrane retention performance for PAS leachate was heavy metals> semi-volatiles organics> volatiles organics. On the average, volatile organic compounds showed the lowest rejection by the RO membranes tested. Several volatile compounds showed excellent (greater than 95 percent) rejection for any one membrane. They were 1,2-dichloropropane, bromoform, meta- and para-xylene, and ortho-xylene; however, the performance of 1,2-dichloropropane was based on only one test. Volatile organics having acceptable, 85 to 95 percent, rejection are: 1,1-dichloroethane; 1,1,1-trichloroethane; bromodichloromethane; methyl isobutyl ketone; and ethylbenzene. The other 12 volatile organic compounds analyzed showed below acceptable levels for all membranes tested. Of the membrane tested, Filmtec had the best rejection of volatile organics. This membrane had the highest mean retentions for 16 out of the 21 VOAs. For the other membranes, the frequency of highest rejection for a particular contaminant were Desal, 3; UOP, 1; and Toray, 1.

Overall, the semi-volatile compounds showed acceptable levels of rejection by RO; approximately one-half of this contaminant class had greater than 85 percent mean retentions. From Table 4, the compounds having acceptable (85 to 95 percent) membrane rejections are: 1,2-dichlorobenzene; 4-methylphenol; 2,4-dimethylphenol; benzoic acid; naphthalene; and 2-methylnaphthalene. The 7 semi-volatile contaminants with less than 85 percent rejection are phenol, benzyl alcohol, 2-methylphenol, isophorone, bis(2-ethylhexyl)phthalate, di-n-octylphthalate, and di-n-butylphthalate. Other semi-volatile compounds were not detected in leachate. Of the 4 membranes tested, the Filmtec membrane showed the best performance. Of the 13 semi-volatile compounds detected in the leachate, the Filmtec membrane had the highest percent rejection for 8 compounds, while UOP, Desal, and Toray had the highest for 2 compounds each (UOP tying once with Filmtec).

TABLE 4. PERCENT REJECTION OF CONTAMINANTS BY REVERSE OSMOSIS MEMBRANES

	UOP		DSI		TORAY		FILMTEC	
	Mean	n	Mean	n	Mean	n	Mean	n
VOLATILE ORGANIC (VOA) ORGANICS								
Methylene Chloride	35.7	12	48.9	11	46.9	7	50.5	11
Acetone	45.9	11	44.5	10	38.3	6	73.8	11
1,1-Dichloroethene	56.7	9	62.7	8	61.8	7	74.7	9
1,1-Dichloroethane	57.2	12	64.7	11	64.3	8	88.2	11
t-1,2-Dichloroethene	10.7	12	28.2	11	30.5	8	47.4	11
Chloroform	ND	11	ND	11	ND	8	ND	11
1,2-Dichloroethane	41.0	12	52.3	12	53.7	9	75.3	11
1,1,1-Trichloroethane	76.9	12	85.2	12	85.7	9	93.3	11
Carbon Tetrachloride	42.9	4	54.1	3	43.2	3	59.3	3
Bromodichloromethane	67.0	10	75.6	10	62.3	7	91.6	10
1,2-Dichloropropane	3.5	3	43.7	2	98.3	1	72.5	1
Cis-1,3-Dichloropropane	0	3	32.7	3	27.5	3	24.7	3
Trichloroethene	43.8	12	59.9	12	50.9	9	59.8	11
Benzene	53.5	12	57.9	12	68.2	9	83.9	11
t-1,2-Trichloroethane								
t-1,3-Dichloropropane	ND	10	ND	11	ND	7	ND	11
Dibromochloromethane								
Methyl Isobutyl Ketone	77.7	11	85.4	11	71.6	8	73.7	11
Bromoform	74.9	10	91.5	9	69.1	8	99.5	9
Tetrachloroethene	78.5	12	61.4	12	46.2	9	66.4	11
Toluene	54.2	12	68.1	12	67.7	9	83.7	11
Chlorobenzene	36.4	12	55.5	11	59.1	8	76.7	10
Ethylbenzene	66.1	11	74.3	11	74.6	9	94.9	10
meta- and para-Xylene	74.2	11	83.9	10	84.6	7	96.3	9
ortho-Xylene	71.9	11	83.2	9	83.4	7	96.6	9
SEMI-VOLATILE (BNA) ORGANICS								
Phenol	54.5	10	55.7	10	52.5	7	72.1	10
Benzyl Alcohol	42.0	2	25.0	2	25.0	2	28.0	3
1,2-Dichlorobenzene	64.4	10	91.7	10	73.3	7	87.9	10
2-Methylphenol	47.3	7	73.4	6	49.0	7	77.8	9
4-Methylphenol	78.6	10	57.4	10	59.8	7	89.8	10
Isophorone	83.9	4	79.9	5	75.0	4	83.9	4
2,4-Dimethylphenol	72.3	10	69.2	10	64.0	7	88.5	10
Benzoic Acid	67.8	7	81.9	8	76.3	5	86.4	8
Naphthalene	74.2	10	80.6	9	70.2	7	88.9	9
2-Methylnaphalene	85.0	5	60.8	4	57.7	2	92.6	5

ND - Means not detected.

TABLE 4 (CONT'D). PERCENT REJECTION OF CONTAMINANTS BY REVERSE OSMOSIS MEMBRANES

	UOP		DSI		TORAY		FILMTEC	
	Mean	n	Mean	n	Mean	n	Mean	n
Bis(2-Ethylhexyl)phthalate	78.4	10	76.4	8	54.9	6	71.1	9
Di-n-octylphthalate	50.0	6	41.7	6	63.7	3	52.3	10
Di-n-butylphthalate	37.5	2	25.0	2	56.2	6	37.5	2
HEAVY METALS								
Antimony	89.6	6	89.6	6	75.8	6	85.7	6
Arsenic	95.4	8	85.0	8	61.5	6	98.6	8
Beryllium	ND	1	ND	1	ND	1	ND	1
Cadmium	ND	9	ND	9	ND	6	ND	9
Chromium	ND	9	ND	9	ND	6	ND	9
Copper	84.4	1	84.4	1	84.4	1	84.4	1
Lead	10.3	9	16.9	8	10.0	8	29.1	7
Mercury	ND	1	ND	1	ND	1	ND	1
Nickel	98.3	9	92.8	9	79.6	6	88.2	9
Selenium	1.7	3	19.4	3	ND	6	15.0	4
Silver	ND	9	ND	9	ND	6	ND	9
Thallium	ND	8	ND	8	ND	6	ND	8
Zinc	45.4	9	33.6	9	27.1	6	53.3	9

ND - Means not detected.

For the heavy metals, antimony, arsenic, and nickel showed relatively high membrane rejection, although lead and zinc had comparatively low mean rejections. Only antimony, arsenic, lead, nickel, and zinc were found in sufficient frequency to provide adequate data for analysis. For each of these contaminants, the following lists the highest mean rejection and corresponding membrane: antimony, 89.6 percent, UOP and DSI; arsenic, 98.6 percent, Filmtec; lead, 29.1 percent, Filmtec; nickel, 98.3 percent, UOP; and zinc, 53.3 percent, Filmtec (Table 2). The overall best performing membrane for the heavy metals was Filmtec. Of the other heavy metals analyzed, beryllium, cadmium, chromium, mercury, silver, and thallium were not detected in either the feed or permeate streams. Copper and selenium had low frequencies of occurence showing 84.4 percent, and 1.7 to 19.4 percent rejection for all membranes, respectively.

3.3 Statistical Analysis

The reverse osmosis test data was statistically analyzed and modeled using SAS Statistical Software version 4.0 by the SAS Institute, Inc., Cary, N.C. Nine target compounds were chosen for SAS analysis. These compounds were methylene chloride, acetone, trichloroethene, toluene, phenol, 1,2-dichlorobenzene, naphthalene, arsenic, and nickel. They were picked due to the frequency of their occurence in the samples, their chemical or steric differentiation within their analyte class, and their relative frequency of occurence in the environment. The statistical analysis of the RO data included: the correlations between a target compound's permeate concentration and its feed concentration or various process parameters, the analysis of variance of factors affecting permeate quality, and modeling of RO performance.

3.3.1 Correlations --

A statistical analysis was performed to explore the correlations between permeate and feed concentrations by compound and by membrane. The correlation between permeate concentration and process parameters by compound and by membrane was also examined. The compilation of these correlations, their supporting plots, and the raw data are contained in Appendix 2. The purpose of this analysis was to determine how contaminant variations in the leachate would affect effluent quality and how the process variables such as pressure, concentration ratio, and time affect effluent quality.

Toluene and naphthalene, and DSI membranes showed the best correlations between permeate and feed concentrations. However, for the target compounds examined, the feed concentration showed no significant affect on permeate quality for most compounds. Table 5 lists the correlation

TABLE 5. CORRELATION BETWEEN PERMEATE CONCENTRATION AND FEED CONCENTRATION BY MEMBRANE TYPE

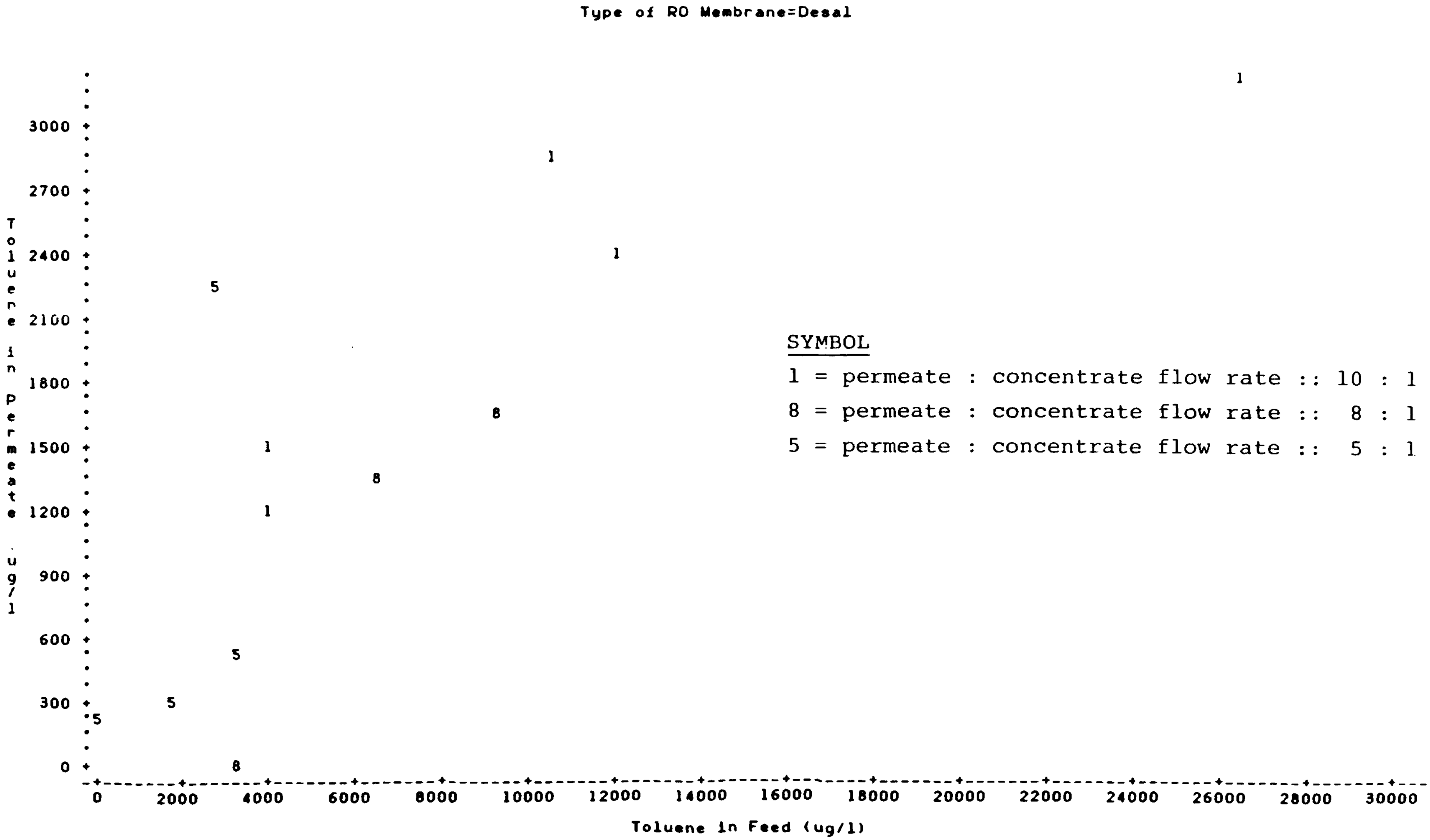
Compound	Membrane Type			
	UOP	DSI	Toray	Filmtec
Methylene Chloride	0.29	0.54	0.44	0.46
Acetone	-0.29	0.62	0.10	0.06
Trichloroethene	0.11	0.47	0.36	0.14
Toluene	0.72*	0.77*	0.62	0.41
Phenol	0.31	-0.42	0.08	0.04
Dichlorobenzene	0.08	0.31	0.71	0.31
Naphthalene	0.52	0.87*	0.82*	-0.53
Arsenic	0.52	0.50	0.08	0.36
Nickel	0.00	0.71*	-0.65	-0.24

* Significant at the 95% confidence level.

coefficients between permeate concentration for a particular feed concentration by compound and by membrane. These coefficients show toluene and naphthalene having both the highest correlation and the greatest frequency of significant correlations. No clear trend existed for the other compounds. Among the membranes tested, DSI showed the highest correlation coefficients and the most frequent significancy. For the DSI membrane, as the feed concentration increased, the permeate concentration increased. The above relationship between toluene and naphthalene's permeate and feed concentrations for the DSI membrane are shown by Figure 6 and 7. For the other membranes, however, even though correlation coefficients were low and did not achieve the 95% confidence level, a review of the plots showed an interesting trend. For naphthalene, arsenic, and nickel, the Filmtec membrane, generally did not show increased permeate concentration as feed concentration increased. Figure 8 illustrates this point. This trend is the most desirable performance for a reverse osmosis membrane because as your influent concentration varies or rises, the effluent (permeate) quality remains constant and predictable. The trend shown in Figure 8 compares favorably to the correlation in Figure 6 where the RO permeate concentration of toluene increased with an increase in toluene feed concentration.

Toluene and naphthalene and Toray membranes showed the best correlations between permeate concentration and the reverse osmosis process parameters. However, overall for the compounds analyzed, the process variables showed no significant affect on permeate quality. The correlations between permeate concentration and process parameters are listed in Table 6. The process parameters examined were ratio of permeate to concentrate flow rates (5X, 8X, and 10X), hydrostatic pressure of the leachate at the membrane's surface (600 and 800 psi), and cumulative operation time. Toluene and naphthalene, as in Table 5, have the highest correlation coefficients and the most significant correlations. The only consistent significant correlation between permeate concentration and process parameters for any membrane was the correlation between permeate concentration and time for the Toray membrane. This correlation existed for most target compounds. Figure 9, a representative plot of this correlation for Toray membranes, shows an increase in permeate concentration with time. There are no additional clear trends in Table 6. The small number of statistically significant correlations indicate the process parameters showed little affect on the permeate concentration compared to concentration changes that can be attributed to chance. Therefore, for a mixed feed such as leachate, the process parameters should be set for conditions which best meet other criteria, such as economics.

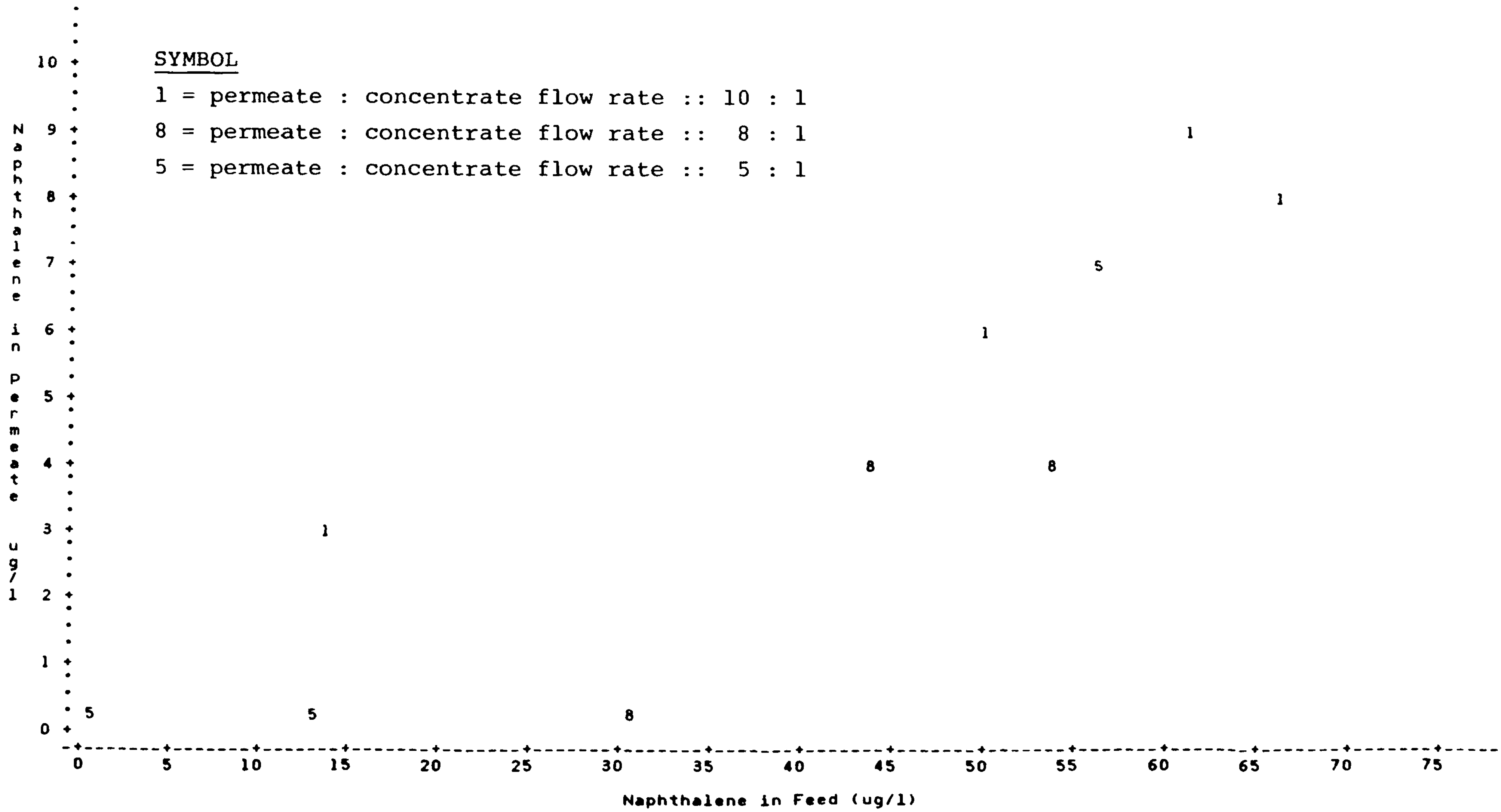
Figure 6. Toluene permeate concentration versus feed concentration



NOTE: 1 OBS HAD MISSING VALUES

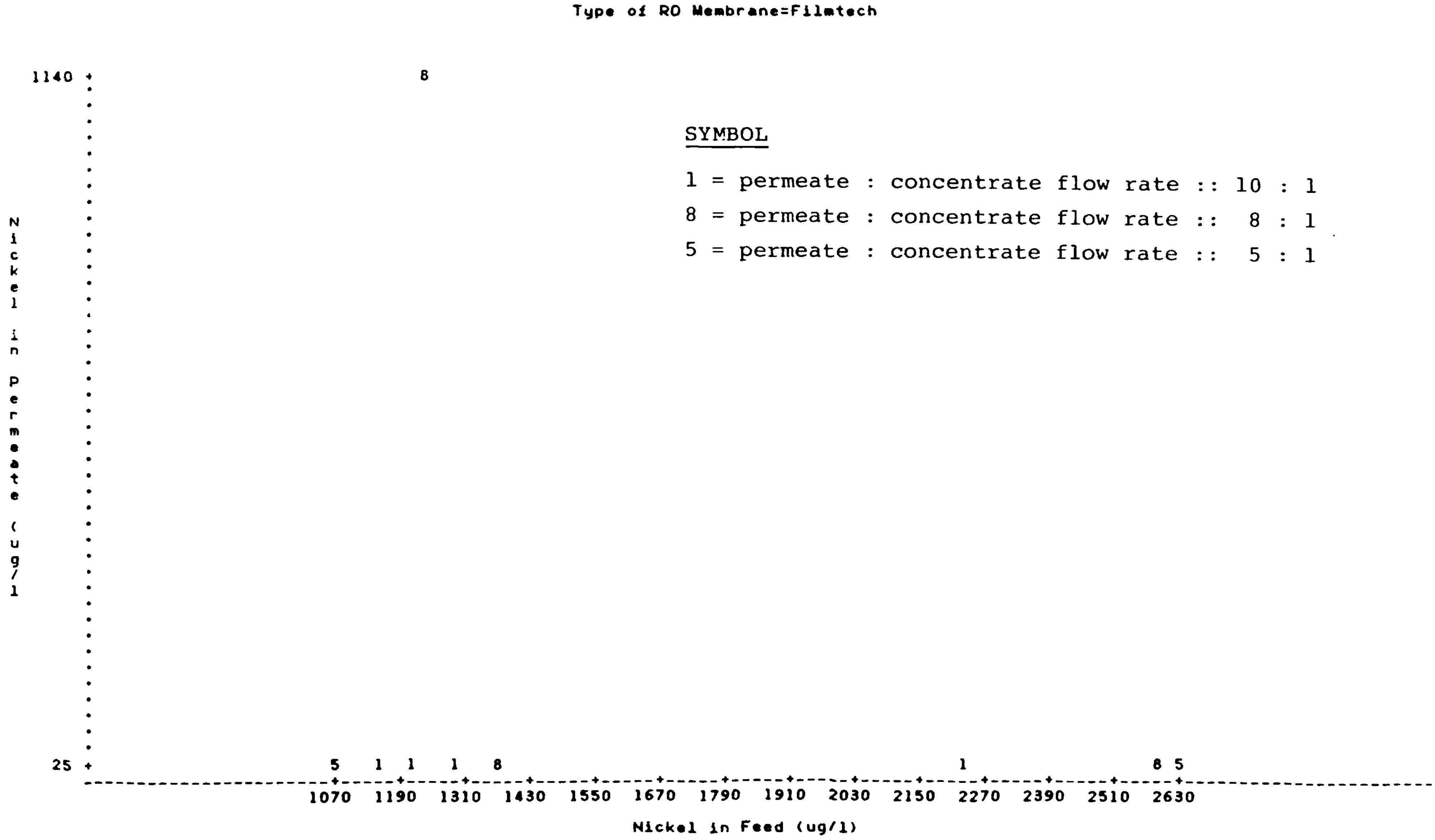
Figure 7. Naphthalene permeate concentration versus feed concentration

Type of RO Membrane=Desal



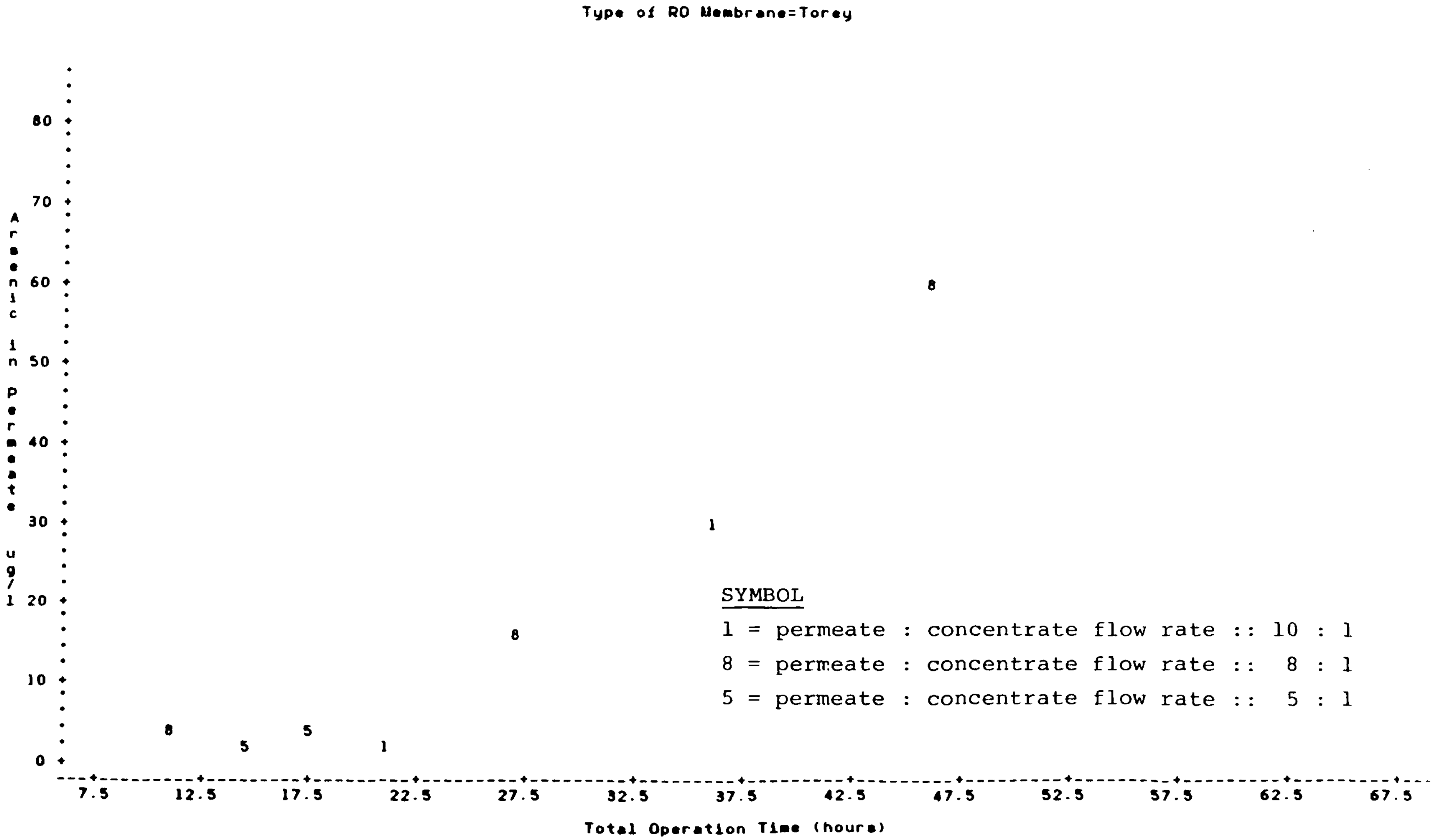
NOTE: 3 OBS HAD MISSING VALUES

Figure 8. Nickel permeate concetration versus feed concentration



NOTE: 4 OBS HAD MISSING VALUES

Figure 9. Arsenic permeate concentration versus time



NOTE: 6 OBS HAD MISSING VALUES

TABLE 6. CORRELATIONS BETWEEN PERMEATE CONCENTRATION AND PROCESS PARAMETERS BY MEMBRANE TYPE

Target	Permeate/Concentrate Ratio				Pressure				Time			
Compound	UOP	DSI	Toray	Filmtec	UOP	DSI	Toray	Filmtec	UOP	DSI	Toray	Filmtec
Methylene Chloride	0.55	0.26	0.08	0.08	-0.36	-0.40	-0.53	-0.60*	-0.11	-0.11	-0.38	-0.32
Acetone	0.14	-0.01	0.44	-0.03	0.33	-0.17	-0.11	-0.51	-0.22	0.04	0.28	-0.47
Trichloroethene	0.40	0.49	0.37	0.02	-0.04	0.22	0.34	-0.02	-0.08	0.09	0.74*	-0.46
Toluene	0.69*	0.62*	0.44	0.35	0.60*	0.62*	0.69*	-0.19	0.57*	0.84*	0.95*	0.12
Phenol	-0.14	0.55	0.15	0.34	-0.20	-0.30	0.33	-0.44	-0.03	-0.15	0.79*	-0.49
Dichlorobenzene	0.27	0.52	0.42	0.52	-0.38	0.43	0.63	0.23	0.20	0.26	0.98*	0.55
Naphthalene	0.43	0.52	0.31	0.13	0.18	0.62*	0.62	-0.70*	0.69*	0.93*	0.98*	-0.37
Arsenic	-0.52	-0.02	0.31	-0.47	-0.44	0.12	0.61	-0.51	-0.59	-0.30	0.95*	-0.31
Nickel	0.00	0.07	0.39	0.02	0.00	-0.31	0.54	0.22	0.00	-0.71*	0.35	0.16

* Significant at the 95% confidence level.

TABLE 7. RELATIVE SIGNIFICANCE OF MEMBRANE TYPE AND PROCESS PARAMETERS ON PERMEATE CONCENTRATION OF TARGET CONTAMINANTS

Compound	Membrane	P/C Ratio	Pressure	Time
Methylene chloride	NS	*	*	NS
Acetone	NS	NS	NS	NS
Trichloroethene	NS	NS	NS	NS
Toluene	*	NS	NS	NS
Phenol	NS	NS	NS	NS
1,2-Dichlorobenzene	*	*	NS	NS
Naphthalene	*	NS	NS	*
Arsenic	*	NS	NS	NS
Nickle	NS	NS	NS	NS

NS = Not significant at the 95% confidence level.

* = Significant at the 95% confidence level.

3.3.2 Analysis of Variance --

An analysis of variance (ANOVA) was calculated to investigate the affect on target contaminant's permeate concentration by the following factors: membrane type, permeate/concentrate ratio, hydrostatic pressure, and cumulative operating time. The ANOVA evaluated each factor independently of the other factors, thereby allowing a separate evaluation of a factor's affect on permeate. Therefore, the ANOVA explains the significance of these factors on the reverse osmosis past test performance. Appendix 3 contains all the ANOVA data output for the target contaminants.

Of the four factors examined, membrane type had the greatest frequency of significant effects on the effluent quality of the target compounds. In a mixed liquid waste such as PAS leachate, a factor which affects the greatest number of compounds in the effluent has the greatest affect on the performance of the system. Membrane type significantly affected the reverse osmosis treatment of toluene, 1,2-dichlorobenzene, naphthalene, and arsenic (Table 7). The other factors significantly affected RO's performance on fewer compounds. Methylene chloride and 1,2-dichlorobenzene permeate concentrations were influenced by the permeate/concentrate ratio factor. Operating pressure and cumulation operation time showed a 95% confidence level of significance for only methylene chloride and naphthalene, respectively. Acetone, trichloroethene, phenol, and nickel were not effected by any of the factors. In conclusion, for PAS leachate, the one factor having the most significant influence on the reverse osmosis test performance was membrane type.

3.3.3 Modeling --

The final phase in the statistical analysis was the selection and evaluation of appropriate models. The models may be used to predict future performance of this treatment technology. The purpose of modeling was to assess how certain independent variables can affect the performance of reverse osmosis in a similar waste stream.

A stepwise technique was used to select appropriate models. To select appropriate models, one hundred and forty four possible models, thirty six models per membrane, were evaluated (Appendix 4). These thirty six models consisted of different combinations of four independent variables: feed concentration, permeate/concentrate ratio, pressure, and cumulative operation time. The combinations consisted of 1 independent variable term models, 2 term models, 3 term models, and 4 term models. SAS chose the best model for each combination of terms for each of the nine target compounds per membrane (Appendix 4). In the stepwise regression, the first model for a particular contaminant has only one independent variable; each subsequent model added one additional terms until a total of four terms per model. The stepwise regression provided a statistical method of sequentially adding more variables to the model which accounted for changes in the permeate concentration.

The selection of appropriate models was performed in the following manner. For each model in the stepwise regression several values were compared. These values, in order of importance, was PROB>F, C(P), and R square. The PROB>F value tested the probability that an R square value could occur by chance. In other words, its value was the probability the model could have accounted for the variability by chance. Therefore, the percent confidence in the model can be calculated as (1-(PROB>F)) x 100. The C(P) statistic is related to bias; the lowest C(P) for the four stepwise regressions was preferred. The final value evaluated for model selection was R square, the proportion of variation in the dependent variables that the independent variable accounted for. As R square increased to the maximum value of 1.0, the model's accuracy increased.

The following ten models were selected as the best representing reverse osmosis performance. They are listed by compound and membrane below. All models selected, with one exception, had greater than 95% confidence and R squared greater then 0.90. The selected models are:

- Toluene - DSI (2), Toray
- 1,2-Dichlorobenzene - Toray
- Napthalene - DSI, Filmtec, Toray, UOP
- Arsenic - Filmtec, Toray

The above models are presented in Table 8, and their respective calculations and plots are contained in Appendix 5.

The permeate concentration of naphthalene was modeled for all four membranes. DSI was slightly affected by time and P/C ratio; Filmtec was moderately affected by pressure and P/C ratio. Toray was only affected by time, while UOP had the naphthalene feed concentration and pressure as terms in its model. Comparing naphthalene models with toluene models, all toluene models have relatively large time and error coefficients.

TABLE 8. SELECTED MODELS OF REVERSE OSMOSIS PERFORMANCE BY CONTAMINANT AND MEMBRANE TYPE

Toluene

DSI: $[\text{toluene}]_{\text{permeate}} = 32.42\ (\text{time}) + 0.08\ [\text{toluene}]_{\text{feed}} - 237.5$

root mean square error = 294.3 R square = 0.94

DSI: $[\text{toluene}]_{\text{permeate}} = 36.43\ (\text{time}) + 0.09\ [\text{toluene}]_{\text{feed}} - 900.1$

root mean square error = 275.5 R square = 0.96

Toray: $[\text{toluene}]_{\text{permeate}} = 137.1\ (\text{time}) + 137.1\ (\text{time}) - 1539.0$

root mean square error = 567.4 R square = 0.94

1,2-Dichlorobenzene

Toray: $[\text{1,2-dichlorobenzene}]_{\text{permeate}} = 0.90\ (\text{time}) - 10.0$

root mean square error = 0.84 R square = 0.97

Naphthalene

DSI: $[\text{naphthalene}]_{\text{permeate}} = 0.13\ (\text{time}) + 0.42\ (\text{p/c ratio}) - 3.86$

root mean square error = 0.84 R square = 0.95

Filmtec: $[\text{naphthalene}]_{\text{permeate}} = 0.003\ (\text{pressure}) + 0.05\ (\text{p/c ratio}) + 2.13$

root mean square error = 0.07 R square = 0.94

Toray: $[\text{naphthalene}]_{\text{permeate}} = 0.37\ (\text{time}) - 2.48$

root mean square error = 1.71 R square = 0.92

UOP*: $[\text{naphth}]_{\text{permeate}} = 0.27\ [\text{naphth}]_{\text{feed}} - 0.05\ (\text{pressure}) + 33.39$

root mean square error = 2.09 R square = 0.70

Arsenic

Filmtec: $[\text{As}]_{\text{permeate}} = 0.11\ (\text{p/c ratio}) - 0.006\ [\text{As}]_{\text{fd}} - 0.0008\ (\text{press}) + 2.41$

root mean square error = 0.03 R square = 0.98

Toray: $[\text{arsenic}]_{\text{permeate}} = 1.6\ (\text{time}) - 21.46$

root mean square error = 7.65 R square = 0.92

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* Model with R square <0.90

4.0 DISCUSSION

4.1 Discharge Criteria

In order to treat a liquid waste at a Superfund site, the treated effluent must be either discharged to surface waters, a publically owned treatment works (POTW), or reinjected into the subsurface. At PAS, a sewer line to a POTW was not available; however, a stream White Creek, bordered the perimeter of the site. To discharge the effluents from an on-site treatment system into this stream, the NYDEC discharge criteria was explored.

The RO unit alone or the RO unit proceeded by the UV unit could not meet the discharge limits for all compounds having limits. With a complex waste stream, such as the PAS leachate, it would be difficult for any single technology to meet the stringent discharge limits for all contaminants of concern. In this case, the permitting agency may grant a temporary waiver to allow a higher discharge limits for the effluent of a temporary on-site treatment system. Another option is the operation of any on-site treatment unit from October 1 to June 1, thereby avoiding the dry summer months when the stream could dry up. Hence, the stream could be reclassified as perennial and a dilution factor added to the calculations. Another method of meeting estimated discharge limits is the use of additional treatment technology.

The objective of using additional technologies is to lower concentrations of compounds of concern in the effluent. The technology of choice could be coupled with an appropriate pretreatment and/or polishing technology to achieve effluent discharge criteria. An example of this approach is the pretreatment of leachate prior to RO with UV. The concentration of volatile and semi-volatile organics fed to the RO unit was substantially lowered by UV pretreatment (see Test #4, Appendix 1). Furthermore, Table 3 shows that this technique did allow four additional compounds to meet effluent criteria. Yet, a more rigorous oxidation pretreatment may offer a better overall treatment of the leachate with the possibility of a dischargeable effluent, but this would surely increase the cost of the treatment. Even with a rigorous UV pretreatment, particular attention would have to be paid to organics recalcitrant to oxidation and poorly rejected by membranes, such as acetone.

The rejection of organics provides a more universal standard of reverse osmosis performance. It allows for an even comparison of RO treatment among contaminants as opposed to discharge criteria, where each compound has their own individual discharge limit. A compound can meet discharge criteria yet have poor RO rejection. This can occur when a compound has a moderate to high discharge criteria and a low feed concentration. An example of this situation is lead removals were percent, yet it met the 50 ug/l discharge limit every test for every membrane (Test 2).

4.2 Percent Contaminant Rejection by Reverse Osmosis

Reverse osmosis contaminant rejection is equivalent to the RO treatment effectiveness. In leachate treatment, the purpose of RO is to reject all undesirable compounds (solutes) yet allowing permeation of clean water (solvent) for reuse, discharge or reinjection. Typically, leachate flows into a RO unit, through a semi-permeable membrane, and out to the environment. The contaminant's reduced permeation through the membrane produces a step change in concentration between the feed and effluent which can be measured as percent rejection. This concentration reduction is not a function of treatment time, as in ultraviolet oxidation, but practically speaking, occurs instantly. Since separation is instantaneous and irreversible, the highest rejections possible are preferred.

As the rejection approaches 100 percent, the contaminant's permeate concentration approaches zero or non-detect. So, to meet the treatment objectives for effluent quality of a leachate containing numerous contaminants, the membrane rejection quantifies the technical feasibility of reverse osmosis for the treatment of a aqueous waste containing a wide range of contaminants.

Comparatively, for the three classes of contaminants, reverse osmosis rejection performance was heavy metals> semi-volatile organics> volatile organics. Leachate treatment by RO was excellent for heavy metals removal, acceptable for for semi-volatile and volatile organics, and unacceptable for other organics.

In general, the heavy metals had high rejections. The rejection of nickel and copper in this study agrees well with the 94 and 95 percent rejections found by Coplan et al. (22). Notable exceptions to the high heavy metal removals were lead, selenium, and zinc. A possible explanation for the success of reverse osmosis in rejecting heavy metals is that separation by reverse osmosis is molecular size (13, 14, 21). In order to permeate the membrane, a molecule has to pass through a polymer barrier with small spaces between membrane molecules. Metals ions cannot move through water as naked ions. These ions move through water with a solution shell of attracted water molecules. This makes their effective size very large; hence, they are excluded from permeation because of their size. Another cause of the high metal rejection may be due to the charge repulsion between metal ions and the membrane barrier. In a low pH solution, such as the pretreated leachate, the polyamide membrane may become protonated giving the membrane an overall positive charge which would repel any positively charged metal cations. Lead was poorly rejected by RO, yet it achieved discharge limit 100 percent of the time because of its low concentration in the leachate.

Overall, organics had mixed membrane rejections. Reverse osmosis achieved acceptable removal (greater than 85%) for six of the thirteen semi-volatiles in the leachate, and nine of the twenty-one volatiles. Several molecular characteristics affect membrane retention. Molecular size and polarity are the major chemical characteristics affecting retention of contaminant compound by RO membranes. Since bromoform is a large molecule than carbon tetrachloride, it was expected and observed to exhibit better rejection. Molecular size and polarity can compete to change the expected rejection. For example, chlorobenzene is large than toluene, but rejection is lower because chlorobenzene is more polar. Polar compounds, like chlorobenzene, are more water soluble. The water solubility is caused by a chlorine induce dipole moment. The negative (chlorine) end attracts the hydrogen on water while the positive end of the molecule attaches the electron pair in water; therefore, this causes a solution effect. This effect causes the molecule to strongly association with water and passes through the membrane with the solvent, water. In another example, phenol and toluene are about the same size, but phenol had lower rejections because of its polarity. Acetone had poor rejections; because it is very small, very polar, and very water soluble. Conversely, worked well with naphthalene because it is a large, good non-polar molecule.

The fact that polarity has such a strong effect on rejection leads one to the assumption that pH will have a strong effect on changing the rejection.

4.3 Statistical Analysis

4.3.1 Correlations --

The purpose of the correlation analysis was to determine if any significant correlation existed between either the leachate concentration or the process parameters and the effluent quality. The effluent quality is the main factor associated with the technical feasibility of a treatment technology and a major factor associated with economic feasibility. Therefore, determination of the independent variables that significantly affect effluent quality (the dependent variable) is of prime importance in this project.

Significant correlations between the permeate concentration (effluent quality) of toluene and naphthalene and their respective feed concentrations were found. In addition, for the compounds several significant correlations were found between permeate concentration and process parameters. An explanation for the classical behavior by only toluene and naphthalene in the nine target compounds analyzed is that these compounds are both relatively large and non-polar. Therefore, the exhibit behavior one would anticipate for a semi-permeable membrane technology.

A significant positive correlation was also found between the Toray membrane and cumulative operation time. This correlation depicts an occurrence that can be the bane of a semi-permeable membrane system, the increase in permeate concentration (or conversely the decrease in effluent quality) with time. This increase indicates a deterioration in membrane integrity probably due to the effects of the leachate's components on the polymeric structure of the membrane. In a full-scale, long term operation, the membrane would have to be replaced to meet effluent quality standards. On the other hand, the Filmtec membrane showed an interesting trend. For several compounds, as the feed concentration increased, the effluent quality remained constant. Even though the increase in feed concentration was within a narrow range, relatively speaking, the consistency in effluent quality is an asset to the design and operation of a proposed treatment system.

For the other compounds and membranes analyzed, there were no clear trends. Mixed correlations was found. The lack of correlation is due to the complexity of the waste water found at PAS where the interactions between parameters and contaminants are very complex and their effects are going to vary from compound to compound and membrane to membrane. The only way to increase the significance of the correlations is to reduce the number of variables and increase the number of samples and tests. This experimental technique will allow experimenters to better explain the importance of various factors on the performance of any one membrane on a per compound basis.

4.3.2 Analysis of Variance --

The objective of the analysis of variance was to investigate the difference in RO performance as a function of the following four factors: 1) membrane type, 2) hydrostatic operating pressure, 3) permeate/ concentrate ratio, and 4) cumulative operating time. This analysis will show what factors were important to the operation of the RO unit.

The ANOVA conclusion was that a difference in performance existed between membranes. This difference was found to be significant in four of the nine target compounds. The significant difference means that one or more membrane rejected contaminants while the others did not.

The other factors has little or no significant affect on permeate quality. Although these other factors did have a significant influence on a few contaminants; for a complex waste stream, these factors could be ignored.

ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE OXIDATION

5.0 ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE TREATMENT INTRODUCTION

5.1 Background

See Section 1.1

5.2 Ultraviolet/Ozone/Hydrogen Peroxide

Ultraviolet (UV) ozonization, UV peroxidation, photolytic ozonation, and enhanced oxidation are all terms indicating the technology of super oxidation by a oxidizing chemical, usually ozone and/or hydrogen peroxide, in the presence of ultraviolet light. Ozone is the second strongest oxidizing compound next to fluorine. This treatment technology has been known for over a decade. Although it is known that UV with ozone is a better oxidizer than ozone alone many of the extremely complex reaction mechanisms have yet to be elucidated [23, 24]. Used initially for potable water treatment, this technique was found to successfully treat cyanide bearing waste waters [25]. This technology is also being used to degrade many different types of organic contaminants. Some compounds which have been oxidized are pentachlorophenol; 2,4-dichloro phenoxyacetic acid; and hexachlorobenzene. Trichloroethene, perchloroethene, and 1,1,1-trichloroethane has been reduced from 470, 96, and 166 ug/l, respectively, to drinking water standards [26, 27]. The successes with various organic laden waste water made UV a primary candidate for PAS leachate treatment.

The objective of the UV study was to test the feasibility of this technology for oxidative destruction of PAS contaminants. To carry out this degradation, leachate was fed to the UV system where the combination of ultraviolet energy, ozone, and hydrogen peroxide destroys the organic constituents. The UV effluent can then be sent for surface discharge or reinjection to the landfill. This technology achieves a leachate contaminant reduction since, ideally, the effluent stream contains decontaminated water.

The UV portion of the report has been divided into several sections: methodology, results, and discussion. The methodology section details the sampling and analysis of aqueous samples taken from the process during testing and the various aspects of site preparation necessary for conducting pilot-scale trials on a hazardous waste site. In addition, the methodology section explains the leachate pretreatment process, the arrangement of the UV system, and the construction of the UV unit. The results section contains two major subsections: discharge criteria and statistics. The discharge criteria subsection details how well the technology met New York State effluent discharge criteria, on a per compound basis. The statistical analysis contains information on correlations and modeling. The correlation looks for significant trends in the relationship between the effluent concentration and process variables. From the data, models were constructed to assist environmental scientists and engineers in the evaluation and prediction of UV performance for this and other hazardous waste sites. The discussion section mirrors the organization of the results section. Finally, for the PAS site and other similar hazardous waste sites, conclusions were drawn from the results of the tests and recommendations were made.

6.0 ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE TREATMENT METHODOLOGY

6.1 Sampling and Analysis

Samples of the UV feed and effluent were taken throughout the study. All sampling, sample storage, and sample shipment was performed in accordance with REAC Standard Operating Procedures (SOP) #2001 to 2005. These SOPs are approved by the ERT and are available on request.

Analyses on the samples generated from the test were performed for the following classes of compounds: volatile organics (VOA) and base neutral/acid extractables (BNA). On-site chemists performed VOA analyses by the US EPA methods 601 and 602 using a Hewlett-Packard (HP) 5840 gas chromatograph (GC) equipped with a flame ionization detector and a purge and trap [16]. BNA analyses were analyzed according to the separator extraction technique of US EPA method 625 with a HP 5995C GC/MS [18].

6.2 Site Preparation

Site preparation consisted of landscaping, support equipment, and supplies, utilities, and health and safety. Since the site was previously capped with PVC, graded with soil, and seeded, only minor landscaping such as grass clipping was necessary. After landscaping, support equipment and supplies were set up prior to installation of the treatment systems. Figure 1 and Photo 1 show the equipment layout at the site. Trailers were used for office space, for hardware and supply storage, and for on-site sample preparation and VOA analysis. All necessary utilities were installed. City water was distributed from the site perimeter for process and human needs and an existing electrial service was temporarily modified to power equipment, trailers, and lights. Additional support equipment included a portable toilet, a back-up compressor, and a diesel fuel tank.

The health and safety of all personnel was of utmost concern. Prior to any site activities, a comprehensive health and safety plan was written which addressed the following items: identification of key personnel, operation safety and health risk analysis, personnel training requirements, personal protective equipment, medical surveillance requirements, air monitoring, site control measures, decontamination plan, emergency response/contingency plan, and confined space entry procedures. To provide adequate personal protection, an ample inventory of protective clothing and gear was accessible and clearly labeled in the storage trailer. To delineate the work area within which protective clothing was required, a zone perimeter was marked with signs and highly visible tape (Figure 1). Along a portion of the perimeter, a decontamination zone was erected and staffed by support personnel. Health and safety equipment, distributed throughout the site at key locations, included fire extinguishers, hospital directions, emergency phone numbers, light towers, emergency horns, and portable eye wash/shower stations.

6.3 Leachate Pretreatment

In this study, all leachate was pretreated prior to treatment prior to treatment by UV. The first objective of pretreatment was to reduce the iron content in the leachate by hydroxide precipitation. The second objective was to increase the solubility of the remaining metals by acid addition to reduce or eliminate their scaling on the quartz shield protecting the UV lamp and to reduce their precipitation inside the reverse osmosis unit used for prior treatment of the leachate before UV oxidation. Metal precipitation is a major cause of irreversible membrane fouling.

The following details the pretreatment scheme. To deliver the leachate to the pretreatment system, recovery wells at the site pumped raw (untreated) leachate from the site into a 200,000 l in-ground storage tank. This leachate was pumped into the pretreatment system. The leachate pretreatment system consisted of the following sequential steps: 1) 50 percent sodium hydroxide addition, to pH 10, for soluble iron precipitation, 2) an 800-liter reaction tank for metal hydroxide flocculent formation, 3) a slant tube lamella clarifier for metal hydroxide precipitate settling, 4) 5-micron and 0.2 micron cartridge filtration for lamella overflow clarification, 5) concentrated hydrochloric acid addition to pH 5 for increasing solubility of residual metals, 6) a 2000-liter tank for reverse osmosis feed storage, and 7) final 0.2 micron cartridge filtration (see Figure 2 and Photo 2). After pretreatment, the feed to the UV was named basified/acidified leachate.

The above details the basic pretreatment scheme. In this study, the UV system treated three feeds differing only in their pretreatment. These feeds included the leachate (mentioned above), RO permeate, and RO concentrate.

6.4 UltraViolet/Ozone/Hydrogen Peroxide Oxidation

The UV unit was provided by Solarchem, Richmond Hill, Ontario, Canada (see Figure 10 and Photo 5). The unit contained three upflow reactors in series with separate ozone, hydrogen peroxide, and acid/base addition ports near the entry to each reactor. The system would control pH and ozone and hydrogen peroxide additions. An ozone generator provides the unit with the necessary oxidant and a catalytic bed scrubbed ozone in the off-gas.

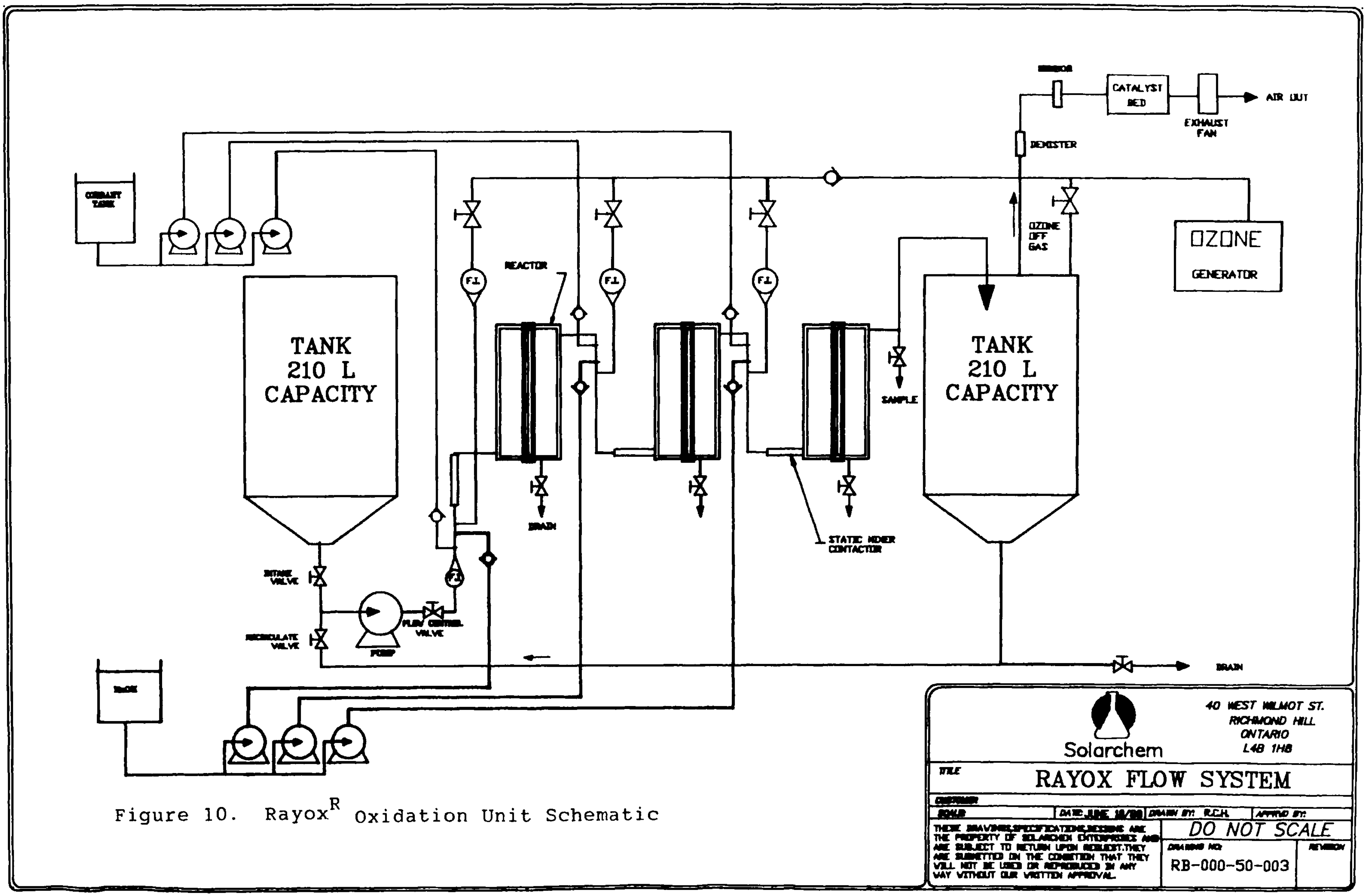

Figure 10. Rayox^{R} Oxidation Unit Schematic

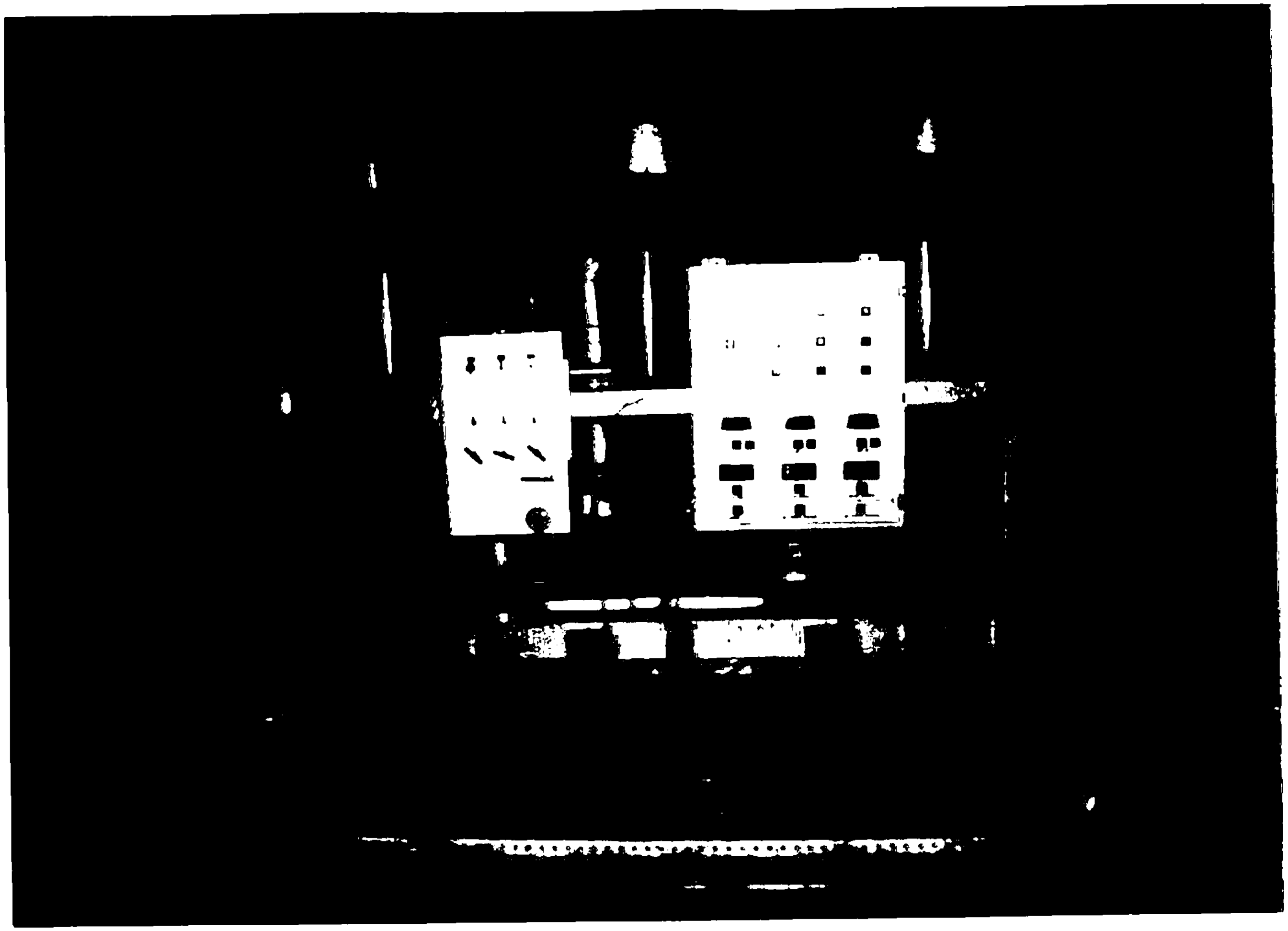

PHOTO 5. RAYOX^R ULTRA-VIOLET OXIDATION UNIT

The engineering study used three different feeds to the RO unit differing only in their pretreatment. Most tests fed the UV unit with pretreated (sodium hydroxide precipitation and hydrochloric acid addition) leachate called basified/acidified leachate. Several test explored UV treatment of pretreatment leachate (sodium hydroxide precipitation and hydrochloric acid addition) followed by RO treated leachate. Both the RO permeate and concentrate streams were fed to the UV system.

6.5 Calculations

See Section 2.5.1 for discharge criteria calculations.

7.0 ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE TREATMENT RESULTS

The results of the UV tests are based on the analyses of samples taken during the trials for two analyte classes: volatile organics, and base neutral/acid extractables. These priority pollutants are compounds of interest to the U.S. EPA because of their impact on human health and the environment. All data from the reverse osmosis field pilot-scale tests are located in Appendix 1, and all data from the UV. The Appendix 1 data is grouped by analyte class: VOA, BNA, or heavy metals; and, within each class, arranged by test numbers. Within each test, the Appendix 1 data can stand alone because it contains the process parameters of that test.

To obtain a broad overview of the UV experiments and to assist in navigating through the raw data for all the tests, two tables summarize all the reverse osmosis tests and organize all the samples by test. Table 9 lists the various UV tests and includes the operational parameters of each test. Table 2-A, in Appendix 1, coordinates the samples taken during each test with the test number, with the sampling location, with the analytes for each sample, and with the time of sampling.

The graphical presentations of the UV results are presented in the Solarchem report. The plots depict the differences between the different run conditions.

7.1 Discharge Criteria

Table 10 lists the results of UV technology alone in meeting discharge criteria. For each contaminant, the table shows the number of tests that an effluent was equal to or lower than the discharge standard or guidance value and the total number of tests for which data was available. These values are presented for both batch and continuous runs and for the three types of UV feed: leachate, RO permeate, and RO concentrate. During the batch runs, the leachate was recirculated thru the UV unit from a feed tank; for the continuous runs, the system was configured for one-pass, flow-through operations.

TABLE 9. ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE OXIDATION OPERATION CHRONOLOGY AT THE POLLUTION ABATEMENT SERVICES SITE

Test #/ Date	UV Feed	Leachate Pretreatment Scheme	Operation Conditions						
			Feed pH	System pH	UV Lamps (#)	Reactors using O_3 (#)	H_2O_2 dosage ml/min	Batch volume or continuous flow rate	Test Duration (hr)
#4 8-13-88	RO permeate	raw leachate -- pH 10--settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	4	10	2	3	0	210 l batch	2
#5 8-18	RO permeate	raw leachate -- pH 10--settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	4	10	3	3	0	210 l batch	2
#6 8-19	basified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- UV	8	10	3	3	10	210 l batch	2
#7 8-19	basified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- UV	8	10	3	3	0	210 l batch	2
#8 8-20	basified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- UV	9.5	10	3	3	30	210 l batch	2
#9 8-22	basified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- UV	9.5	10	3	3	30	210 l batch	2
#10 8-23	basified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- UV	10	10	0	3	30	210 l batch	2
#11 9-7	basified leachate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- UV	10	10	3	3	0	4 l min continuous	3
#12 9-9	RO concentrate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	5	10	3	3	0	210 l batch	3
#13 9-10	RO permeate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	5	5	3	3	0	210 l batch	2

TABLE 9. ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE OXIDATION OPERATION CHRONOLOGY AT THE POLLUTION ABATEMENT SERVICES SITE (CONT'D)

			Operation Conditions						
Test #/ Date	UV Feed	Leachate Pretreatment Scheme	Feed pH	System pH	UV Lamps (#)	Reactors using O_3 (#)	H_2O_2 dosage ml/min	Batch volume or continuous flow rate	Test Duration (hr)
#14 9-12	RO permeate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	5	8/5 **	1	3	0	210 l batch	2
#15 9-13	RO permeate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	5	5	3	3	0	4 l/min continuous	2
#16 9-13	RO permeate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	5	10	3	3	0	4 l/min continuous	1
#17 9-14	RO permeate*	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	5	5	1	3	0	4 l/min continuous	2.2
#18 9-14	RO permeate*	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5	5	5	1	1	0	4 l/min continuous	1.5
#19 9-14	RO permeate*	-- reverse osmosis -- UV raw leachate -- pH 10 -- settle	5	10/5 ***	1	3	0	4 l/min continuous	1.8
#20 9-14	RO permeate*	-- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	5	10	1	3	0	4 l/min continuous	1.7
#21 9-15	RO concentrate	raw leachate -- pH 10 -- settle -- filter (5 & 0.2 um) -- pH 5 -- reverse osmosis -- UV	4	5	3	3	0	210 l batch	3

* Contaminated with leachate due to membrane leak in #3 reverse osmosis pressure vessel.

** pH 8 in reactors #1 & 2, pH 5 in reactor #3

*** pH 10 in reactors #1 & 2, ph 5 in reactor #3

Page 2 of 2

TABLE 10. NUMBER OF TESTS* USING ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE OXIDATION (with and without reverse osmosis pretreatment) WHICH MET NEW YORK STATE DISCHARGE CRITERIA

Contaminant Volatile	Discharge Criteria	Feed Type for Batch Test			Feed Type for Continuous Test	
		Leachate	Permeate	Concentrate	Leachate **	Permeate **
<u>Volatile Organics</u>						
Methylene Chloride	500	4 (4)	4 (4)	0 (2)	0 (5)	2 (2)
1,1-Dichloroethene	0.7	1 (5)	2 (4)	1 (2)	1 (2)	1 (2)
1,1-Dichloroethane	500	5 (5)	4 (4)	1 (2)	4 (5)	2 (2)
1,2-Dichloroethane	80	2 (5)	4 (4)	0 (2)	0 (5)	1 (2)
1,1,1-Trichloroethane	500	5 (5)	4 (4)	2 (2)	5 (5)	2 (2)
Carbon Tetrachloride	4	--	1 (2)	0 (1)	0 (3)	0 (2)
Bromodichloromethane	500	--	2 (2)	1 (2)	2 (4)	2 (2)
Trichloroethene	11	4 (5)	3 (3)	0 (1)	0 (5)	2 (2)
Benzene	0.1	0 (5)	0 (4)	0 (2)	0 (4)	0 (2)
Bromoform	500	--	2 (2)	0 (2)	1 (5)	2 (2)
Toluene	500	5 (5)	4 (4)	2 (2)	5 (5)	2 (2)
Chlorobenzene	5	4 (4)	4 (4)	2 (2)	11 (5)	2 (2)
Ethylbenzene	500	5 (5)	4 (4)	2 (2)	3 (4)	2 (2)
Xylenes	500	5 (5)	4 (4)	2 (2)	2 (4)	2 (2)
<u>Semi-Volatile Organics</u>						
Phenol	5	2 (2)	2 (2)	0 (1)	1 (5)	1 (2)
1,2-Dichlorobenzene	5	2 (2)	1 (1)	--	4 (5)	2 (2)
Naphthalene	100	2 (2)	1 (1)	--	4 (4)	2 (2)
Bis(2-ethylhexyl) phthalate	0.6	0 (2)	0 (1)	--	0 (1)	0 (2)
Di-n-octylphthalate	500	2 (2)	2 (2)	1 (1)	1 (1)	--
Di-n-butylphthalate	500	2 (2)	2 (2)	1 (1)	1 (1)	--

* - Number on left is the number of tests meeting discharge criteria compared with the total number of tests (in parenthesis).

** - Results of Test 17, 18, 19, and 20 using permeate feed were placed in leachate column due to feed contamination from membrane leak.

After treating both leachate and RO permeate during batch tests, the UV system met discharge limits for most compounds. Only 1,1-dichloroethane, benzene, carbon tetrachloride, and bis(2-ethylhexyl)phthalate eluded discharge criteria. These compounds had the low effluent limits of 0.7, 4.0, 0.1, and 0.6 ug/l, respectively. The RO concentrate feed did not respond as well to the batch treatment. The concentrate contained substantially higher contaminant concentrations compared with the other two UV feed streams. Therefore, under the same batch operating conditions, the effluent after concentrate treatment contained fewer compounds achieving discharge criteria.

Percent contaminant destruction, a value similar to percent membrane rejection, was not calculated for the UV tests. The rate of removal and residual contaminant level are functions of several factors: the UV light intensity, the oxidizing agent, and the treatment time. So with enough oxidizing power and retention time, most compounds can be mineralized to non-detectable concentrations. Therefore, for UV oxidation, the importance information derived from testing (from a process perspective) is the reduction of contaminant concentration as a function of time and as a function of oxidant quantity (dosage units). The latter relationship is shown in the Solarchem report.

7.2 Statistics

The UV test data was statistically analyzed and modeled using SAS Statistical Software version 4.0 (SAS Institute, Inc., Cary, N.C.). Seven target compounds chosen for SAS analysis were methylene chloride, acetone, trichloroethene, toluene, phenol, 1,2-dichlorobenzene, and naphthalene. They were picked for the following reasons: frequency of occurrence in the samples, their chemical and steric differentiation within their analyte class, and their relative frequency of occuance in the environment.

The UV results did not lend well to statistical analyses. Correlations calculated on the relationships between a target compound's effluent concentration and the process parameters were not strong (Appendix 6). Furthermore, these correlations had low levels of confidence. Therefore, the statistical correlations observed could not be significantly attributable to the independent variables, the process parameters, but could be the result of chance. The main reason for the lack of significance is that too many process parameters were varied in a small number of tests and samples. In the 18 UV trial runs, 5 process parameters were varied. They were number of UV lamps, number of reactors using O_3, hydrogen peroxide dosage, and continuous (flow-through) versus batch operation mode.

Similarly to the correlational analysis, models generated for UV oxidation of leachate were not adequate for developing explanations and predictions for UV performance (Appendix 7).

8.0 ULTRAVIOLET/OZONE/HYDROGEN PEROXIDE TREATMENT DISCUSSION

8.1 Discharge Criteria

After treatment of a liquid waste at a Superfund site, the options for the effluent are discharge to surface waters, discharge to a POTW or reinjection into the subsurface. At the PAS site, a sewer line to a POTW was not available, and subsurface injection, a discharge option, did not have published criteria. For surface waters to receive treated effluent, the NYDEC standards and guideline values must be met for published compounds.

Batch UV treatment was able to lower most organic contaminant concentrations in leachate and RO permeate to dischargeable levels. The organic compounds that did not meet NYDEC discharge criteria were found to have low published water quality standards and guidance values. With a complex waste stream, such as PAS leachate, it is difficult for any single technology to meet the stringent discharge limits for all contaminants of concern. In this case, the permitting agency may grant a temporary waiver to allow higher discharge limits for a temporary on-site treatment system.

This temporary waiver could be based on the operation of the treatment system between October 1 and June 1 of any year, thereby avoiding the dry summer months when the stream could dry up. Therefore, the stream could be reclassified as perennial, and a dilution factor added to the calculations. Another method of meeting discharge criteria is using additional treatment technologies to support UV oxidation.

The objective of using additional technologies was to reduce the residual contaminant concentrations in the effluent. The UV system could be coupled with appropriate technology's pretreating the UV feed and/or polishing its effluent. Some examples for UV effluent polishing is a staged RO system to remove residual organic and any metals or a sulfide precipitation to lower the effluent's heavy metal content.

A notable possible problem in meeting NYDEC discharge standard is the residual acetone content for which published standards or guidance values could not be found. Since the variety and amount of organics preent probably greatly exceeds the number and concentration of compounds found in the priority pollutant analysis, it is possible that one or any number of these unknowns may be forming acetone as an intermediate oxidative product. The real problem lies not in the intermediary status of this compound, but in the fact that this contaminant appears to be highly refractory to $UV/O_3/H_2O_2$ oxidation. This refractory nature may be due to the physical nature of the wastewater. Researchers have found that a significantly longer reaction was required to destroy organics in wastewater versus distilled water [26]. This find implicates the impact that the organic and inorganic constituents have on the rate of UV treatment of organics, especially refractory compounds.

8.2 Statistics

Statistical analysis of the UV results did not yield any useful information. Careful attention should be given to the experimental design in future engineering studies whose objective is to evaluate the applicability of alternative waste remediation. The experimental design should be such as to evaluate applicability. Although it may be desirable to optimize process parameters, the amount of testing, sampling, and their associated cost, necessary to obtain a statistically valid answer may preclude optimization during the technology application evaluation phase of a project. A process parameter optimization study could follow the evaluation selection of appropriate technologies for a site remediation.

9.0 CONCLUSIONS

- Reverse osmosis alone and ultraviolet/ozone/hydrogen peroxide oxidation pretreatment followed by RO was able to meet the discharge criteria for 13 and 16 compounds, respectively, of the 27 individual compounds of concern; however, the RO effluents did not achieve the standards and guidance values set by the NYDEC for contaminants. Therefore, RO or UV/RO must be coupled with other technologies for successful leachate treatment at PAS.

- Overall, for the three classes of contaminant compounds in the leachate, reverse osmosis showed excellent removals of heavy metals, acceptable removals for some semi-volatile and below acceptable for volatile organics; and unacceptable removals for the remaining organics.

- Reverse osmosis worked well concentrating heavy metals since rejection were usually above 95 percent with lead, selenium, and zinc notable exceptions.

- Reverse osmosis may be a feasible technology to remove semi-volatile organics from leachate since six of the thirteen compounds found in the leachate had removals 85 percent or greater.

- Generally, reverse osmosis did not reject volatile organics.

- In general, reverse osmosis can be successfully used with waste waters containing heavy metals and used, cautionsly, with waste water containing organics.

- For organic contaminants, the two primary factors affecting rejection are molecular size and polarity; the larger the size and smaller the polarity, the greater the membrane retention.

- Of the nine target contaminants statistically analyzed, only naphthalene and toluene showed a significant correlation between permeate concentration and feed concentrations and between permeate concentration and process parameters. This correlation may be due to the fact that naphthalene are relatively large compounds and are non-polar molecules; therefore, the exhibit a classical effect due to reverse osmosis separation. For the other seven compounds, no clear trend was apparent.

- The Toray membrane showed a significant increase in permeate concentration with time. The increase may be the result of membrane deterioration. On the other hand, the Filmtec membrane exhibited an interest trend; the permeate quality remained constant for increases in feed concentration of certain compounds a desirable characteristic for any membrane.

- UV treatment of leachate or RO permeate met the NYDEC discharge limits for most, but not all, published organic compounds. To achieve effluent discharge quality for organics with low NYDEC published standards and guidance values, a longer retention time and/or greater dosage units are required.

- Batch UV treatment achieved the discharge criteria for more organic compounds when compared with continuous, flow-through treatment. The longer retention time in the system and hence the greater dosage units, are responsible for this result.

- Acetone was formed during UV treatment. It appears to be an intermediate compound during oxidative destruction of the complex leachate. This is a serious problem since acetone proved to be refractory to oxidative destruction.

10.0 RECOMMENDATIONS

- To meet NYDEC discharge criteria for on-site treatment effluent discharge into White Creek, reverse osmosis is not recommended as a stand-alone technology. Reverse osmosis must be preceded or followed by additional technologies. One possible technology is ultraviolet/ozone/hydrogen peroxide (UV) oxidation (for organic contaminant reduction) A rigorous oxidation should be explored prior to installation of any RO system with careful attention given to compounds recalcitrant to oxidation and inadequately rejection by RO, such as acetone. In addition, a staged RO may provide the separation required effluent quality. As another option, an appropriate technology could follow reverse osmosis to polish the effluent.

- Excellent treatment rejection (greater than 85 percent) make reverse osmosis a viable option for heavy metal laden waste water; although, RO is not recommended on lead, selenium, and zinc containing waste without additional tests due to the low rejection (less than 85 percent) for these metals. Reverse osmosis is not recommended for many volatile organics and some semi-volatile organics because of the low treatment efficiency with these contaminants.

- Since molecular polarity appears to have a strong effect on organic compound's rejection, the effect of feed pH should be explored in future tests.

- Based on data on discharge criteria, percent rejection, and statistical correlations, the Filmtec HR membrane is the membrane of choice for use with PAS leachate. Compared with the other membranes tested, it met the NYDEC discharge criteria more frequently, had consistently higher percent rejections of contaminants, and exhibited the trend of steady effluent quality at increasing feed concentrations.

- To lower the organic loading in the treated UV effluent and to meet the NYDEC discharge criteria for organics, the UV system must provide more dosage units (mg of oxidizing agent per liter of leachate).

- UV treatment does not treat the heavy metals in the leachate; therefore, another treatment technology should follow UV oxidation, such as a staged RO system or another appropriate technology.

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APPENDIX A

ENVIRONMENT CANADA REPORT

REVERSE OSMOSIS AND ULTRAVIOLET PHOTOLYSIS/OZONATION TESTING

AT THE PAS SITE - OSWEGO N.Y.

Introduction

The PAS Superfund site is a former solvent incineration facility in Oswego N.Y. In 1979 it was cleaned up and a slurry wall and leachate collection system installed. Approximately 350,000 gallons (1,200,000 litres) of leachate, which contains ppm levels of metals and solvents, is collected for treatment/disposal annually. Reverse osmosis (RO) and ultraviolet (UV) photolysis/ozonation were investigated as possible measures for reducing the volume of leachate requiring treatment/disposal in a trial carried out in August/September 1988.

Test Set-up

The set-up for the testing, as originally envisioned, is as shown in Figure I. It was anticipated that adjusting the pH of the leachate to 10 would precipitate the metals and that the precipitate could be removed from solution by microfiltration using disposable cartridge filters. It was soon discovered that although the thermodynamics was correct, the kinetics were not and much of the precipitate did not form until after the filters.

A settling tank and a Lamella clarifier were added to the system as shown in Figure II. This allowed time for the precipitate to form before the filters. There was, however, the need to remove approximately one gallon per hour of sludge from the bottom of the clarifier and to change a set of filters approximately every half hour. This could have been remedied by use of a cross-flow microfiltration system but it was judged to not be cost-effective to bring a unit to the trial site at that stage in the testing. After the field trial had been completed, the efficacity of cross-flow microfiltration was confirmed in laboratory testing using actual leachate from the site.

Technology Investigated

As previously stated, the objective of the trial was to determine whether or not RO and UV Photolysis/ozonation, together or singly, could be used to treat the leachate so as to greatly reduce the volumes requiring further treatment. A description of these technologies is given in subsequent paragraphs.

Reverse Osmosis (RO)

Reverse Osmosis is a pressure driven membrane process originally developed for the provision of drinking water from salt and brackish sources. In use, the water to be treated is passed under pressure, (200-400 psi for brackish sources and 400-800 psi for salt sources) across the surface of a semi-permeable membrane. A portion of the water and some contaminants then pass through the membrane by a process of solution/diffusion. The remaining stream passes tangentially across the surface of the membrane. When used for industrial processes or for a chemical spill or leachate a portion of the tangential stream (concentrate) is fed back to be mixed with the incoming feed stream. This allows the contaminants in the original feed to be concentrated to higher levels while up to 95% of that feed passes through the membrane as cleaner permeate. The contaminants removed will depend upon the materials used in the membrane surface layer and backing. Most membranes will reject inorganic compounds but proper care must be taken to ensure that the organics will neither pass through or destroy the membrane.

The RO unit used in this trial was the Environment Canada mobile unit. It is a diesel powered, trailer mounted, self-contained unit with a nominal capacity of 550 gallons (2000 litres) per hour.

Ultraviolet (UV) Photolysis/Ozonation

The UV photolysis/Ozonation unit used for this trial was a Solarchem RAYOX unit which was transported and operated in a 20 foot truck. The RAYOX process is an enhanced oxidation process. In these processes, the principal oxidizing agents are radicals. Radicals have much greater oxidizing power than their precursors which are normally ozone (O_3) or hydrogen peroxide (H_2O_2).

In the RAYOX process, O_3, and sometimes H_2O_2, are combined with UV light. This results in a synergistic effect. If contaminated water with an oxidant source is exposed to short wavelength UV light (<300 nm), and particularly light closely matched to the absorption spectrum of the contaminants, there is a large increase in the rate of oxidation of the contaminants.

Many contaminants which absorb UV light dissociate into fragments called radicals. These radicals typically react very rapidly with oxygen to form peroxy radicals such as $HCOO_2$ which can themselves participate, in a complex way, in the oxidation of the contaminants present. Alternatively, they can decompose directly into simpler molecular fragments.

Some contaminants do not dissociate to a significant extent upon absorption of UV light, but instead form a relatively long lived reactive intermediate called a triplet. This species has a sufficient lifetime to encounter and react with any oxidizing species present yielding, as products, more oxidizing compounds which will be subject to all of the oxidizing processes underway. If sufficient time is allowed, the contaminants will be fully mineralized.

In addition to direct photooxidation of the contaminants, the use of UV light has a powerful complimentary benefit, the formation of strong oxidizing agents such as the hydroxyl radical (HO.) Once formed, the HO. radical will result in rapid oxidation of the contaminants present. Its importance can be demonstrated in the oxidation of phenol where the oxidation rate with the HO. radical is one million times as fast as with molecular O_3.

Using an enhanced oxidation process such as RAYOX, a wide range of organic and inorganic compounds can be quickly oxidized. Intermediates formed are normally less stable than the original compounds and are readily oxidized. This is particularly attractive in environmental remediation technology because the result is on-site destruction of the contaminants.

Procedure

As previously discussed, the first step normally undertaken was the alkination to pH 10 with 25% NaOH to precipitate the metals. The filtered supernatant was then fed either to an inline mixer where the pH was adjusted to 5 with HCl to remove the $CaCO_3$ as $CaCl_2$ or directly to the UV Photolysis equipment dependent upon which process was being used. Details of the procedure followed in each process are discussed below.

Reverse Osmosis Alone

The basified, filtered, acidified leachate was fed to a 550 gallon (2000 litre) tank from which the RO unit was fed. A second set of filters were placed in line between the tank and the RO unit as a precautionary measure but these proved to be superfluous. The leachate was fed at 800 psi to the membranes and the recycle control adjusted to give a permeate/concentrate flow ratio of 5:1, 8:1 or 10:1 as required. (This is generally referred to as the concentration ratio.) The mobile RO unit can contain up to 12 4x40 inch membranes but only 8, pairs of UOP 1001, DSI B441, Toray SP110 and Filmtec HR membranes were used in this trial. Samples of RO feed, permeates from individual membrane pairs and concentrate were taken at appropriate intervals and the run continued for 2 to 40 hours as desired.
The concentrate and permeate were re-injected into the leachate field as requested by N.Y. DEC.

Reverse Osmosis Followed By UV Photolysis/Ozonation

The same procedures as outlined above were followed except that the concentrate or permeate (as desired for the trial in progress) was fed to the UV Photolysis unit. THe same procedures as for UV photolysis alone were then followed.

Ultraviolet Photolysis/Ozonation Alone

The leachate, normally basified and filtered but not acidified was fed to the UV Photolysis unit. It was then subjected to O_3 treatment alone or some combination of O_3, UV, H_2O_2 and NaOH. Samples were taken at appropriate intervals and the effluent was discharged to the leachate field.

UV Photolysis/Ozonation Followed By RO

The procedures given in the previous paragraph were followed except that the UV effluent was fed to a 190 gallon (700 litre) tank and the pH was adjusted to 5 with HCl. The RO unit was then run for 2 hours or more with the concentrate and permeate being returned to the tank. Samples were taken at appropriate intervals. On completion of the trial, the tank contents were fed through the RO unit to the leachate field.

Results

Reverse Osmosis Alone

The actual time in which the RO unit was run amounted cumulatively to about 70 hours. Results for individual runs were not tabulated but the mean rejection by each pair of membranes is tabulated as follows:

(a) Organic compounds concentration - Table I
(b) Organic compounds rejection - Table II
(c) Inorganic compounds - Table III

Variation with time for individual compounds is included in Appendix A.

RO Fluxes

The RO flow rates achieved during the trial are shown as follows:

(a) Feed, Concentrate and combined permeate - Table IV and Figure III
(b) Individual Permeates - Table V and Figure IV.

UV Photolysis/Ozonation Alone

The mean destructions of compounds in the leachate is tabulated in Table VI and Figure V.
The conditions used in the different UV runs varied greatly. The parameters and results of individual runs are included in Appendix B.

RO Followed BY UV Photolysis/Ozonation

The mean results of this combination are recorded as follows:

(a) UV Photolysis/Ozonation of concentrate - Tables VII and VIII and Figure VI;
(b) UV Photolysis/Ozonation of permeate - Batch - Tables IX and X;
(c) UV Photolysis/Ozonation of permeate - Flow through- Tables XI and XII;
(d) UV Photolysis/Ozonation - Combined results - Figure VII.

UV Photolysis/Ozonation Followed By RO

There was only one run during which this combination was used. The results are given in Tables XII and XIII.

Microfiltration

As previously mentioned, it was decided to rely on the use of microfiltration cartridges rather than use the mobile microfiltration unit during the field trial. It was recognized, however, that cdoss-flow microfiltration was the prefered method of removal for the alkali precipitated metal hydroxides. A laboratory scale trial involving actual Oswego leachate was therefore carried out. THe pH was adjusted to 9,10,11 or 12 and the solution microfiltered. The results are included in Table XIV.

Discussion of Results

General

The results for all aspects of this trial were obtained by analysis of samples by gas chromatography for organics and atomic absorption spectroscopy for the metals. In the case of the volatiles organics, this involved purge and trap introduction of contaminants to the GC column. This technique is most accurate in the 5-200 ppb range. Above this limit, the accuracy drops off rapidly. It was, therefore, necessary to dilute samples such that the major contaminants would be within the desired concentration range, The wide range of concentration of concentration made this difficult at best. As a result, some of the higher concentrations reported, particularly for the concentrates, are probably, at best, an order of magnitude figure.

In the case of the metals, the accuracy of the technique used falls off at the lower levels. Those metals reported at very low levels may, therefore, be suspect.

Reverse Osmosis Alone

The objectives of this portion of the trial were to determine which of the commercialy available membranes tested gave the cleanest permeate from this leachate and to determine the extent to which the contaminants could be concentrated in the concentrate. The results will therefore be discussed for each of the pairs of membranes used and for the concentrate.

The rejections achieved for the membranes will be categorized as follows:

excellent - 95% and above
good - 85 to 94%
fair - 70 to 84%
poor - 69% and below

UOP

The results for this membrane ranged from poor to good with only those for Bromoform and nickel being cosidered excellent. There was no rejection for 1,1-Dichloroethene, it was concentrated in the permeate. All other halogenated alkene results were poor as were all of the other halogenated alkanes except Bromodichloromethane and 1,1,1-Trichloroethane. Acetone rejection was poor while Methyl Isobutyl Ketone gave fair rejections. For the aromatics, the results ranged from poor to good with the larger molecules normally giving the better results.

Analysis of the graphs of the changes in concentration for the various contaminants with time shows no evidence of degradation of the membrane over the period of the test. There was virtually no change in rejection for any of the metals while, for the organics, there were more compounds showing a slight improvement in rejection with time than there were showing no change or a slight degradation. The overpressuring of the system to 1200 psi, which ocurred at approximately 43 hours into the cumulative time does not appear to have had any short term effect.

In general, the UOP 1001 membrane was suitable for use against the metals in the PAS leachate but not for the organics.

DSI B441

The DSI B441 gave the best rejection of all those tested for Dichloromethane, 82.2%. Rejection of Bromoform was excellent while Trichloroethane was good. All other halogenated aklane and alkene rejections were fair or poor but, with the exception of Tetrachloroethane/ene, they were better than the UOP 1001 membrane. Acetone rejection was fair while that for Methyl Isobutyl Ketone was good. Most aromatic rejections were either good or fair with the exception of Benzene which was poor and Benzoic Acid which was excellent. Metals rejection varied from poor to good.

As was the case for the UOP membrane, analysis of the changes in metal and organic concentration in the feed and permeate shows no degradation in membrane performance with time. Metals rejection stayed essentially constant while there was a slight increase in the rejection of most organics.

In general, based on the results of this trial, the DSI B441 membrane is considered to be marginally acceptable for use on leachate similar to that at the PAS site.

Toray SP110

The results in Tables I and II indicate that the rejections of halogenated alkanes and alkenes were poor for all compounds except Trichloroethane and Bromodichloromethane which were fair and Bromoform which was good. The rejection of acetone was poor while that for Methyl Isobutyl Ketone was fair. Benzoic Acid rejection was fair, but, for all other aromatics it was poor. Metals rejections were poor except for Antimony which was fair.

Analysis of feed and permeate change with time reveals the reason for the disappointing performance of the Toray membrane. Until the overpressurization at 1200 psi, the rejections for this membrane were norally in the range between those for the DSI and those for the Filmtec. After that event, the Toray degraded rapidly. It was obviously damaged.

If the mean values for the duration of the trial are used as a guide, the Toray SP110 membrane is unacceptable for use with leachates similar to that at the PAS site. Realizing that the membranes were damaged by the overpressurization, the performance changes to acceptable with the proviso that this membrane must be kept within its intended pressure range at all times.

Filmtec HR

Except for Dichloromethane where it had the worst performance and Tetrachloroethane/ene where it was second best, the Filmtec membrane pair had the best rejection of all those compared for organics. Its rejection was excellent for Trichloroethane and Bromoform and good for 1,1-Dichloroethane and Bromodichloromethane. All other halogenated alkanes had fair rejections (except for the poor performance on Dichloromethane mentioned previously.) Acetone rejection was fair while that for

Methyl Isobutyl Ketone was good. All aromatic rejections were either good or excellent with 8 of the 13 being in the latter category.Except for nickel where it was second, the Filmtec had the highest metals rejection of any of those tested.

Analysis of the feed and permeate shows that the Filmttec HR membranes were umaffected by the overpressurization or any of the other factors which might have come into play during this trial. It is considered to be the best of the membranes tested, and to be very suitable for concentrating leachate similar to that at the PAS site.

Concentrate

During the trial, the RO unit was operated at concentration ratios of 5:1, 8:1 or 10:1. Given the mean rejections and fluxes of the membranes used, this should have resulted in concentations in the concentrate 3 to 8 times those in the feed. That is the case for the BNA's if the very poor rejections and high fluxes of the Toray membranes after the overpressurization incident are taken into account. The discrepancy in the VOA results is attributed to the inaccuracy of the GC Purge and Trap method at the high concentrations and, in the case of some of the membranes, to the build up of some contaminants on the membrane surface followed by solution/diffusion into the permeate.

RO Fluxes

Tables IV and V and Figures III and IV demonstrate the changes in the concentrate and permeate flows with time during the trial. Feed flux is the sum of these. All of the membranes underwent an initial period of acclimation to the leachate and compaction followed by more or less steady state operation until yhe overpressurization occured. Periodic feed or permeate flushes were required to maintain the steady-state flux. After overpressurization, the Toray membranes were badly damaged and its permeate flux increased rapidly.

The decrease in permeate flux for all membranes during the last 8 hours of the trial is the result of metals precipitating on the surface of the membranes. The alkination of the leachate had been turned off deliberately to determine whether or not it was necessary. The answer was in the affirmative.

UV Photolysis/Ozonation Alone

Problems were experienced with the analysis of acetone in all UV photolysis runs. A chemical which is produced as an intermediate co-elutes with acetone on the GC. The fact that it was an intermediate and not acetone was confirmed by GC/MS. Acetone was, therefore, not included in the results reported.

UV photolysis of the alkaline, filtered leachate gave excellent results for all of the runs.The total VOC removal (exempt acetone)was greater than 99% for runs 6 through 9, slightly less for run 10 where the UV light was off but ozone was used, and 94.7% for run 11 where the starting concentrations were much higher. On runs 6 through 9, the final effluent concentrations met U.S.EPA maximum monthly indirect discharge standards for all VOA's. (BNA's were not analysed for in the

UV/O3 runs.) In run 10, where UV light was not used, the more refractory compounds such as the dichloroethanes did not meet those standards. For run 11, the short apparent run time realized in the flowthrough mode of operation did not allow sufficient contact time between the oxidants and target compounds at the concentations present.

RO followed by UV Photolysis/Ozonation

RO - UV/O3 - Permeate(Batch)

This combination gave excellent results. Except for acetone, which as explained earlier had analytical problems due to co-elution, all compounds were removed to at least the 98.7% level.The U.S.EPA discharge criteria were met. The pH of the solution during UV/O3 treatment did not appear to have any impact on the efficiency of the process when using permeate as the feed.

RO - UV/O3 - Permeate(Flow through)

The results of this technique appear, at first glance, to indicate that this sequence of operations was not very efficient. Total removals range from poor to excellent. This drop in performance compared to operation of the UV/O3 unit in the batch mode was, however, caused by the overpressurization of the RO membranes which effectively destroyed the Torays. From that time onward, the combined permeate was increasingly rich in organics and inorganics. That this was the reason can be seen from Table XV which gives the mean results for the first two runs using this combination and which took place before the deterioration of the permeate.These results are excellent and are virtually identical to those in the batch mode. The U.S.EPA criteria were once more met.

RO - UV/O3 - Concentrate

During these 2 tests, the UV/O3 unit was run in the batch mode. At 343,002.9 ppb mean total organics, these were the most concentrated solutions fed to the UV/O3 unit. Inspite of those high levels, there was in excess of 95% destruction of 14 out of 22 compounds during the same 2 hour period used for most leachate and permeate batch runs. It appears likely that 1.5 to 2.0 times as much additional processing would have resulted in an effluent which met the standards for indirect discharge. This can be seen in Figure VI which also demonstrates that the UV/O3 reaction rate with the organics is second order in concentration. THere was also no degradation in the performance of the UV/O3 unit due to the concentrated metals present. Optimization of this combination of technologies, which time did not allow, would probably result in improved total destructions which met discharge criteria.

UV/O3 (Flow through) - RO

Only one run was attempted using this sequence of technologies. Excellent total removals were obtained for 13 of 24 compounds but the discharge criteria were not met for many.

This could have been improved with slower flow through rates but this combination does not appear to be as effective as the reverse order.

PH Adjustment with Microfiltration

The precipitate formed at the various pH's was as follows:

(a) pH 9 - 1.276 g/l
(b) pH10 - 3.241 g/l
(c) pH11 - 4.963 g/l
(d) pH12 - 4.455 g/l

A comparison of these results with those in Table XIV reveals that the precipitate was not all metal hydroxides. The leachate is, however, known to contain at least 800 ppm of calcium. This is probably in the form of CaO and $CaCO_3$. The variance of $CaCO_3$ solubility with NaOH concentration is not known but the solubility of $Ca(OH)_2$ in aqueous NaOH drops rapidly with increasing NaOH concentration. The dark brown precipitate was, therefore, probably a mixture of hydrated metal hydroxides and calcium compounds.

The objective of pH adjustment was to remove the metals so that they would not interfere with the operation of the RO or UV/O_3 units. Table XIV data show that pH 10 was the optimum pH for that purpose.

Conclusions

Although this trial took place over a 6 week period, the actual RO operation amounted to approximately 70 hours. The UV/O_3 unit operation amounted to a similar amount. This must be taken into account when considering these conclusions.

Based on information gathered during this trial as well as that obtained in previous and subsequent work using leachate from the same site it is concluded that:

(a) the UV/O_3 unit, utilizing the RAYOX process was capable of destroying virtually all of the organic compounds in the leachate from the PAS site provided that proper system settings and adequate time were used. Under the same provisions, the unit was also capable of destroying the organics in the RO concentate to a similar level;

(b) the effluent from the UV/O_3 unit was clean enough for re-injection into the well field or for discharge to a municipal treatment facility. The standards for surface discharge are not known;

(c) the RO unit was capable of producing a permeate suitable for re-injection and a 10% to 20% by volume concentrate requiring further treatment providing that the proper membranes were used. In that regard, the Filmtec HR membrane was the best choice of those tested; the UOP 1001 and DSI membranes were not adequate for this task, on this leachate; and, the Toray membranes are adequate only if proper measures are taken to ensure that inadvertent overpressurization does not occur;

(d) the combination of RO followed by UV/O_3 of the permeate resulted in an effluent which was suitable for re-injection or discharge to amunicipal treatment facility. The standards required for surface discharge are not known. The RO concentrate must still be trated at a proper facility:

(e) the combination of RO followed by UV/O3 treatment of the concentrate resulted in a permeate suitable for re-injection and a concentrate with 87% of the organics removed. Longer run times would result in an effluent with approximately the same levels of organics as UV/O3 alone or UV/O3 treatment of RO permeate. Further specialized treatment of that effluent would not be required;

(f) the combination of UV/O3 treatment of the leachate followed by RO treatment of the effluent is not as effective as the converse; and,

(g) hydroxide precipitation of metals followed by cross-flow microfiltration should be the first step in any treatment system.

Recommendations

The various systems trialed at the PAS site result in:

(a) a small amount of effluent requiring further specialized treatment and a large volume suitable for re-injection; or,

(b) all of the treated leachate (except the metal hydroxides) suitable for re-injection or treatment at a municipal teatment facility.

At present all of the leachate requires treatment at a specialized facility. The options proposed in subsequent paragraphs should be compared to the current practice in terms of present and probable future costs before any decision to proceed further is made.

If it is desired to reinject all of the treated leachate into the PAS site or any similar site, there are 2 mobile system options to accomplish this. These are:

(a) Option I - a stand alone UV/O3 system: and,

(b) Option III - an RO system followed by UV/O3.

Both of these options will also in a treated leachate suitable for discharge to a municipal treatment facility.

If a small volume of concentrated leachate requiring specialized treatment is acceptable, then Option II, RO alone may be considered.

The details of the 3 options are given in subsequent pages. All must be preceeded by pH adjustment and microfiltration.

The approximate costs of the 3 options as mobile skid mounted systems are as follows:

(a) Option I - $160,000. U.S.

(b) Option II - $90,000. U.S.and,

(c) Option III - $165,000. U.S.

All systems are manual or partially automated and require operator support. The cost of the MF sub-system is included.

It is recommended that:

(a) more detailed costing be obtained and that a mobile system be built if it appears to be more cost- or environmentally effective over a reasonable period of time. Such a system, if properly scaled could be used for demonstrations and/or assistance at other sites; and,

(b) before the desired system is built, a trial on at least 25,000 gallons of PAS or similar leachate be undertaken, using available sub-systems temporarily connected, to verify the results of this trial.

OPTION I

MOBILE MF - UV/O3 SYSTEM

Capacity 1600-2000 gal/day (8 hour day)

System Components

A. System Feed Pump
   -3.5 gal/min chemical resistant pump

B. Alkali Injection Sub-system
   1. 55 gal polyethylene tank
   2. Alkali injection pump
   3. In-line mixer

C. Metals Removal Sub-system
   1. 200 gal polyethylene settling tank
   2. 0.5 gal/min pump capable of moderate solids handling
   3. 2 - 5 gal bag filter housings with 0.1-2.0 bag filters
   4. Microfiltration unit with 2 Enka MD 080 TP 2L membranes or equivalent

D. UV/O3 Sub-system
   -UV/O3 unit using RAYOX or similar process, capable of 200-250 gal/hour destruction of 10-100 ppm organics

OPTION II

MOBILE MF - RO SYSTEM

Capacity 1600-2000 gal/day (8 hour day)

System Components

A. System Feed Pump
   -3.5 gal/min chemical resistant pump

B. Alkali Injection Sub-system
   1. 55 gal polyethylene tank
   2. Alkali injection pump
   3. In-line mixer

C. Metals Removal Sub-system
   1. 200 gal polyethylene settling tank
   2. 0.5 gal/min pump capable of moderate solids handling
   3. 2 - 5 gal bag filter housings with 0.1-2.0 bag filters
   4. Microfiltration unit with 2 Enka MD 080 TP 2L membranes or equivalent

D. Calcium Removal Sub-system
   1. 55 gal polyethylene tank
   2. Acid injection pump
   3. In-line mixer
   4. 200 gal polyethylene feed tank

E. RO Sub-system
   -RO unit containing 8 to 10 Filmtec HR membranes and capable of operating at 5:1 to 10:1 concentration ratio

OPTION III

MOBILE MF - RO - UV/O3 SYSTEM

Capacity 1600-2000 gal/day (8 hour day)

System Components

A. System Feed Pump
   -3.5 gal/min chemical resistant pump

B. Alkali Injection Sub-system
   1. 55 gal polyethylene tank
   2. Alkali injection pump
   3. In-line mixer

C. Metals Removal Sub-system
   1. 200 gal polyethylene settling tank
   2. 0.5 gal/min pump capable of moderate solids handling
   3. 2 - 5 gal bag filter housings with 0.1-2.0 bag filters
   4. Microfiltration unit with 2 Enka MD 080 TP 2L membranes or equivalent

D. Calcium Removal Sub-system
   1. 55 gal polyethylene tank
   2. Acid injection pump
   3. In-line mixer
   4. 200 gal polyethylene feed tank

E. RO Sub-system
   -RO unit containing 8 to 10 Filmtec HR membranes and capable of operating at 5:1 to 10:1 concentration ratio

F. UV/O3 Sub-system
   - UV/O3 unit using RAYOX or similar process, capable of 20-50 gal/hour destruction of 50-500 ppm organics

TABLE I

OSWEGO RO RESULTS - ORGANICS (CONCENTRATIONS)

COMPOUND	FEED	UOP	DSI	TORAY	FILMTEC	CONCENTRATE
DICHLOROMETHANE	26666.7	8677.3	4749.6	11306.9	14828.7	22443.6
ACETONE	26813.1	11567.6	15987.6	19361.5	5841.8	54438.6
1,1-DICHLOROETHANE	1103.6	284.8	278.3	494.6	84.0	3517.3
1,1-DICHLOROETHENE	1099.0	1289.9	277.1	2378.8	237.7	10922.1
1,2-DICHLOROETHANE	2214.0	886.4	867.9	1109.6	348.1	6077.4
t-1,2-DICHLOROETHENE	22082.2	16339.7	14435.5	10102.7	7937.1	30626.4
1,1,1-TRICHLOROETHANE	819.9	147.8	120.2	243.6	36.2	2412.5
TRICHLOROETHENE	266.2	112.0	85.2	181.2	74.2	267.4
BENZENE	921.1	379.7	401.1	397.3	66.8	2543.1
BROMODICHLOROMETHANE	677.5	151.8	129.9	202.7	60.9	2682.1
METHYL ISOBUTYL KETONE	151.2	25.3	20.8	33.1	15.2	462.5
BROMOFORM	31031.9	1346.1	528.7	3871.5	111.0	114708.3
TETRACHLOROETHANE/ENE	332.4	64.5	176.3	268.5	78.8	1216.8
TOLUENE	7934.6	2550.6	1457.5	3225.7	424.2	15083.8
CHLOROBENZENE	1393.1	582.2	369.8	564.8	116.6	2009.5
ETHYLBENZENE	5745.4	1303.2	702.5	2001.1	173.7	7810.6
m,p-XYLENE	8615.1	1548.2	862.5	2985.5	221.1	12890[illegible]
o-XYLENE	13352.7	2391.4	1702.5	5339.5	299.7	57672.
PHENOL	1911.0	327.0	534.0	1038.0	122.0	5906.0
DICHLOROBENZENE	100.0	24.0	13.0	56.0	3.0	
2-METHYLPHENOL	937.0	143.0	149.0	357.0	14.0	3185.0
4-METHYLPHENOL	3115.0	292.0	717.0	2085.0	71.6	10736.0
2,4-DIMETHYLPHENOL	992.0	158.0	175.0	661.0	16.0	3286.0
BENZOIC ACID	10920.0	690.0	399.0	2823.0	48.3	21574.0
BIS(2-ETHYLHEXYL)PHTHALATE	80.0	17.0	8.0	38.0	8.0	

TABLE 11

OSWEGO RO RESULTS - ORGANIC COMPOUND % REJECTIONS

	UOP	DSI	TORAY	FILMTEC
DICHLOROMETHANE	67.5	82.2	57.6	44.4
ACETONE	56.9	40.4	27.8	78.2
1,1-DICHLOROETHANE	74.2	74.8	55.2	92.4
1,1-DICHLOROETHENE	(-17.4)	74.5	(-116.5)	78.4
1,2-DICHLOROETHANE	60.0	60.8	50.0	84.3
t-1,2-DICHLOROETHENE	25.7	34.6	54.2	63.9
1,1,1-TRICHLOROETHANE	82.0	85.3	70.2	95.6
TRICHLOROETHENE	57.9	68.0	31.9	72.1
BENZENE	58.9	56.5	56.9	92.7
BROMODICHLOROMETHANE	77.6	80.8	70.1	91.0
METHYL ISOBUTYL KETONE	83.3	86.2	78.1	89.9
BROMOFORM	95.7	98.3	87.5	99.6
TETRACHLOROETHANE/ENE	80.6	46.7	19.2	76.2
TOLUENE	67.9	81.6	59.3	94.7
CHLOROBENZENE	58.2	73.5	59.5	91.6
ETHYLBENZENE	77.3	87.8	65.2	97.0
m,p-XYLENE	82.0	90.0	65.3	97.4
o-XYLENE	82.1	87.2	60.0	97.8
PHENOL	82.9	72.1	45.7	93.6
DICHLOROBENZENE	76.0	87.0	44.0	97.0
2-METHYLPHENOL	84.7	84.1	61.9	98.5
4-METHYLPHENOL	90.6	77.0	33.1	97.7
2,4-DIMETHYLPHENOL	84.1	82.4	33.4	98.4
BENZOIC ACID	93.7	96.3	74.2	99.6
BIS(2-ETHYLHEXYL)PHTHALATE	78.8	90.0	52.0	90.0

TABLE III

OSWEGO RO RESULTS - METALS - CONCENTRATION(PPB) & %REJECTED

COMPOUND	FEED	UOP	DSI	TORAY	FILMTEC
LEAD	23.0	24.3/(-5.7)	23.3/(-1.3)	31.7/(-37.8)	17.7/23.0
ANTIMONY	6.0	1.0/83.3	1.0/83.3	1.7/71.7	1.0/83.3
ZINC	41.8	25.8/38.3	32.1/23.3	32.2/23.0	13.6/67.5
NICKEL	1638.9	50.0/96.9	142.2/91.3	817.8/50.1	171.1/89.6
ARSENIC	41.6	2.2/94.7	7.9/81.0	26.9/35.3	1.0/97.6

TABLE IV

FLOWRATES VERSUS OVERALL RUN TIME FOR RO UNIT IN OSWEGO

	OVERALL RUNTIME	PERM#1 FLUX	PERM#2 FLUX	PERM#3 FLUX	PERM#4 FLUX	COLLECTIVE[1.] PERM FLUX	PERM#1,2+4[2.] COL. FLUX	CONCENTRATE FLUX
1	8.00	8.01	9.58	4.74	4.98	22.99	22.57	5.43
2	11.32	5.09	5.89	3.38	3.47	17.75	14.45	2.17
3	14.33	10.84	6.39	3.74	6.43	24.55	23.66	4.50
4	16.00	4.43	5.88	3.23	3.16	15.95	13.47	
5	17.92	2.46	4.41	2.52	1.76	10.80	8.63	1.32
6	19.33	1.72	3.31	2.19	1.50	8.92	6.53	
7	22.83	2.74	4.00	2.61	1.86	10.17	8.60	0.38
8	25.33	4.10	4.24	3.88	3.21	14.50	11.55	1.80
9	27.00	3.72	4.73	4.67	3.73	13.80	12.18	1.60
10	31.25	3.85	4.11	4.15	3.32	14.00	11.28	1.80
11	35.42	2.47	2.49	3.21	2.50	9.00	7.46	1.00
12	37.33	2.42	2.64	3.96	2.74		7.80	
13	39.75	3.17	3.41	5.64	3.85	15.00	10.43	1.50
14	41.42	4.54	3.04	4.73	4.18	7.51	11.76	1.60
15	45.25	3.66	3.57	5.12	3.35	15.00	10.58	2.00
16	49.50	3.90	4.27	8.97	3.67	20.00	11.84	1.90
17	51.50	3.48	4.31	10.71	3.64	21.00	11.43	2.10
18	53.50	2.78	3.87	9.42	3.49		10.14	
19	55.50	3.55	3.88	10.53	4.06	22.00	11.49	2.10
20	57.50	3.07	3.03	9.86	3.89	19.00	9.99	1.90
21	60.50	2.99	4.10	9.82	3.81	20.00	10.90	3.30
22	63.17	3.88	4.05	9.94	4.28	22.00	12.21	3.50
23	65.33	2.86	4.24	8.34	3.57	18.80	10.69	2.80
24	67.75	2.49	3.71	7.84	3.47	16.00	9.67	2.00

1. The actual collective stream was measured, therefore only approximately equal to the sum of perm#1, perm#2, perm#3 and perm#4.

2. The numerical sum of perm#1, perm#2 and perm#4.

TABLE V

FLOWRATES VERSUS OVERALL RUN TIME FOR RO UNIT IN OSWEGO

OVERALL RUNTIME (hr)	PERM#1 FLUX (L/min)	PERM#2 FLUX (L/min)	PERM#3 FLUX (L/min)	PERM#4 FLUX (L/min)
8.00	8.01	9.58	4.74	4.98
11.92	5.09	5.89	3.38	3.47
14.33	10.84	6.39	3.74	6.43
16.00	4.43	5.88	3.23	3.16
17.92	2.46	4.41	2.52	1.76
19.33	1.72	3.31	2.19	1.50
22.83	2.74	4.00	2.61	1.86
25.33	4.10	4.24	3.88	3.21
27.00	3.72	4.73	4.67	3.73
31.25	3.85	4.11	4.15	3.32
35.42	2.47	2.49	3.21	2.50
37.33	2.42	2.64	3.96	2.74
39.75	3.17	3.41	5.64	3.85
41.42	4.54	3.04	4.73	4.18
45.25	3.66	3.57	5.12	3.35
49.50	3.90	4.27	8.97	3.67
51.50	3.48	4.31	10.71	3.64
53.50	2.78	3.87	9.42	3.49
55.50	3.55	3.88	10.53	4.06
57.50	3.07	3.03	9.86	3.89
60.50	2.99	4.10	9.82	3.81
63.17	3.88	4.05	9.94	4.28
65.33	2.88	4.24	8.34	3.57
67.75	2.49	3.71	7.84	3.47

TABLE VI

UV PHOTOLYSIS/OZONATION OF LEACHATE - MEAN RESULTS

COMPOUND	FEED	UV EFFLUENT	%DESTROYED
DICHLOROMETHANE	4360.2	418.5	90.4
1,1-DICHLOROETHANE	495.0	60.8	87.7
1,1-DICHLOROETHENE	286.0	53.9	81.2
1,2-DICHLOROETHANE	1138.6	350.8	69.2
t-1,2-DICHLOROETHENE	4920.4	96.9	98.0
1,1,1-TRICHLOROETHANE	304.1	37.1	87.8
TRICHLOROETHENE	113.7	21.6	81.0
BENZENE	547.8	16.9	96.9
BROMODICHLOROMETHANE	155.8	14.1	90.9
METHYL ISOBUTYL KETONE	54.7	4.5	91.8
BROMOFORM	8004.0	56.5	99.3
TETRACHLOROETHANE/ENE	314.0	13.8	95.6
TOLUENE	3496.3	21.2	99.4
CHLOROBENZENE	659.7	10.4	98.4
ETHYLBENZENE	3086.7	1.1	100.0
m,p-XYLENE	4941.2	1.0	100.0
o-XYLENE	6905.4	2.1	100.0

TABLE VII

OSWEGO RESULTS - RO(CONC) - UV(BATCH) - MEAN CONCENTRATIONS

	RO FEED	RO CONC	UV 15 MIN	UV 30 MIN	UV 60 MIN	UV 120 MIN	UV 1UV 180 MIN
DICHLOROMETHANE	74893.8	7613.8	26782.3	21503.0	8072.2	1733.6	7204.2
ACETONE	30693.8	34355.4	86924.9	98264.9	46880.4	48905.1	—
1,1-DICHLOROETHANE	1093.8	2970.0	1795.6	1795.6	1469.4	813.2	924.6
1,1-DICHLOROETHENE	1192.1	103.9	2639.7	2861.8	624.8	387.1	601.5
1,2-DICHLOROETHANE	2070.6	4835.9	4241.7	4293.4	4032.7	2774.3	2934.7
t-1,2-DICHLOROETHENE	37840.7	24861.8	11520.1	5073.7	739.3	552.8	758.9
1,1,1-TRICHLOROETHANE	1044.4	1615.6	1040.6	997.9	278.8	168.8	1.0
TRICHLOROETHENE	284.8	72.6	1.0	1.0	77.6	81.6	1.0
BENZENE	920.9	2542.4	963.8	434.6	171.5	117.5	92.9
BROMODICHLOROMETHANE	597.5	875.0	580.2	469.2	497.3	527.4	766.8
METHYL ISOBUTYL KETONE	96.3	151.2	171.0	232.7	143.1	134.8	176.7
BROMOFORM	1312.5	166971	38837.7	1573.9	1076.4	1762.6	2484.1
TETRACHLOROEHTANE/(ENE)	443.1	303.7	564.4	827.6	385.4	241.2	460.6
TOLUENE	6845.9	12729.8	5581.8	1425.0	1136.0	895.9	386.4
CHLOROBENZENE	1058.1	1682.8	965.7	450.5	117.9	59.6	1.0
ETHYLBENZENE	5064.9	7480.6	3204.1	616.0	49.7	22.1	6.9
m,p-XYLENE	7087.9	11192.6	4543.7	644.4	16.6	2.5	1.0
o-XYLENE	11562.1	19960.8	8680.0	5666.1	131.5	1.0	1.0
PHENOL	789.5	7926.0	24864.0	13895.0	4740.0	0.0	28.0
2-METHYLPHENOL	406.5	4115.0	549:0	1436.0	360.0	50.0	1:0
4-METHYLPHENOL	504.0	12417.0	538.0	11044.0	322.0	64.0	11.0
2,4-DIMETHYLPHENOL	438.0	3184.0	2693.0	998.0	146.0	0.0	0.0
BENZOIC ACID	5212.0	15042.0	67585.0	12833.0	40076.0	11513.0	27860.5

TABLE VIII

OSWEGO RESULTS - RO(CONC) - UV(BATCH) - % CONCENTRATED AND % REMOVAL

	% RO CONCENTRATED	% UV REMOVAL
DICHLOROMETHANE	—	5.4
ACETONE	11.9	--
1,1-DICHLOROETHANE	171.5	68.9
1,1-DICHLOROETHENE	—	--
1,2-DICHLOROETHANE	1133.6	39.3
t-1,2-DICHLOROETHENE	--	96.9
1,1,1-TRICHLOROETHANE	54.7	99.9
TRICHLOROETHENE	--	98.6
BENZENE	176.1	96.3
BROMODICHLOROMETHANE	48.9	12.4
METHYL ISOBUTYL KETONE	57.1	--
BROMOFORM	12621.6	98.5
TETRACHLOROEHTANE/(ENE)	—	--
TOLUENE	85.9	97.0
CHLOROBENZENE	59.0	99.9
ETHYLBENZENE	47.9	99.9
m,p-XYLENE	57.9	100.0
o-XYLENE	72.6	100.0
PHENOL	903.9	99.6
2-METHYLPHENOL	912.3	100.0
4-METHYLPHENOL	2363.7	99.9
2,4-DIMETHYLPHENOL	626.9	100.0
BENZOIC ACID	188.6	--

TABLEIX

OSWEGO RESULTS - RO(PERM) - UV(BATCH) MEAN CONCENTRATIONS

COMPOUND	RO FEED	RO PERM	UV 15 MIN	UV 30 MIN	UV 60 MIN	UV 120 MIN
DICHLOROMETHANE	11233.9	28369.1	12333.5	6481.5	2103.4	142.7
ACETONE	13383.9	7197.9	6165.9	6293.0	5597.5	3097.5
1,1-DICHLOROETHANE	993.7	377.7	234.4	125.5	40.8	2.7
1,1-DICHLOROETHENE	1331.4	170.8	93.4	143.7	107.2	35.2
1,2-DICHLOROETHANE	1769.3	548.7	309.4	164.5	52.3	5.5
t-1,2-DICHLOROETHENE	8411.7	4311.0	1164.4	390.0	41.1	3.7
1,1,1-TRICHLOROETHANE	534.2	30.4	24.5	7.8	1.5	1.3
TRICHLOROETHENE	447.5	80.0	31.5	13.0	1.7	1.0
BENZENE	780.0	182.6	44.7	13.6	1.9	0.8
BROMODICHLOROMETHANE	865.6	52.5	32.7	9.3	1.0	1.0
METHYL ISOBUTYL KETONE	193.4	10.9	7.1	1.0	1.0	1.0
BROMOFORM	3998.6	76.4	22.8	27.9	47.1	2.5
TETRACHLOROEHTANE/(ENE)	191.6	44.7	38.9	7.7	2.4	2.8
TOLUENE	5337.2	3768.8	1049.1	244.4	34.3	2.4
CHLOROBENZENE	888.1	180.0	55.0	14.4	2.1	1.0
ETHYLBENZENE	3759.7	384.3	86.1	24.0	2.3	0.6
m,p-XYLENE	5900.9	548.5	156.0	46.9	3.3	0.7
o-XYLENE	10068.9	866.6	194.3	55.7	5.2	1.0
PHENOL	334.0	271.5	94.5	3.5	0.5	0.5
2-METHYLPHENOL	0.0	2.5	24.0	1.0	0.0	0.0
4-METHYLPHENOL	1572.5	158.0	65.5	3.0	0.0	0.0
2,4-DIMETHYLPHENOL	974.5	60.0	6.5	0.0	0.0	0.0
BENZOIC ACID	30.0	307.0	42.5	10.0	11.5	0.0

TABLE X

OSWEGO RESULTS - RO(PERM) - UV(BATCH) PERCENT REMOVALS

	% RO REMOVAL	% UV REMOVAL	% TOTAL REMOVAL
DICHLOROMETHANE	--	99.5	98.7
ACETONE	46.2	57.0	76.9
1,1-DICHLOROETHANE	62.0	99.3	99.7
1,1-DICHLOROETHENE	87.2	79.4	97.4
1,2-DICHLOROETHANE	69.0	99.0	99.7
t-1,2-DICHLOROETHENE	48.7	99.9	100.0
1,1,1-TRICHLOROETHANE	94.3	95.7	99.8
TRICHLOROETHENE	82.1	98.8	99.8
BENZENE	76.6	99.6	99.9
BROMODICHLOROMETHANE	93.9	98.1	99.9
METHYL ISOBUTYL KETONE	94.4	90.8	99.5
BROMOFORM	98.0	96.7	99.9
TETRACHLOROEHTANE/(ENE)	76.7	93.7	98.5
TOLUENE	29.4	99.9	100.0
CHLOROBENZENE	79.7	99.4	99.8
ETHYLBENZENE	89.8	99.8	100.0
m,p-XYLENE	90.7	99.9	100.0
o-XYLENE	91.4	99.9	100.0
PHENOL	18.7	99.8	99.9
2-METHYLPHENOL	--	100.0	100.0
4-METHYLPHENOL	90.0	100.0	100.0
2,4-DIMETHYLPHENOL	93.8	100.0	100.0
BENZOIC ACID	--	100.0	100.0

TABLE XI

OSWEGO RESULTS - RO-UV/O3(FLOW THROUGH)

COMPOUND	RO FEED	UV FEED	UV PRODUCT	%RO REJECTION	%UV DESTRUCTION	% REMOVAL
DICHLOROMETHANE	18662.8	3736.8	822.2	80.0	78.0	95.6
ACETONE	32901.9	10017.5	9407.8	69.6	6.1	71.4
1,1-DICHLOROETHANE	1576.1	1702.2	214.0	-8.0	87.4	86.4
1,1-DICHLOROETHENE	578.5	257.0	1.4	55.6	99.5	99.8
1,2-DICHLOROETHANE	3163.9	1277.7	907.2	59.6	29.0	71.3
t1,2-DICHLOROETHENE	34699.1	17392.3	1096.9	49.9	93.7	96.8
1,1,1-TRICHLOROETHANE	1240.0	430.6	182.9	65.3	57.5	85.3
TRICLOROETHENE	229.2	90.7	55.3	60.4	39.0	75.9
BENZENE	1308.6	1105.5	167.6	15.5	84.8	87.2
BROMODICHLOROMETHANE	731.7	280.1	248.8	61.7	11.2	66.0
METHYL ISO-BUTYL KETONE	259.9	48.4	35.3	81.4	27.1	86.4
BROMOFORM	26116.9	14220.6	6608.5	45.6	53.5	74.7
TETRACHLOROETHANE/ TETRACHLOROETHENE	429.5	277.0	193.6	35.5	30.1	54.9
TOLUENE	13835.3	4856.7	215.7	64.9	95.6	98.4
CHLOROBENZENE	2292.9	797.5	80.0	65.2	90.0	96.5
ETHYLBENZENE	9913.7	3054.2	96.6	69.2	96.8	99.0
m,pXYLENE	14345.8	4001.8	76.2	72.1	98.1	99.5
oXYLENE	24788.5	7078.9	209.9	71.4	97.0	99.2
PHENOL	1987.3	772.8	42.8	61.1	94.5	97.8
4-METHYL PHENOL	4083.9	1378.8	44.3	66.2	96.8	98.9
2,4-DIMETHYL PHENOL	1304.6	710.0	9.0	45.6	98.7	99.3
BENZOIC ACID	794.9	2306.7	463.8	-190.2	79.9	41.7

TABLE XII

OSWEGO RESULTS UV(FLOWTHROUGH) - RO(PERMEATE) - MEAN CONCENTRATIONS

	UV FEED	UV PROD	RO PERM
DICHLOROMETHANE	16765.6	1670.9	1445.7
ACETONE	27268.1	9531.4	2036.3
1.1-DICHLOROETHANE	806.1	178.2	45.0
1.1-DICHLOROETHENE	746.5	124.9	30.0
1.2-DICHLOROETHANE	2289.8	1018.5	496.5
t-1.2-DICHLOROETHENE	10514.8	318.8	1017.1
1.1.1-TRICHLOROETHANE	552.7	122.9	25.1
TRICHLOROETHENE	401.6	60.9	52.0
BENZENE	914.6	60.0	52.9
BROMODICHLOROMETHANE	623.2	56.5	0.0
1.2-DICHLOROPROPANE	74.3	18.6	0.0
METHYL ISOBUTYL KETONE	113.6	13.7	8.6
BROMOFORM	32016.1	226.1	0.0
TETRACHLOROEHTANE/(ENE)	475.5	45.2	27.7
TOLUENE	3508.3	75.5	277.9
CHLOROBENZENE	768.2	41.1	117.5
ETHYLBENZENE	2832.0	171.8	0.0
m,p-XYLENE	4566.5	--	226.2
o-XYLENE	7479.2	1222.2	294.3
PHENOL	7632.0	121.0	58.0
2-METHYLPHENOL	1619.0	20.0	15.0
4-METHYLPHENOL	5027.0	67.0	49.0
2,4-DIMETHYLPHENOL	812.0	6.0	6.0
BENZOIC ACID	31526.0	46.0	0.0

TABLE XIII

OSWEGO RESULTS - UV(FLOWTHROUGH) - RO(PERMEATE) - % REMOVALS

	% UV REMOVAL	% RO REMOVAL	% TOTAL REMOVAL
DICHLOROMETHANE	90.0	13.5	91.4
ACETONE	65.0	78.6	92.5
1.1-DICHLOROETHANE	77.9	74.7	94.4
1.1-DICHLOROETHENE	83.3	76.0	96.0
1.2-DICHLOROETHANE	55.5	51.3	78.3
t-1.2-DICHLOROETHENE	97.0	--	90.3
1.1.1-TRICHLOROETHANE	77.8	79.6	95.5
TRICHLOROETHENE	84.8	14.6	87.1
BENZENE	93.4	11.8	94.2
BROMODICHLOROMETHANE	90.9	100.0	100.0
1.2-DICHLOROPROPANE	75.0	100.0	100.0
METHYL ISOBUTYL KETONE	87.9	37.2	92.4
BROMOFORM	99.3	100.0	100.0
TETRACHLOROEHTANE/(ENE)	90.5	38.7	94.2
TOLUENE	97.8	--	93.5
CHLOROBENZENE	94.6	--	84.7
ETHYLBENZENE	93.9	100.0	100.0
m,p-XYLENE	--	--	95.0
o-XYLENE	83.7	75.9	96.1
PHENOL	98.4	52.1	99.2
2-METHYLPHENOL	98.8	25.0	99.0
4-METHYLPHENOL	98.7	26.9	99.0
2,4-DIMETHYLPHENOL	99.3	0.0	99.3
BENZOIC ACID	99.9	100.0	100.0

TABLE XIV

MICROFILTRATION - CONCENTRATION OF METALS (PPM)

METAL	LEACHATE	pH 9 FILTRATE	pH 10 FILTRATE	pH 11 FILTRATE	Ph 12 FILTRATE
Fe	34.27	0.18	0.07	0.17	0.30
As	<0.02	<0.02	<0.02	<0.02	<0.02
Sb	0.03	0.03	<0.02	<0.02	0.02
Pb	0.11	0.22	0.29	0.29	0.44
Ni	1.30	0.97	1.04	1.04	0.98
Zn	0.11	0.10	0.02	<0.02	0.02

TABLE XV

OSWEGO RESULTS - RO-UV/O_3(FLOW THROUGH) - 1ST 2 RUNS

	RO FEED	UV FEED	UV PRODUCT	%RO REJECTION	%UV DESTRUCTION	% REMOVAL
DICHLOROMETHANE	3188.3	504.8	39.9	84.2	92.1	98.7
ACETONE	41498.9	3455.4	1656.9	91.7	52.0	96.0
1,1-DICHLOROETHANE	2180.5	257.7	5.8	88.2	97.7	99.7
1,1-DICHLOROETHENE	854.5	60.1	4.3	93.0	92.8	99.5
1,2-DICHLOROETHANE	4359.4	704.6	74.5	83.8	89.4	98.3
t1,2-DICHLOROETHENE	22969.5	5426.6	12.2	76.4	99.8	99.9
1,1,1-TRICHLOROETHANE	1082.7	62.6	7.9	94.2	87.4	99.3
TRICLOROETHENE	218.9	31.9	0.4	85.4	98.7	99.8
BENZENE	1730.5	1491.4	9.4	13.8	99.4	99.5
BROMODICHLOROMETHANE	699.1	22.0	0.0	96.9	100.0	100.0
METHYL ISO-BUTYL KETONE	66.4	8.9	0.0	86.6	100.0	100.0
BROMOFORM	17827.7	19.7	0.0	99.9	100.0	100.0
TETRACHLOROETHANE/ TETRACHLOROETHENE	405.8	102.0	0.9	74.9	99.1	99.8
TOLUENE	17731.0	2164.1	12.8	87.8	99.4	99.9
CHLOROBENZENE	2943.1	434.8	0.4	85.2	99.9	100.0
ETHYLBENZENE	12793.7	954.1	0.1	92.5	100.0	100.0
m,pXYLENE	19546.0	1263.4	0.0	93.5	100.0	100.0
oXYLENE	34403.1	2211.6	0.0	93.6	100.0	100.0
PHENOL	1310.0	360.5	3.0	72.5	99.2	99.8
4-METHYL PHENOL	3407.0	457.5	0.0	86.6	100.0	100.0
2,4-DIMETHYL PHENOL	1195.0	314.0	0.0	73.7	100.0	100.0
BENZOIC ACID	0.0	0.0	7.5			

FIGURE I

ORIGINAL SET-UP

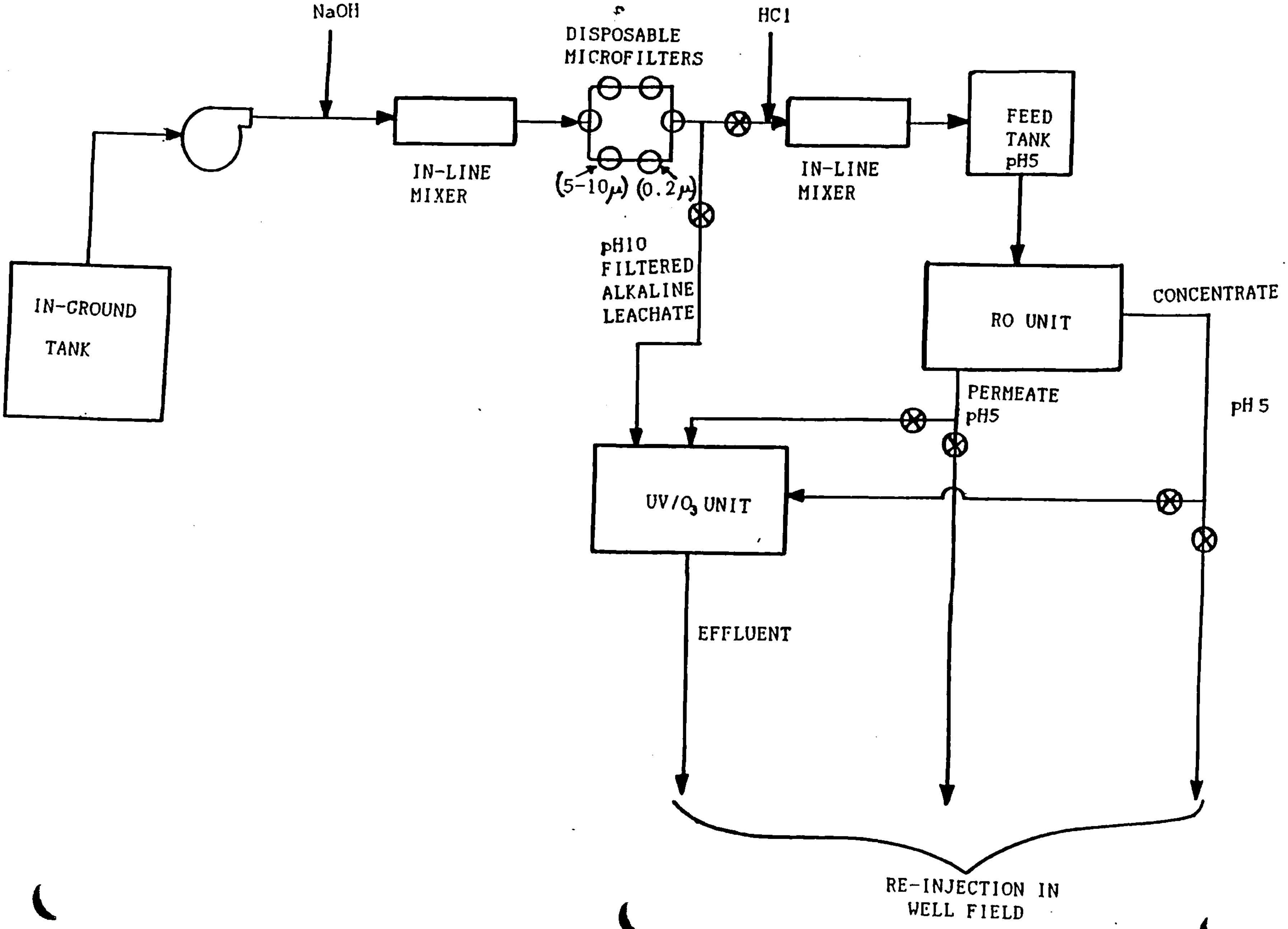


FIGURE II

MODIFIED SET-UP

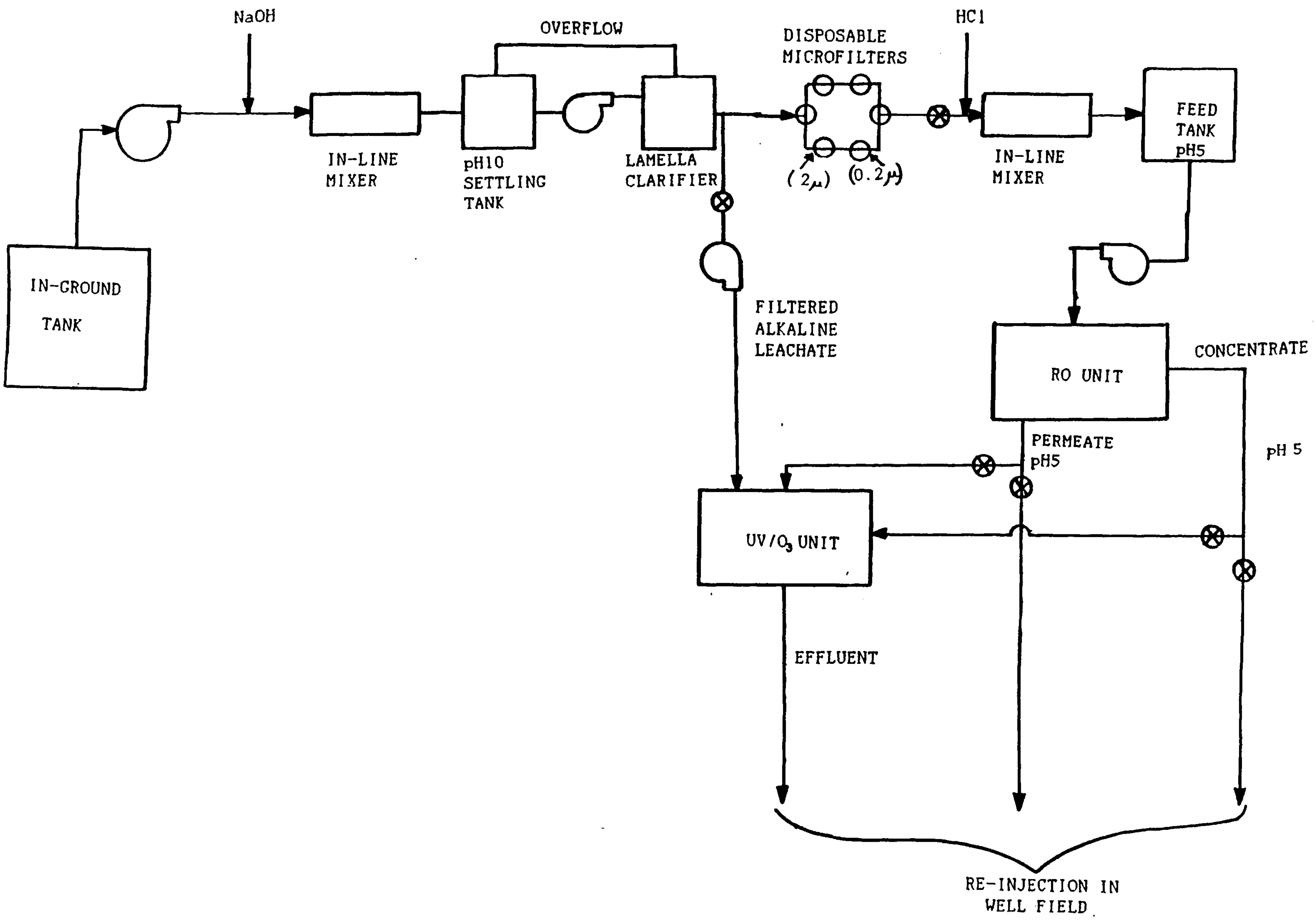


FIGURE III

FLOWRATES VERSUS OVERALL RUN TIME FOR RO UNIT IN OSWEGO

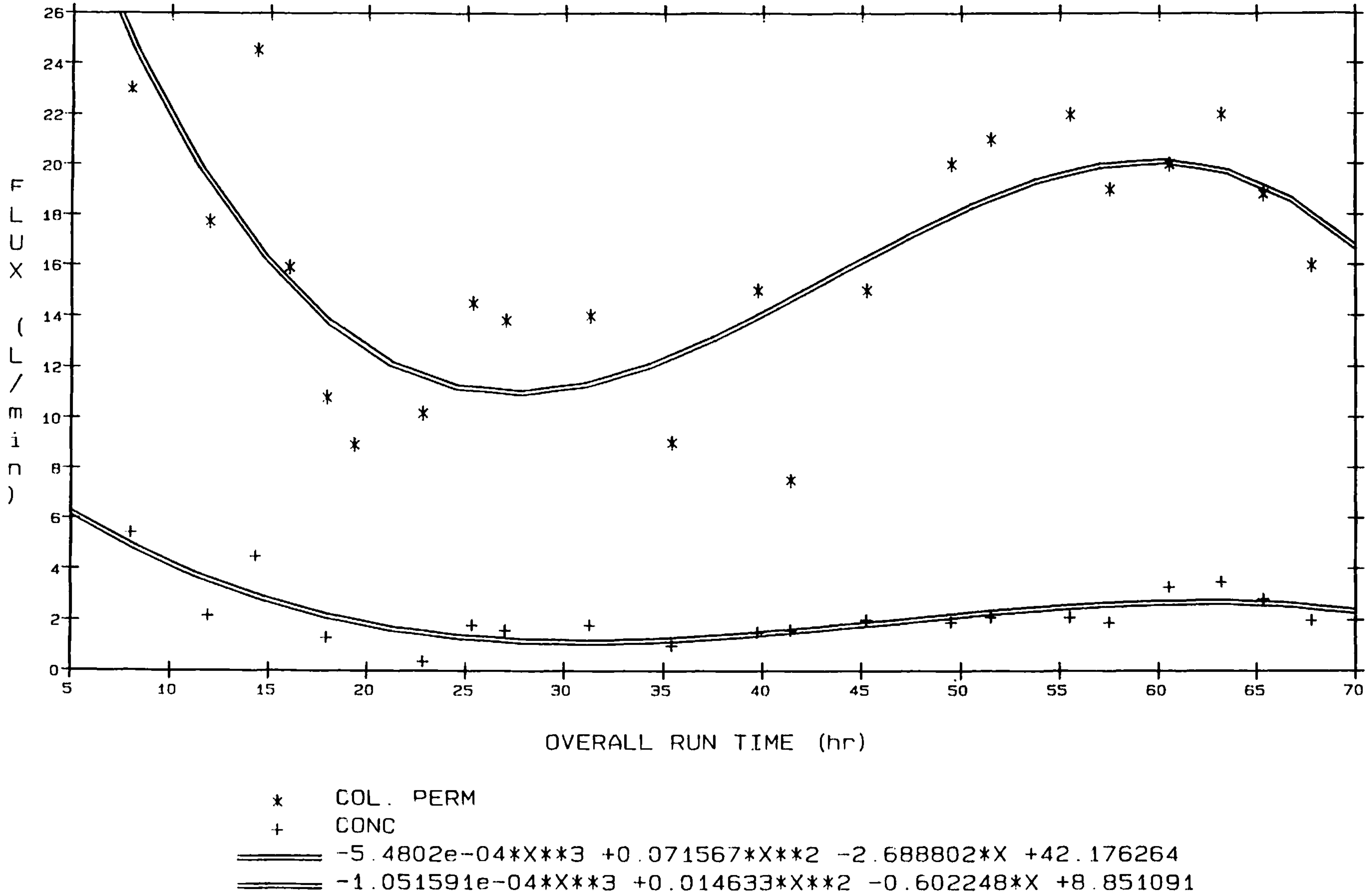


FIGURE IV

FLOWRATES VERSUS OVERALL RUN TIME FOR RO UNIT IN OSWEGO

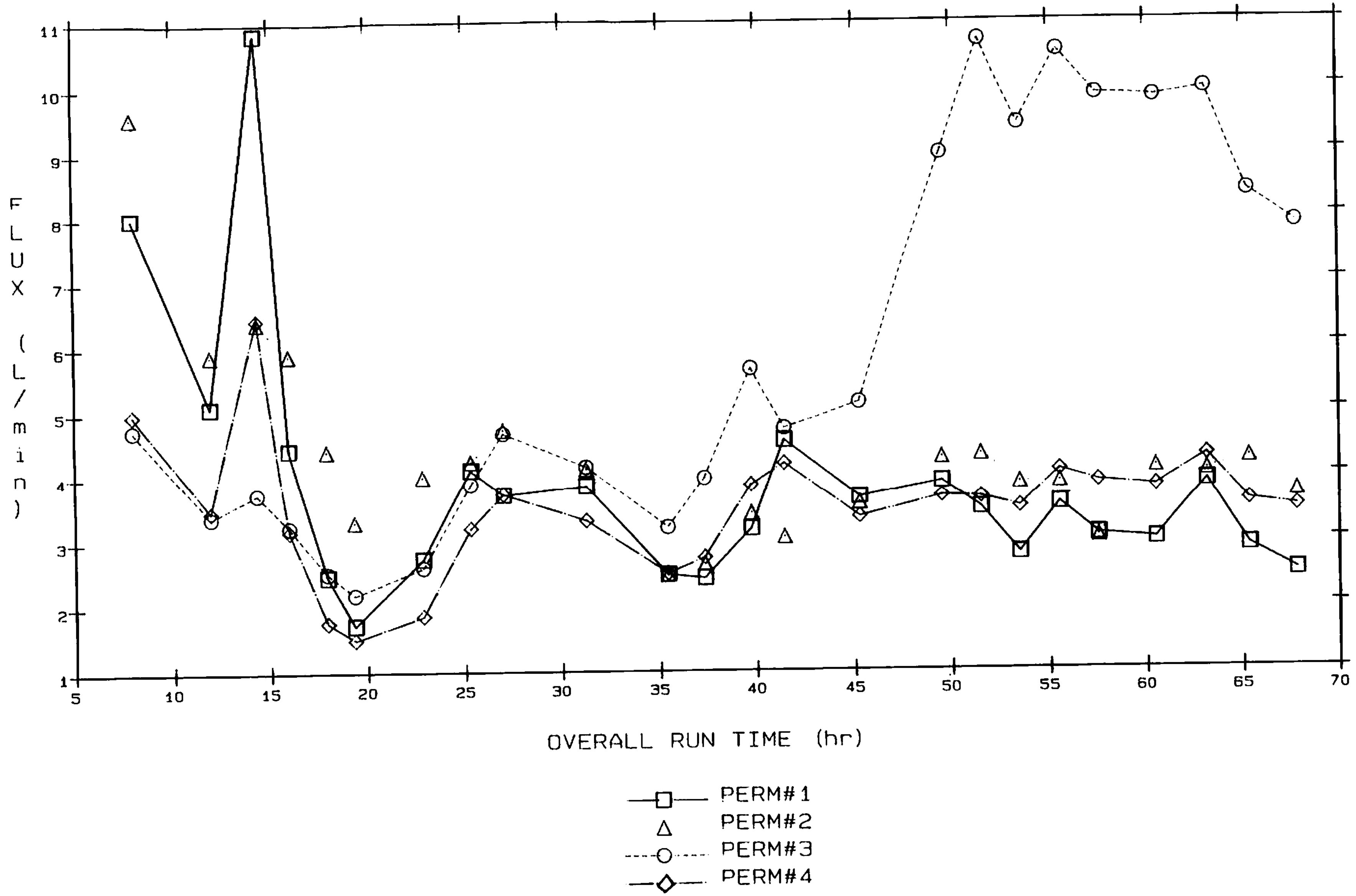
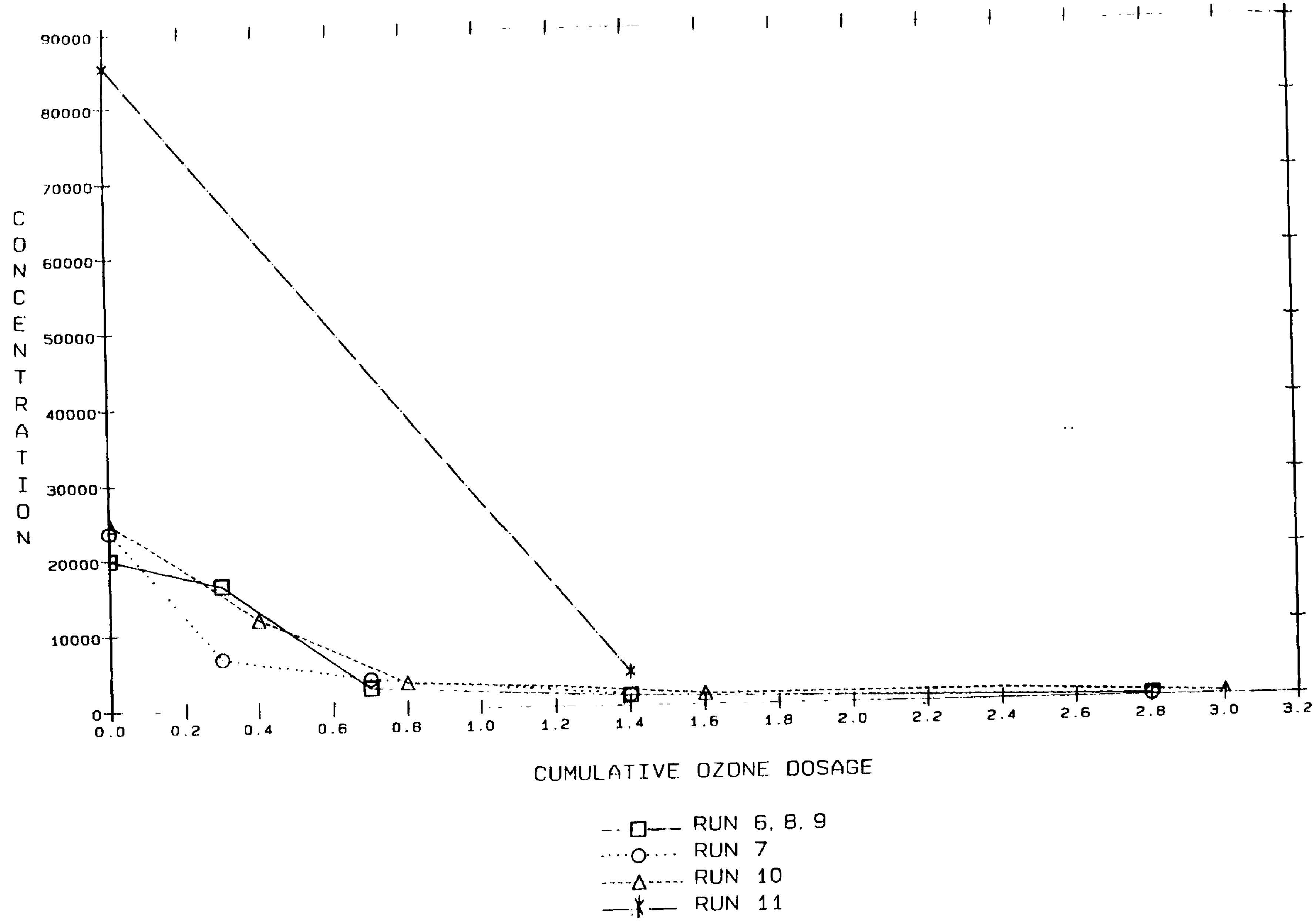


FIGURE V. UV/O_3 TREATMENT OF LEACHATE



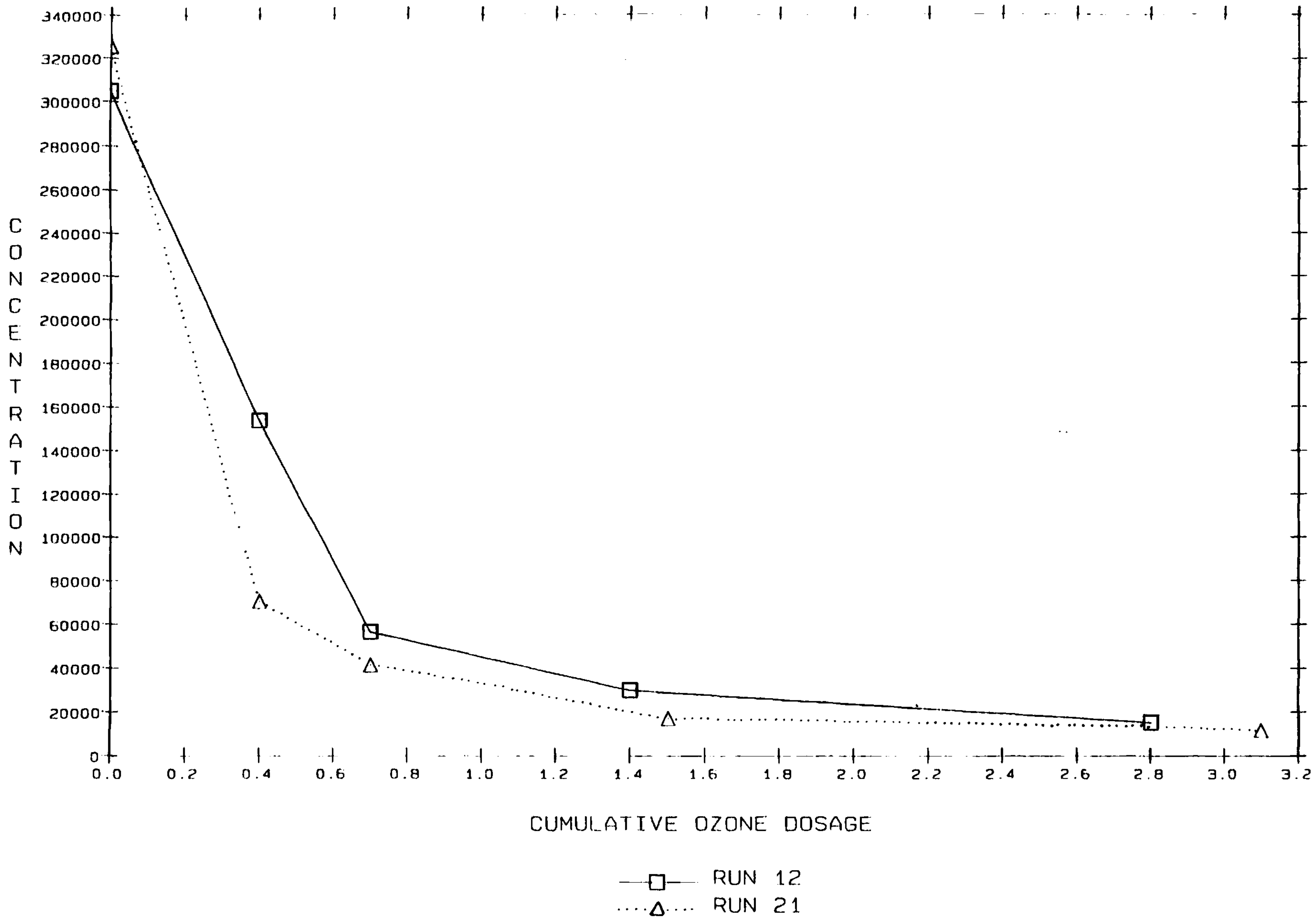


FIGURE VI: UV/O_3 TREATMENT OF CONCENTRATE

FIGURE VII: UV/O_3 TREATMENT OF PERMEATE

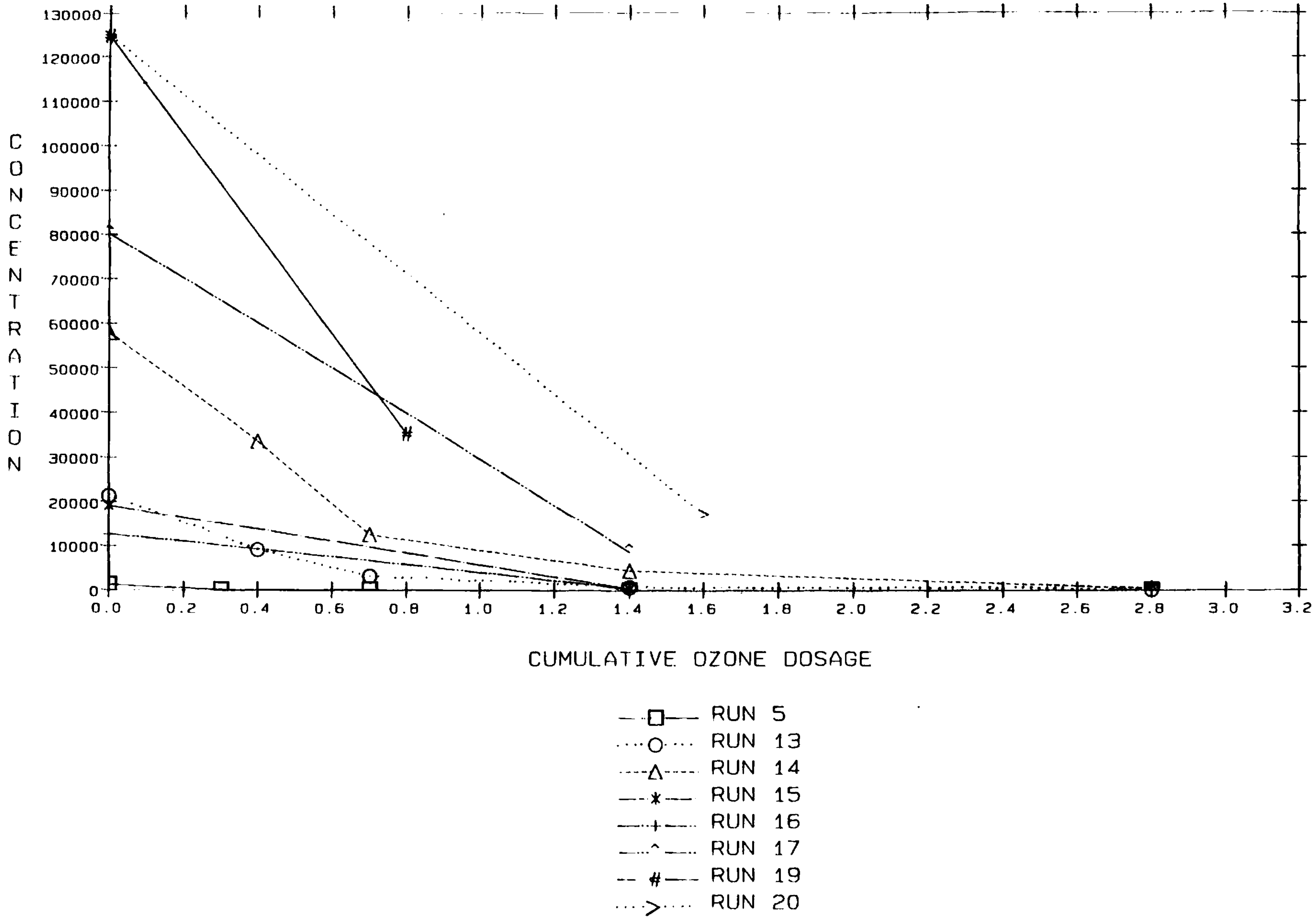


FIGURE VIII OPTION I:
MICROFILTRATION-ULTRAVIOLET PHOTOLYSIS/OZONATION

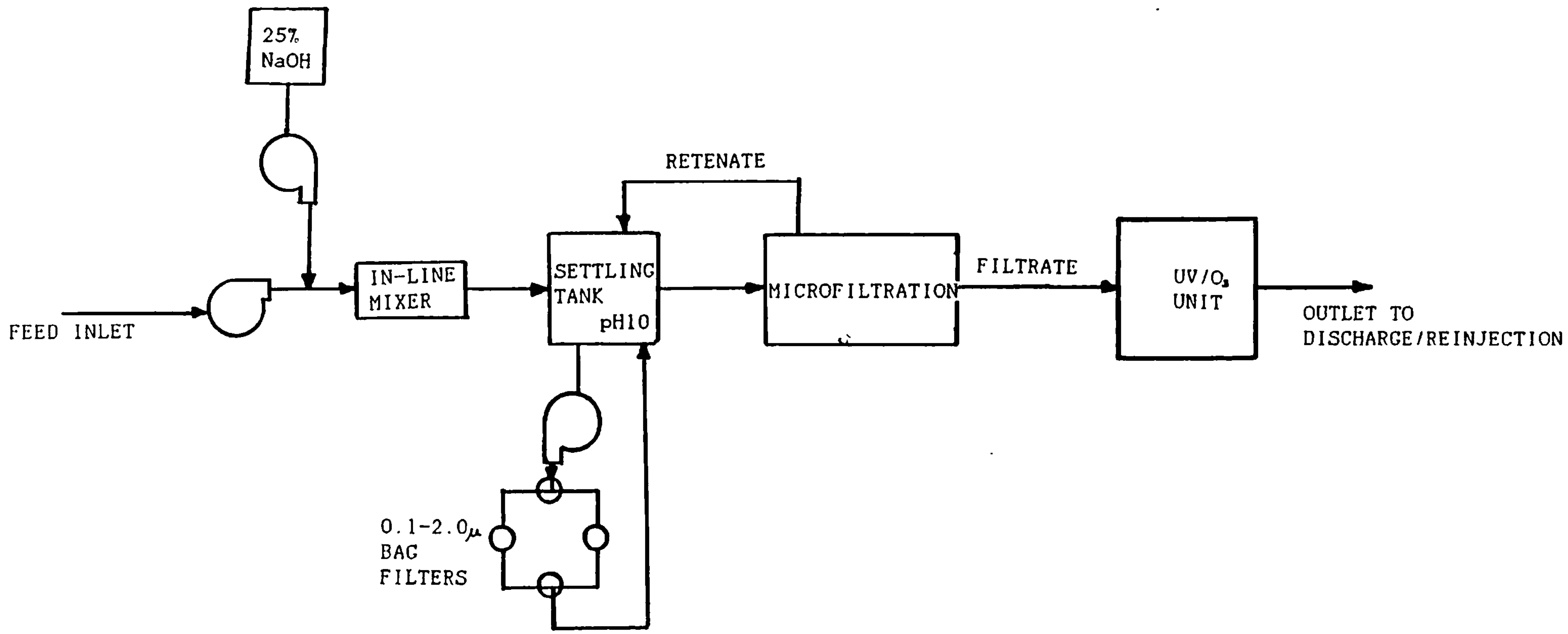


FIGURE IX OPTION II:
MICROFILTRATION-REVERSE OSMOSIS

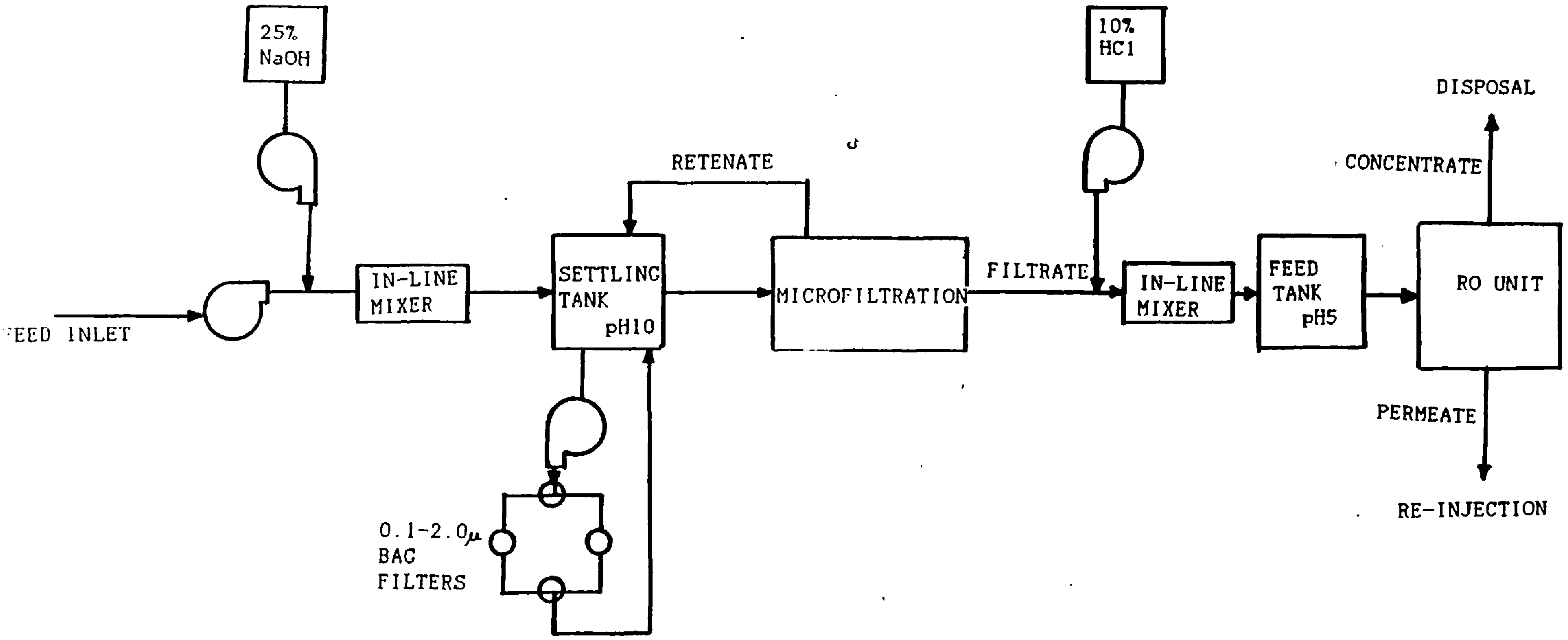
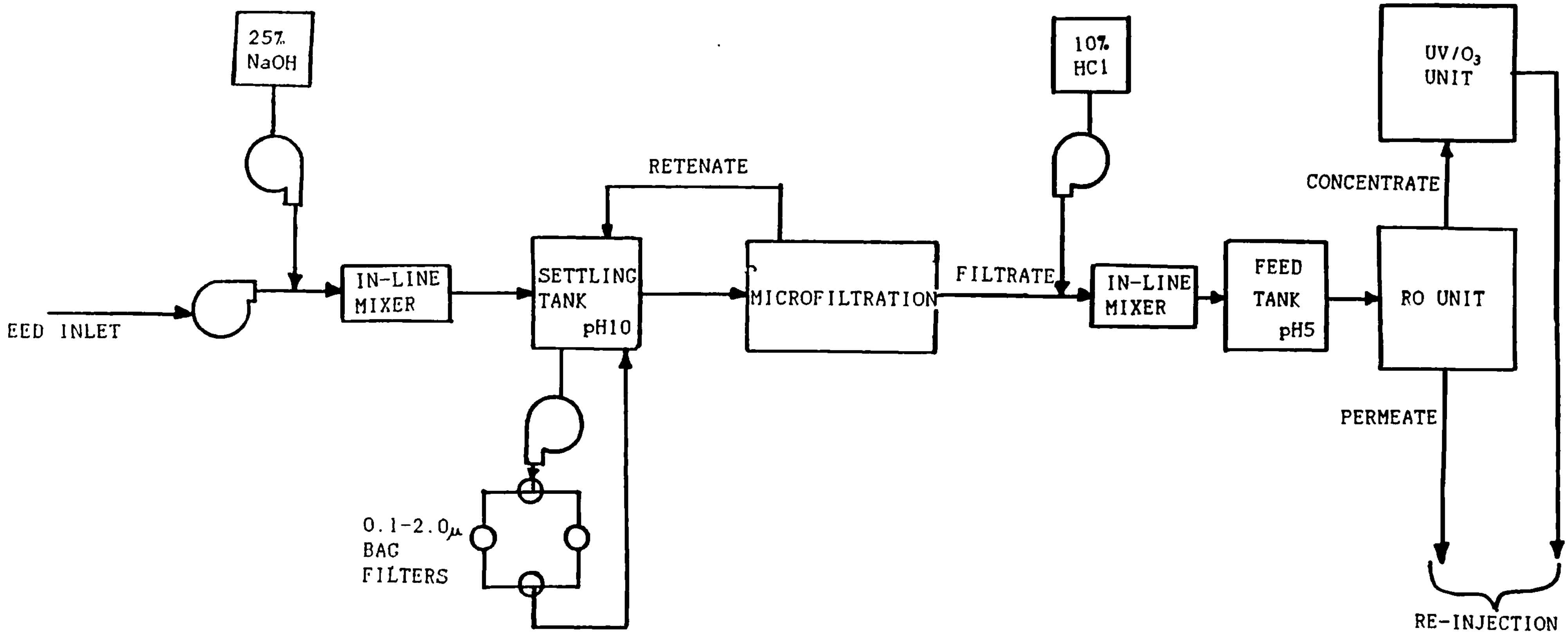


FIGURE X OPTION III:
MICROFILTRATION-REVERSE OSMOSIS-ULTRAVIOLET PHOTOLYSIS/OZONATION



APPENDIX A

OSWEGO RO RESULTS - DICHLOROMETHANE

TIME(HR)	FEED	PERM1	PERM2	PERM3	PERM4	CONCENTRATE
0.8						
8.0	128.70	169.13	0.00		88.45	
9.5						
11.5	14426.00	10405.42			4745.57	14993.68
17.5	99641.80	7888.80	25117.36	34033.30	55439.43	100270.20
22.0	19981.30	34164.60	39273.20	62228.40	79914.10	
29.0	2486.45	1306.59	2399.22	1296.51	691.28	
40.0	4469.14	1853.38	1886.51	1191.60	778.20	1576.00
45.7	1907.30	2906.70	801.49	965.21	2789.12	13366.30
57.0	50145.60	19552.50	2747.66	23210.20	1117.58	1492.20
63.5	23334.94	3415.94	1883.47	2270.54	1165.33	2963.00
70.0	50145.60	5110.30	20707.60	5259.68	1557.91	

NOTE:

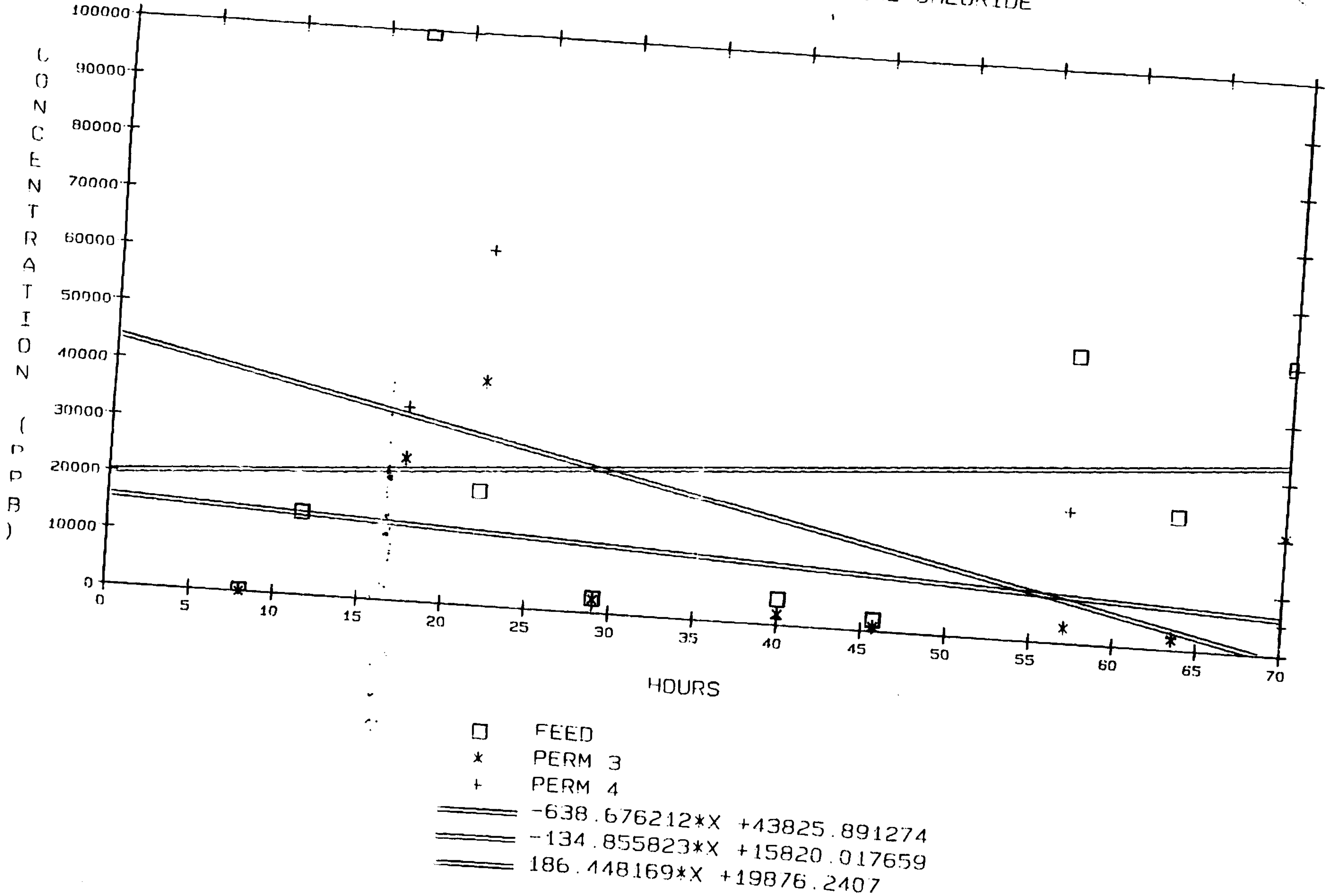
PERM 1 is UOP

PERM 2 is DSI

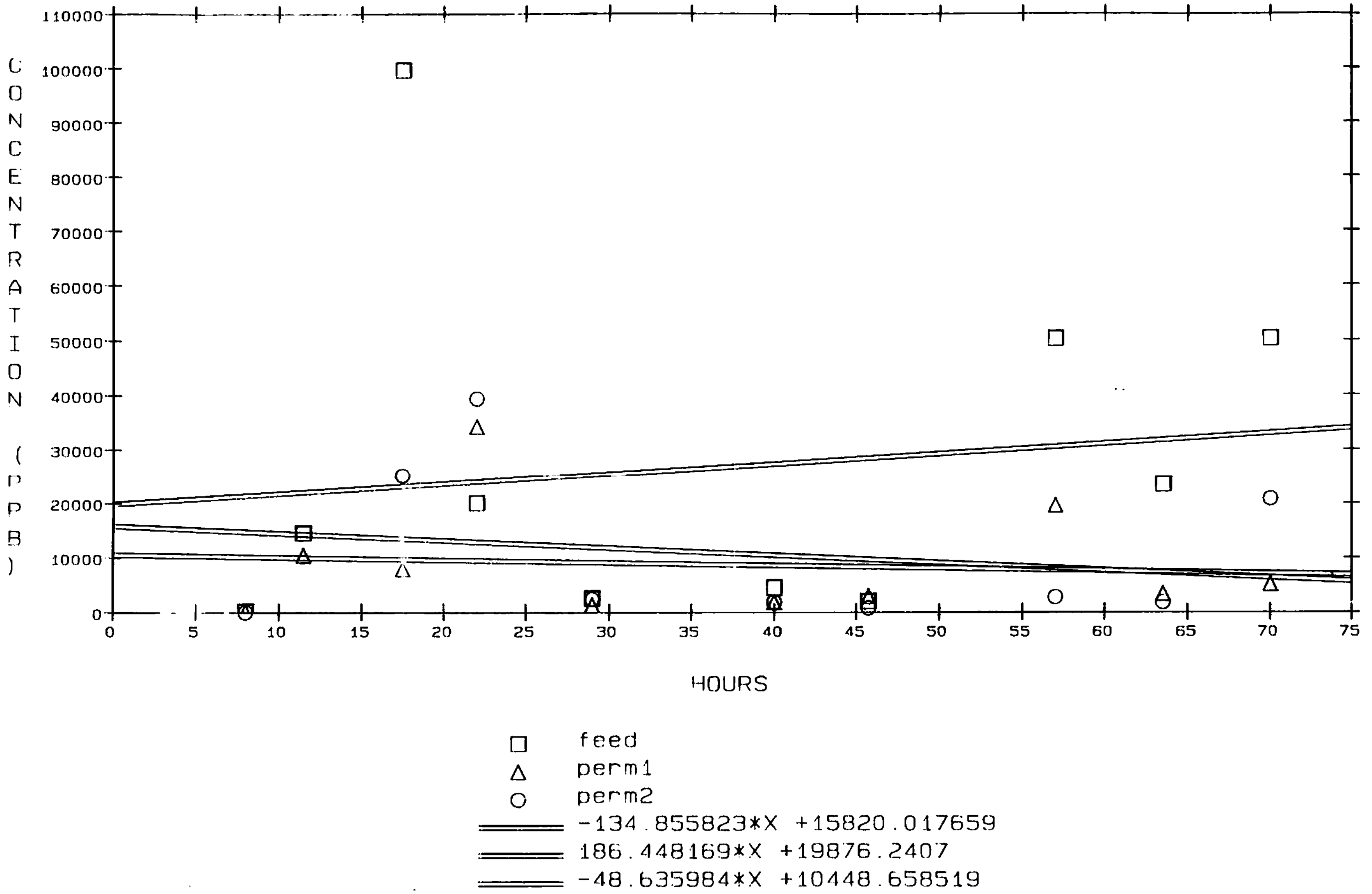
PERM 3 is TORAY

PERM 4 is FILMTEC

RO RESULTS AT OSWEGO - METHYLENE CHLORIDE



RO RESULTS AT OSWEGO - METHYLENE CHLORIDE

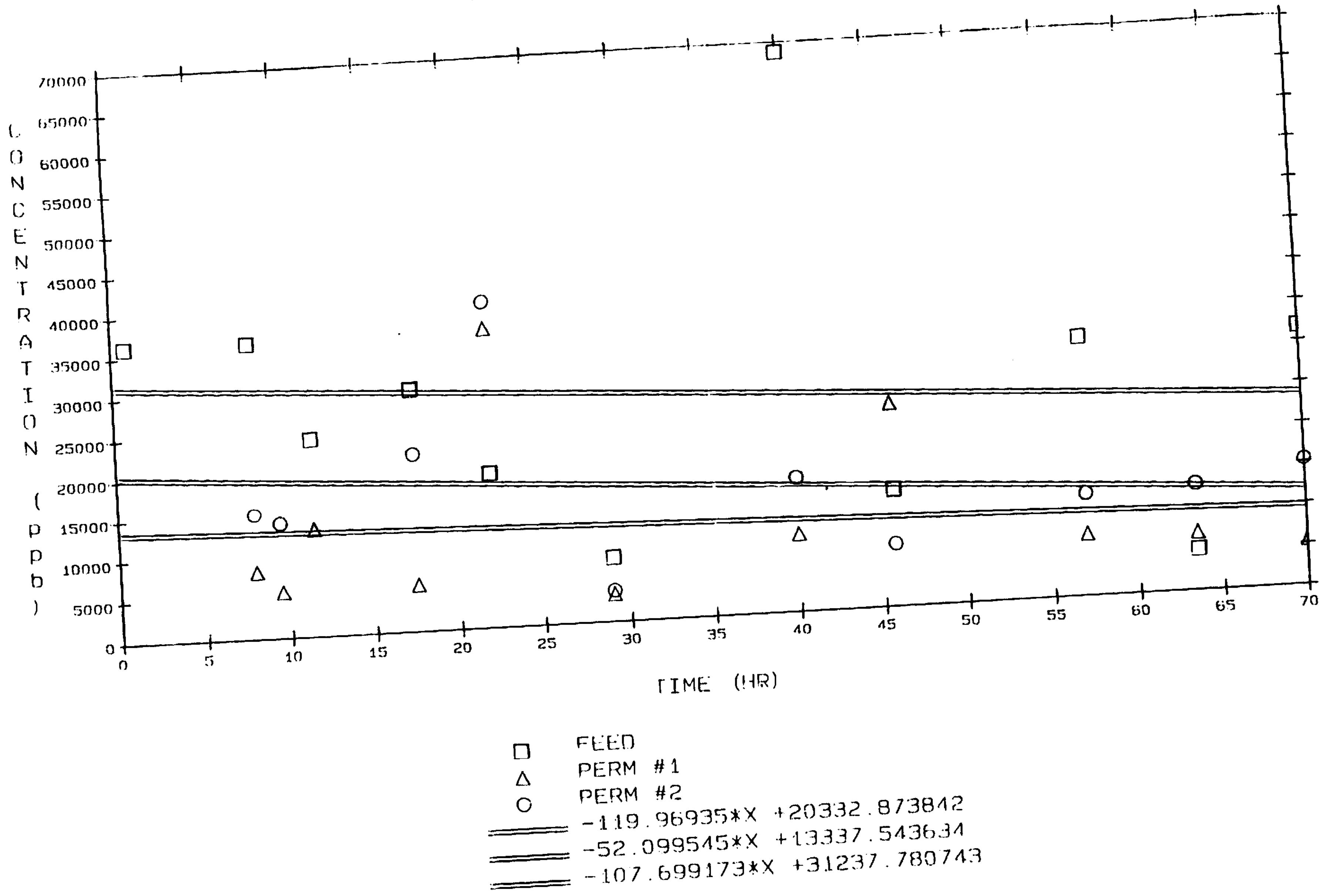


RO RESULTS AT OSWEGO - ACETONE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	conc
0.8						
8.0	36174.30	8199.00	15278.30		8125.74	
9.5		5578.51	14049.40	14313.70	5670.34	77770.78
11.5	24219.50	13165.70			7078.09	3543.93
17.5	29715.90	5707.11	21846.21	18829.18	11912.85	
22.0	18953.10	36740.90	39999.40	30952.70	14051.70	
29.0	7814.75	3366.63	3780.52	5120.53	1711.07	
40.0	68767.50	9453.33	16465.88	13610.70	3077.99	61873.32
45.7	14230.50	24889.40	7606.13	24469.34	7969.82	133432.00
57.0	31671.60	7546.30	12493.80	14567.90	1609.43	31765.10
63.5	4912.34	7038.90	12994.30	9184.69	1474.95	18246.70
70.0	31671.60	5557.60	15361.90	43204.50	1577.91	

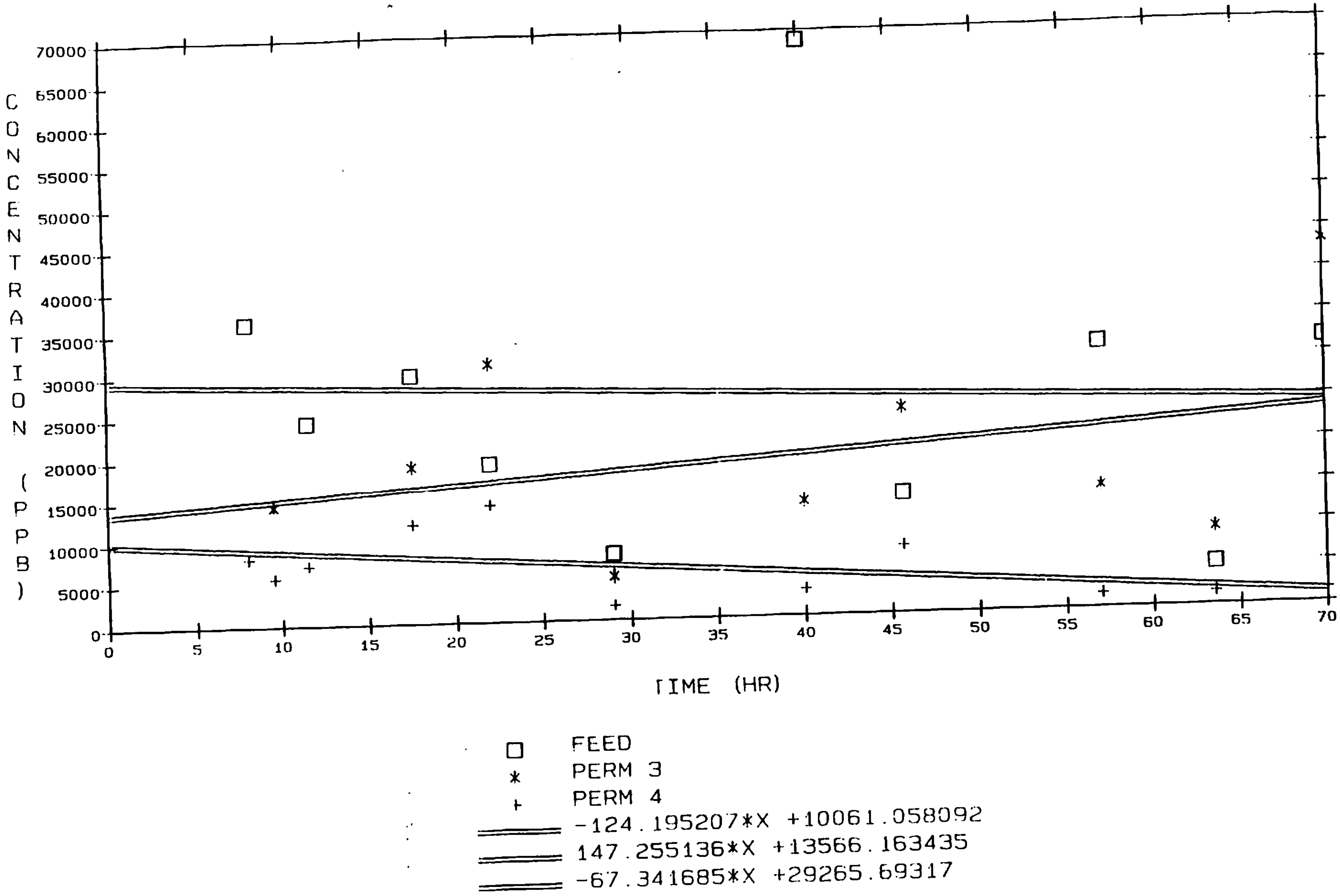
CH3COCH3

RO RESULTS AT OSWEGO - ACETONE



ACE

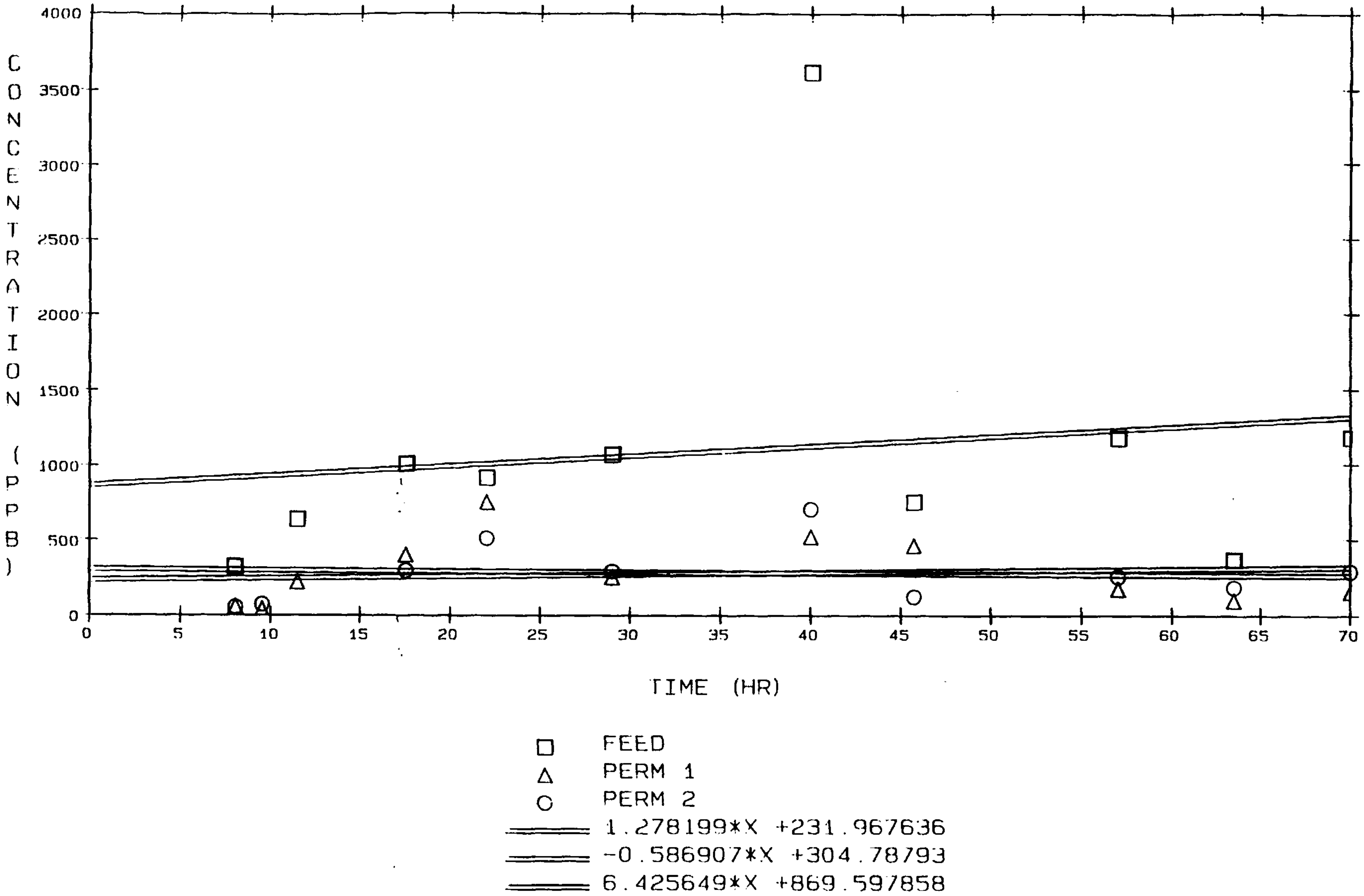
RO RESULTS AT OSWEGO - ACETONE

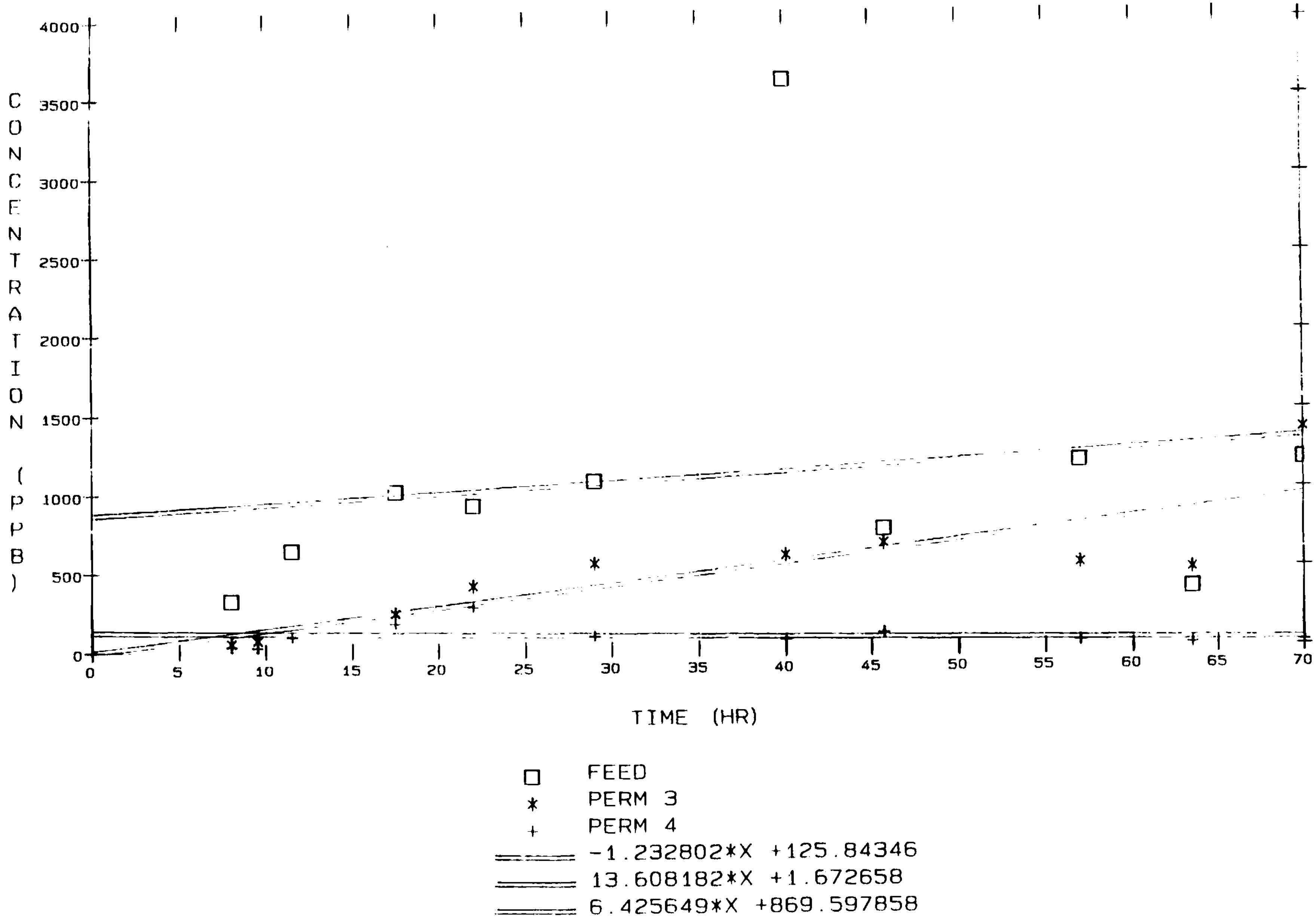


OSWEGO RO RESULTS - 1,1 DICHLOROETHANE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0	319.63	56.34	51.76	51.77	33.16	936.23
9.5		39.65	71.09	71.09	25.22	1175.23
11.5	634.73	218.27			92.08	3564.05
17.5	1009.19	399.86	297.07	236.59	172.71	4180.33
22.0	918.89	751.99	511.37	406.15	277.32	
29.0	1068.45	251.59	289.66	540.28	86.25	
40.0	3611.80	519.11	704.28	589.50	55.80	5635.20
45.7	749.10	465.49	121.88	658.48	96.95	8288.10
57.0	1178.50	175.63	260.01	528.49	41.29	3215.70
63.5	367.41	98.80	184.76	491.75	15.60	1143.90
70.0	1178.50	156.61	290.76	1371.51	27.20	

OSWEGO RO RESULTS - 1.1 DICHLOROETHANE



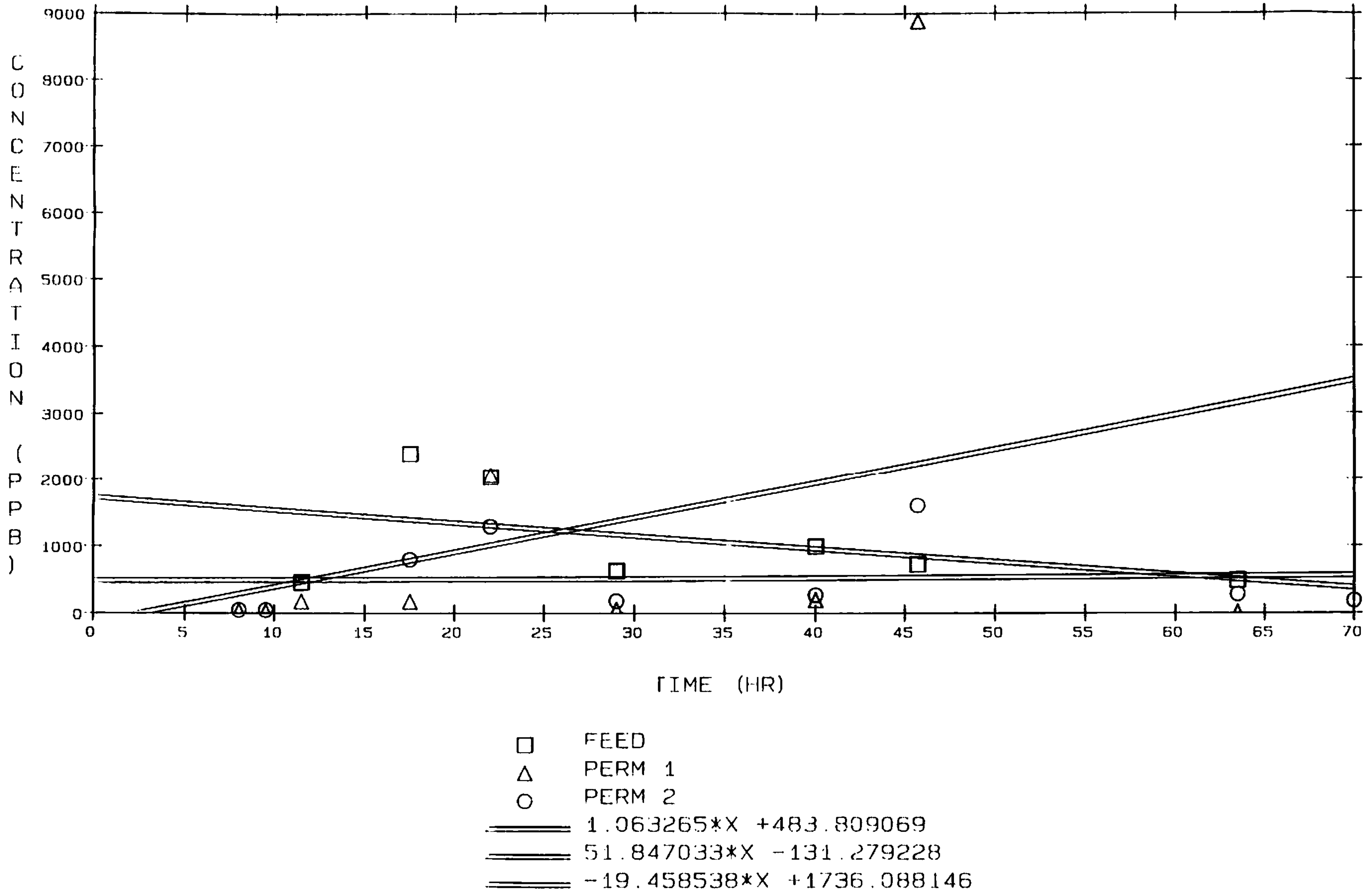


OSWEGO RO RESULTS - 1, 1 DICHLOROETHANE

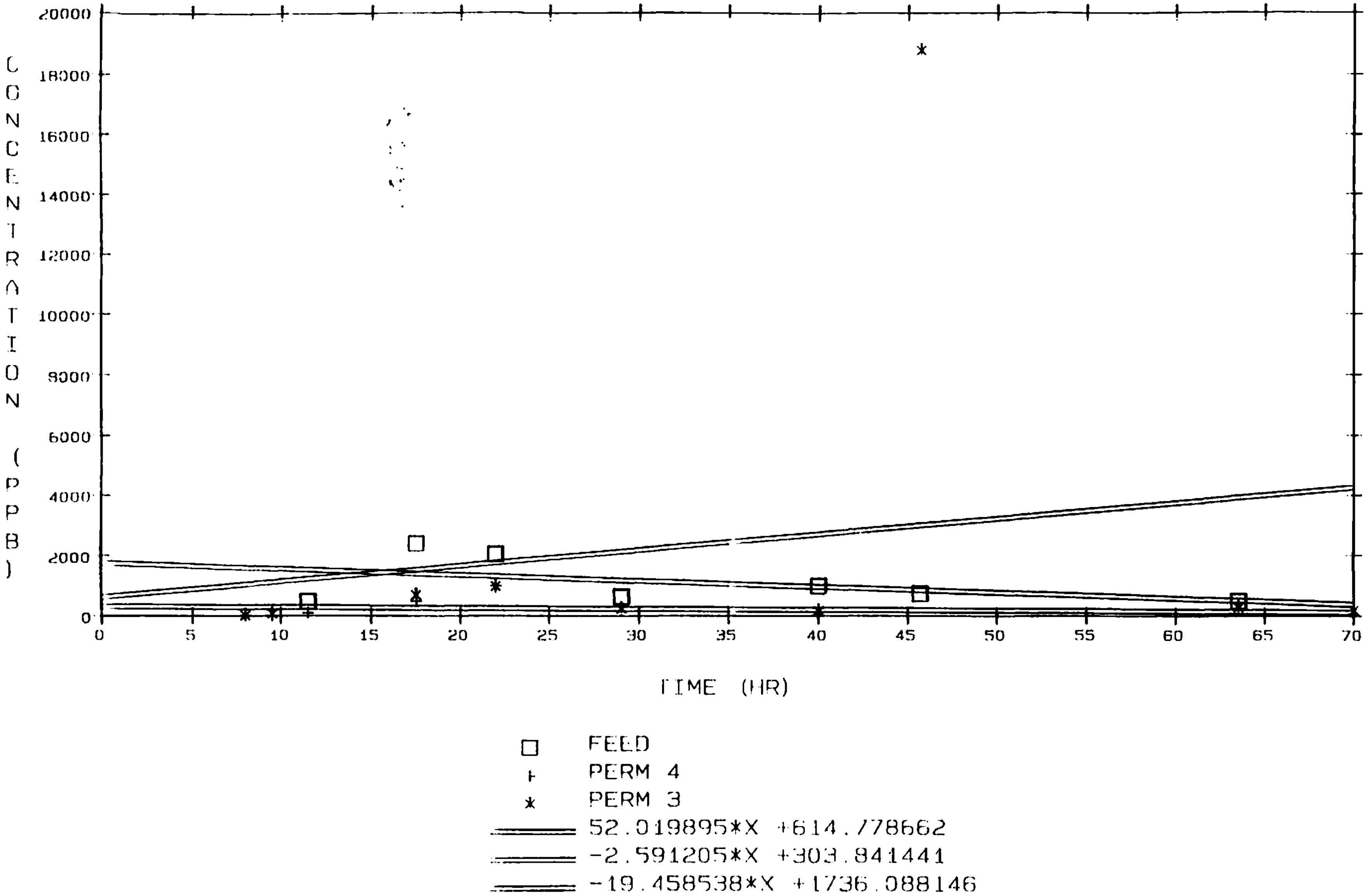
OSWEGO RO RESULTS - 1,1-DICHLOROETHENE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0		27.97	40.60	22.19	12.77	224.59
9.5		19.08	71.09	66.50	15.40	
11.5	448.92	174.17			92.08	1371.56
17.5	2383.21	173.48	297.07	686.31	497.35	7052.92
22.0	2034.25	2062.18	511.37	982.38	998.99	
29.0	628.55	53.28	289.66	248.02		
40.0	987.10	197.60	704.28	155.68	24.33	1758.70
45.7	721.97	8885.32	121.88	18779.82		54757.10
57.0			260.01			
63.5	488.72	16.07	184.76	284.41		367.90
70.0			290.76	184.17	23.44	

OSWEGO RO RESULTS - 1, 1 DICHLOROETHENE



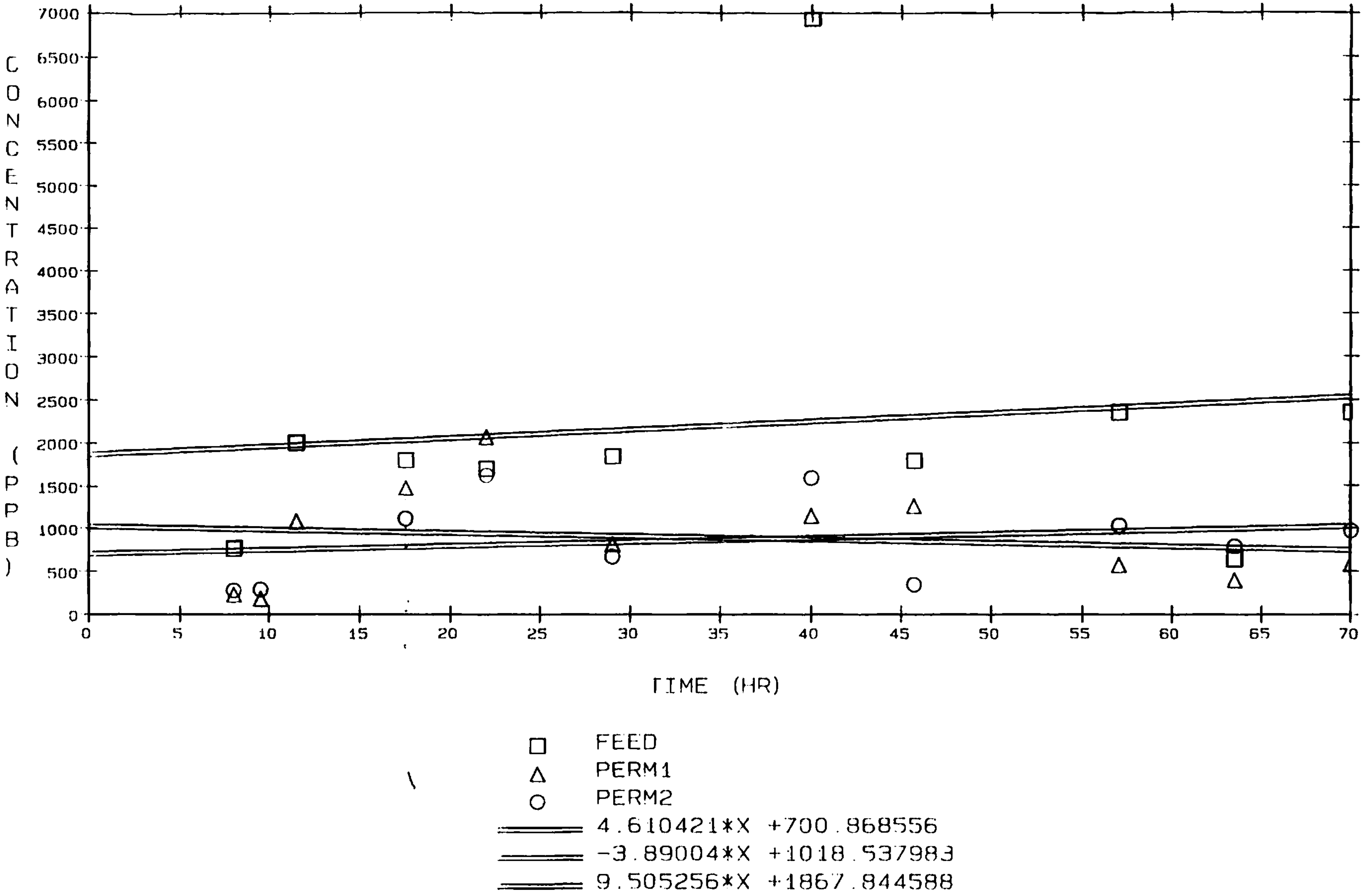
OSWEGO RO RESULTS - 1. 1 DICHLOROETHENE



OSWEGO RO RESULTS - 1,2 DICHLOROETHANE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0	764.11	223.14	271.88	230.93	167.52	1935.71
9.5		172.11	281.27	269.97	136.30	2912.57
11.5	1995.84	1075.78			516.29	7748.54
17.5	1794.34	1468.25	1115.08	905.67	828.35	5997.85
22.0	1700.76	2066.46	1622.42	1473.45	777.69	
29.0	1837.80	809.15	672.05	1164.50	264.58	
40.0	6931.25	1133.57	1588.39	1283.19	241.28	8311.50
45.7	1787.60	1252.34	339.24	1200.78	480.13	12661.70
57.0	2346.80	572.17	1029.99	788.00	181.16	6638.40
63.5	634.96	396.17	787.31	1070.21	81.87	2413.20
70.0	2346.80	581.07	970.95	2679.20	154.07	

OSWEGO RO RESULTS - 1,2 DICHLOROETHANE



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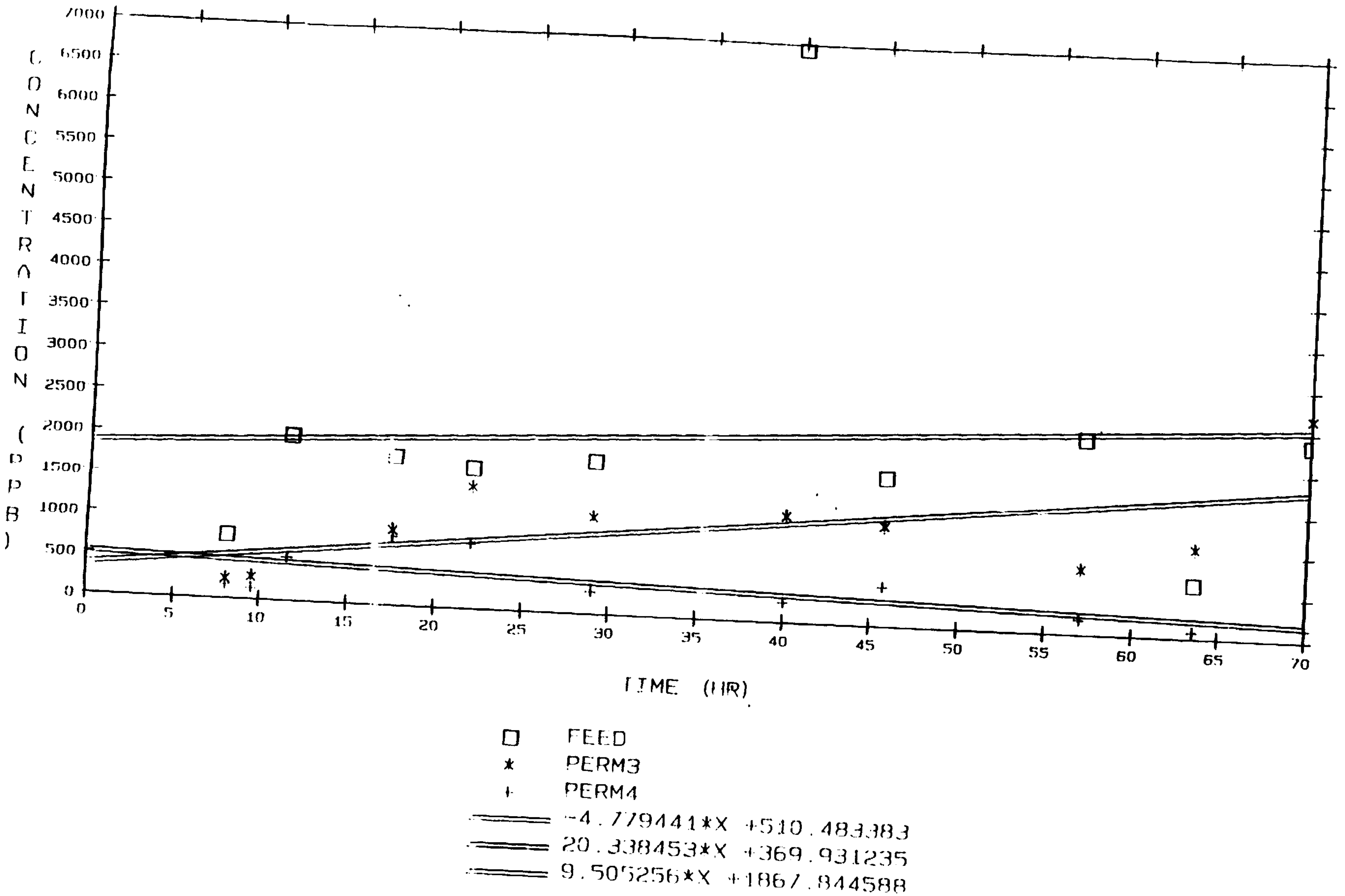
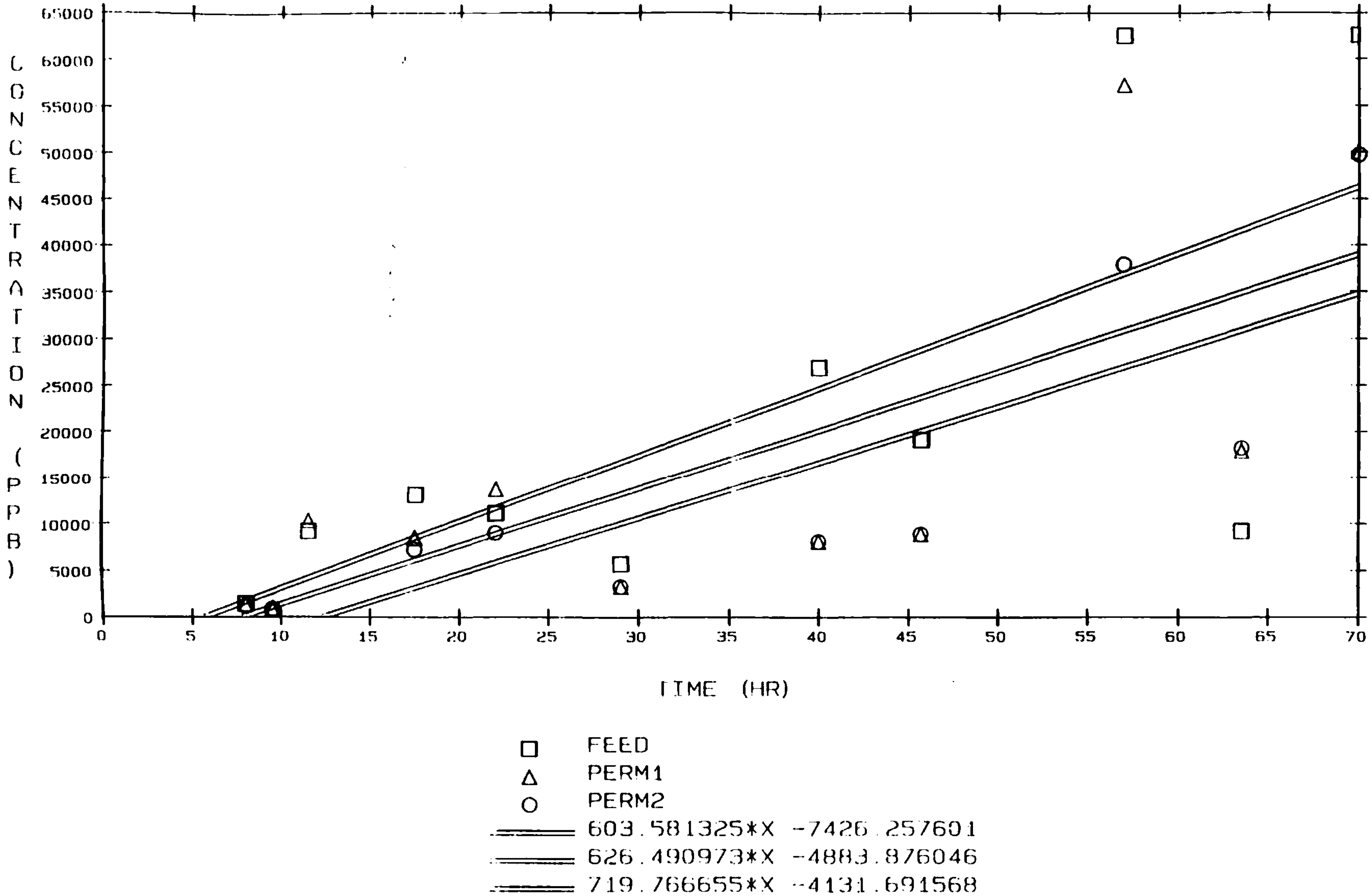
OSWEGO RO RESULTS 1,2 DICHLOROETHANE



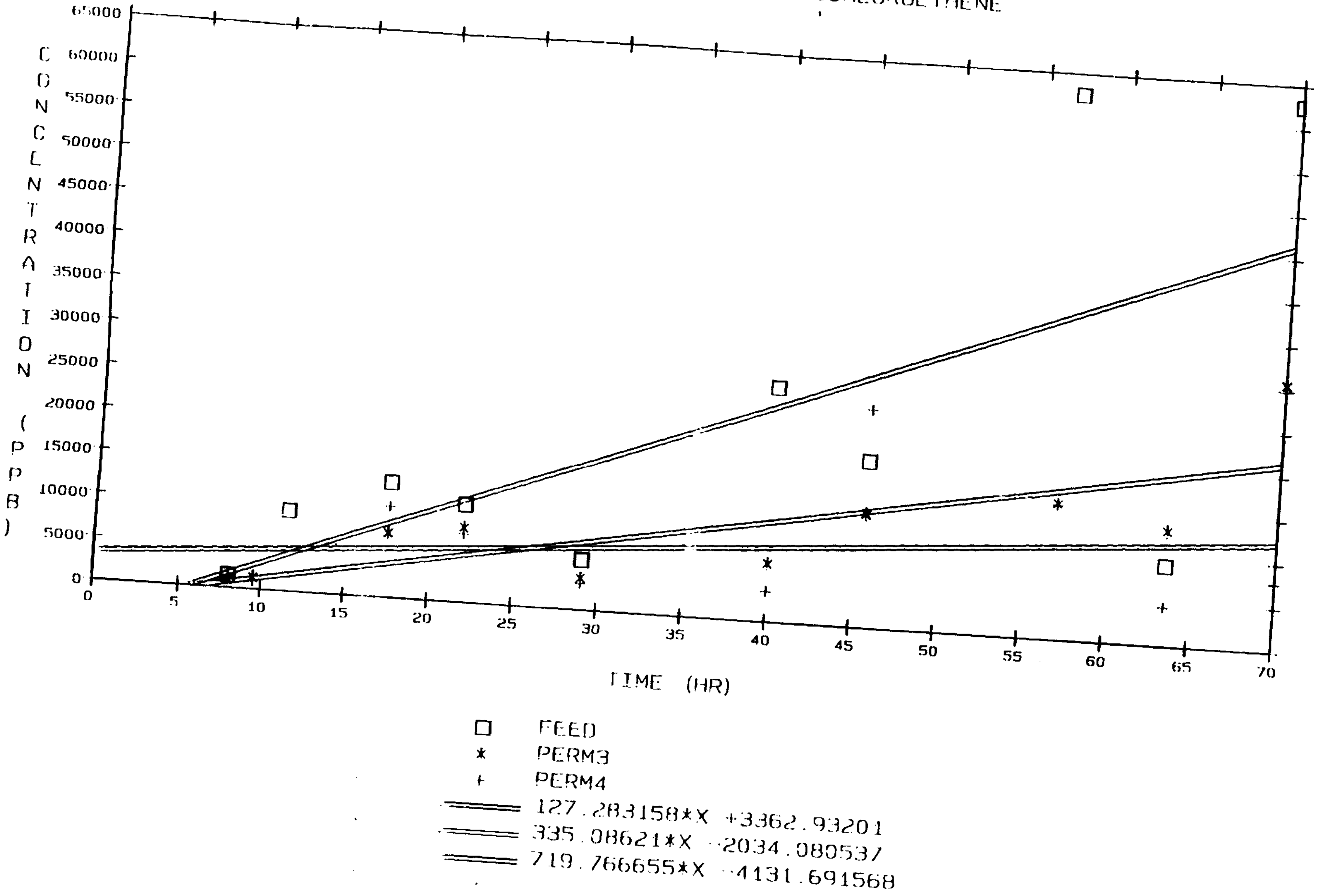
OSWEGO RO RESULTS - t1,2 DICHLOROETHENE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0	1431.42	1430.14	1137.54	932.17	1097.02	1990.74
9.5		922.89	889.53	1308.19	927.53	2216.09
11.5	9186.93	10335.30				18813.68
17.5	13104.60	8489.04	7227.12	7415.03	10429.73	20228.75
22.0	11129.40	13770.00	8970.02	8560.02	7811.68	
29.0	5693.95	3289.27	3289.27	3656.43	3018.95	
40.0	26856.60	8095.13	8095.13	6649.09	3497.87	13271.20
45.7	19082.30	8819.47	8819.47	13065.49	25118.50	114456.00
57.0	62576.80	57279.50	37935.70	15615.20	15454.55	50515.60
63.5	9183.30	17966.40	18264.30	13177.00	4502.60	23519.60
70.0	62576.80	49999.90	49726.50	30648.80	7872.85	

OSWEGO RO RESULTS - t1,2 DICHLOROETHENE



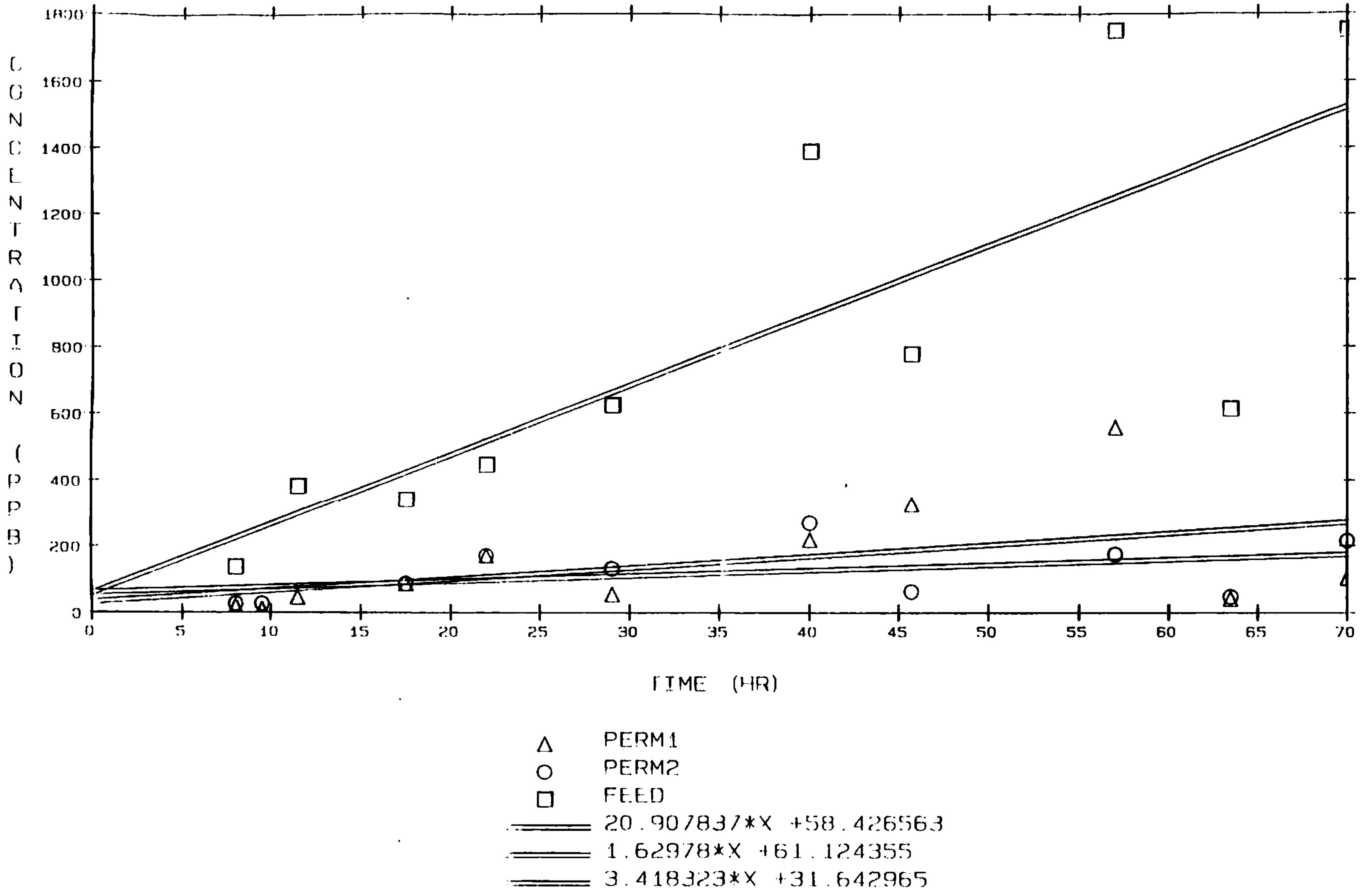
OSWEGO RO RESULTS T1,2 DICHLOROETHENE



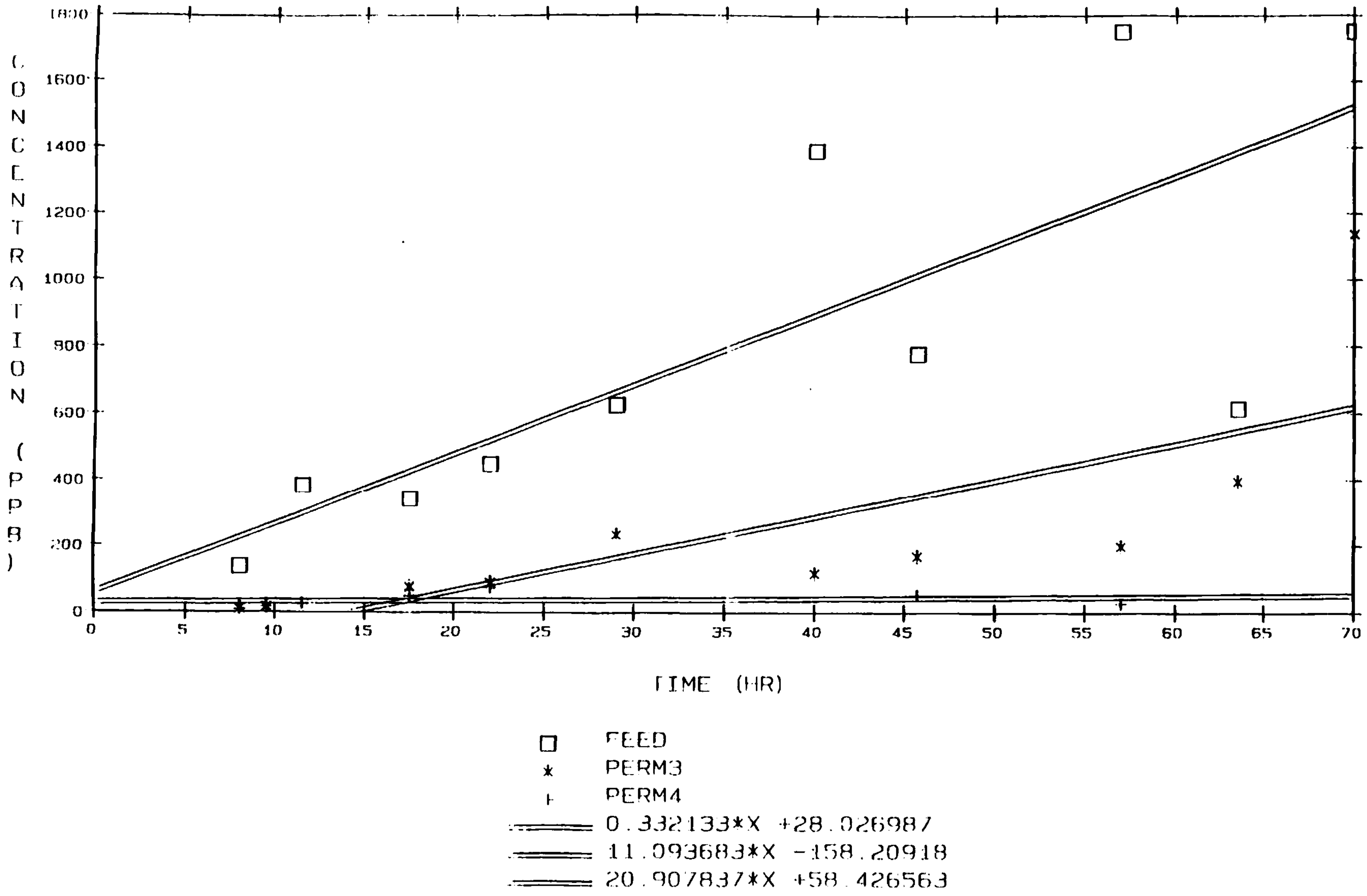
OSWEGO RO RESULTS - 1,1,1 TRICHLOROETHANE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8 8.0	134.77	19.17	25.31	10.53	9.34	401.77
9.5		9.67	26.16	14.46	16.93	954.38
11.5	380.12	45.45			26.17	1613.01
17.5	340.38	85.18	85.18	74.80	49.02	1907.46
22.0	445.08	168.97	168.97	88.86	72.34	
29.0	623.40	54.48	130.54	232.97		
40.0	1388.35	217.69	268.24	115.68		3169.40
45.7	777.10	323.68	61.55	168.31	50.84	4712.30
57.0	1748.50	556.90	173.32	197.07	28.41	4961.90
63.5	612.70	41.88	48.08	395.47		1579.60
70.0	1748.50	102.43	214.20	1137.89		

OSWEGO RO RESULTS - 1,1,1 TRICHLOROETHANE



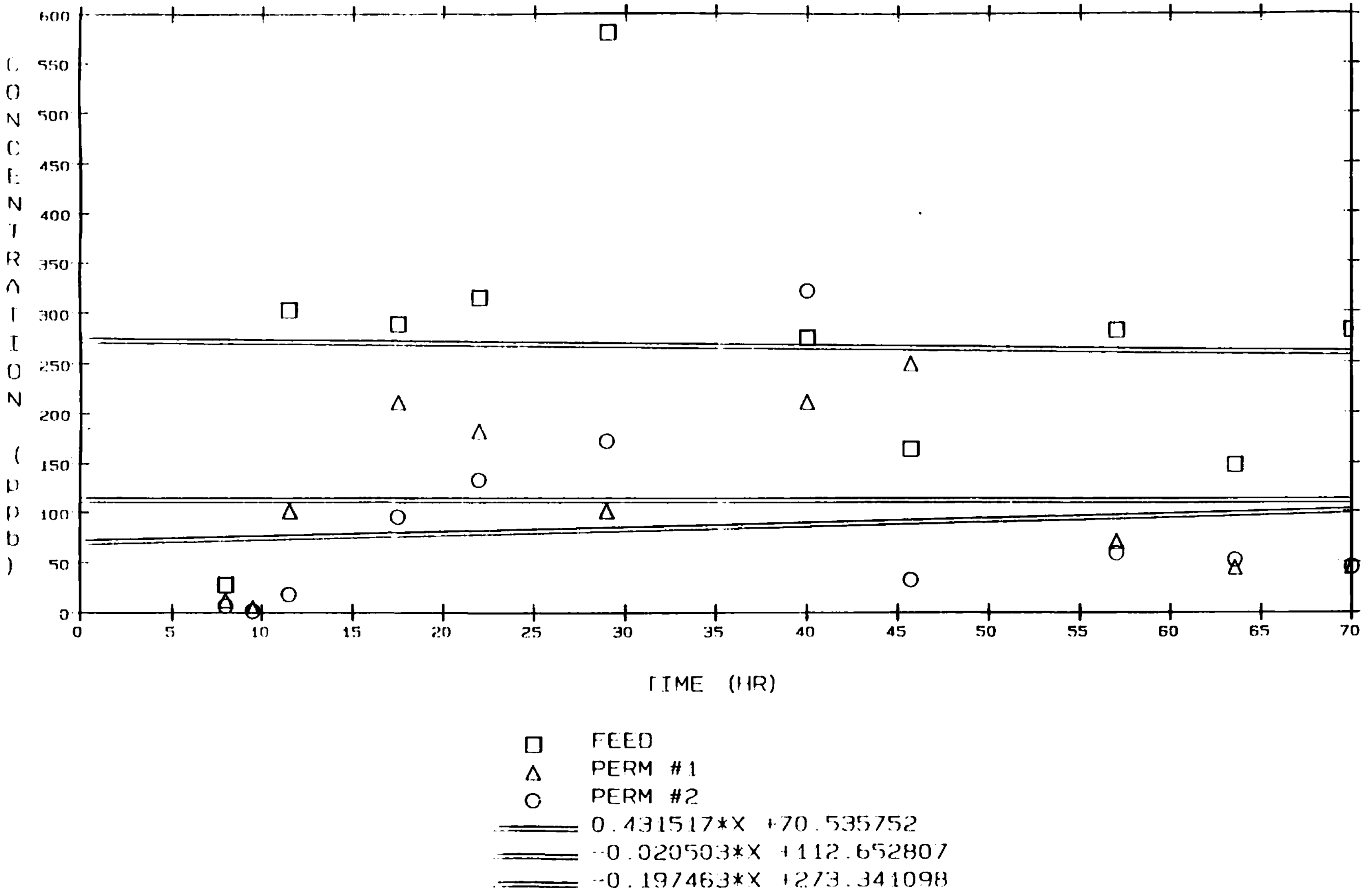
OSWEGO RO RESULTS - 1,1,1 TRICHLOROETHANE



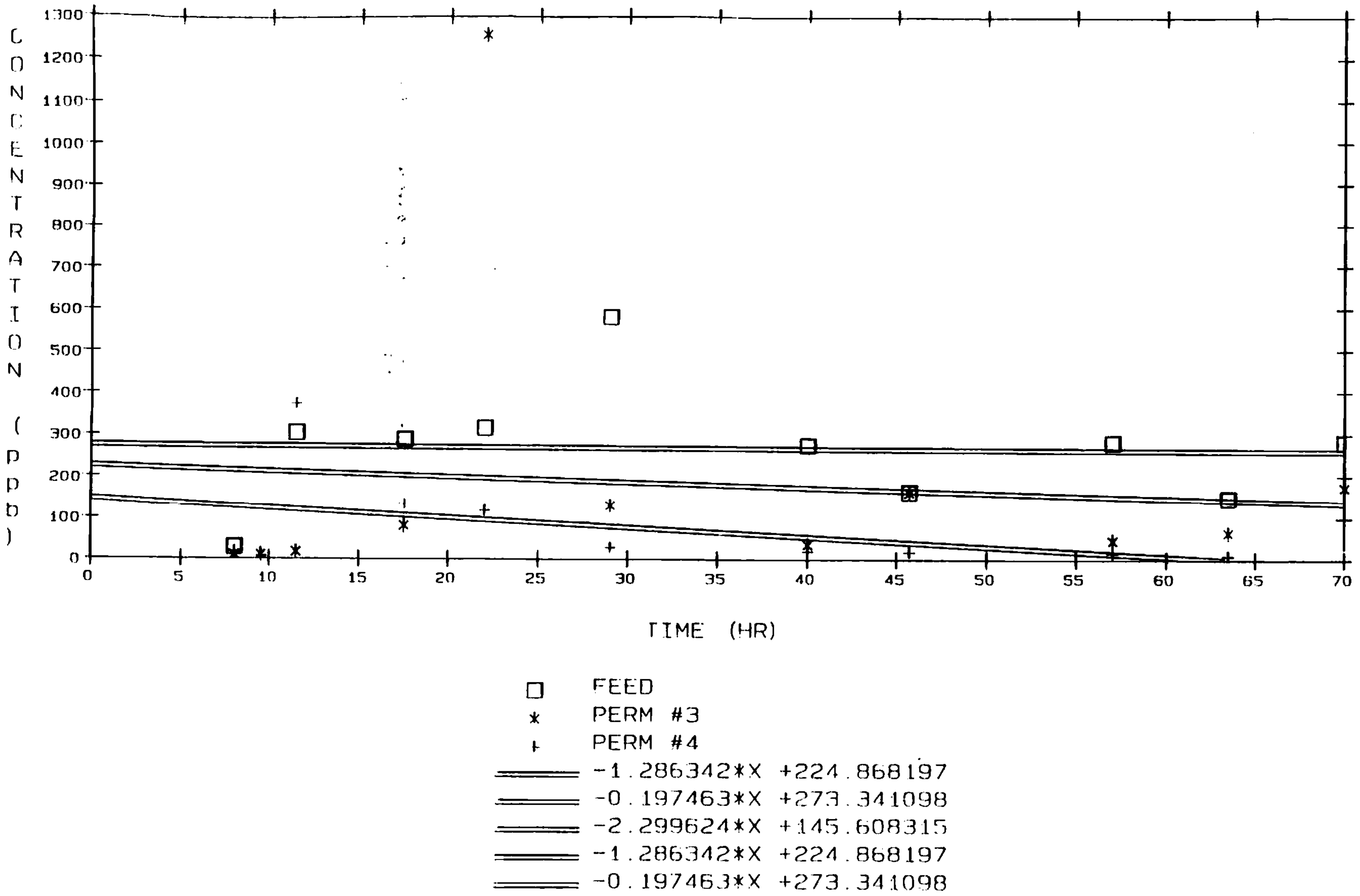
OSWEGO RO RESULTS - TRICHLOROETHENE

TIME (HR)	FEED	PERM #1	PERM #2	PERM #3	PERM #4	CONC
0.8						
8.0	27.525	12.344	6.498	10.700	16.498	0.00
9.5		4.248	1.323	11.048	6.891	0.00
11.5	302.430	101.324	18.056	17.439	372.855	1000.47
17.5	288.280	210.793	95.654	80.277	133.059	0.00
22.0	314.600	182.380	133.580	1258.000	118.380	
29.0	580.300	101.110	172.340	129.530	28.380	
40.0	274.350	210.450	321.330	36.800	20.990	0.00
45.7	163.500	248.500	32.400	162.400	18.890	0.00
57.0	281.400	70.270	58.560	47.090	16.899	1314.30
63.5	147.710	44.760	52.070	65.060	9.480	92.10
70.0	281.400	45.340	45.340	174.500	0.000	0.00

OSWEGO RO RESULTS - TRICHLOROETHENE



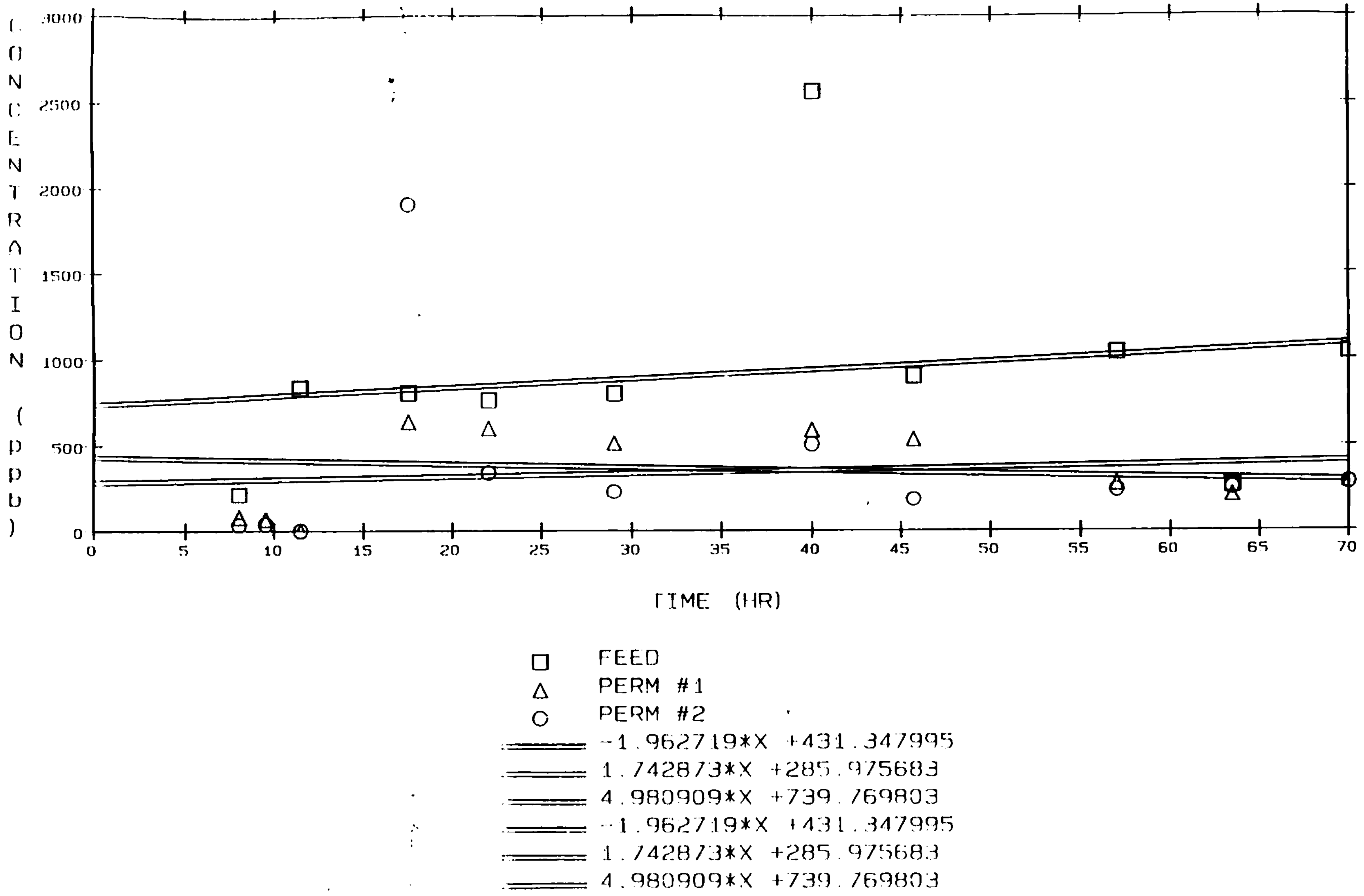
OSWEGO RO RESULTS TRICHLOROETHENE



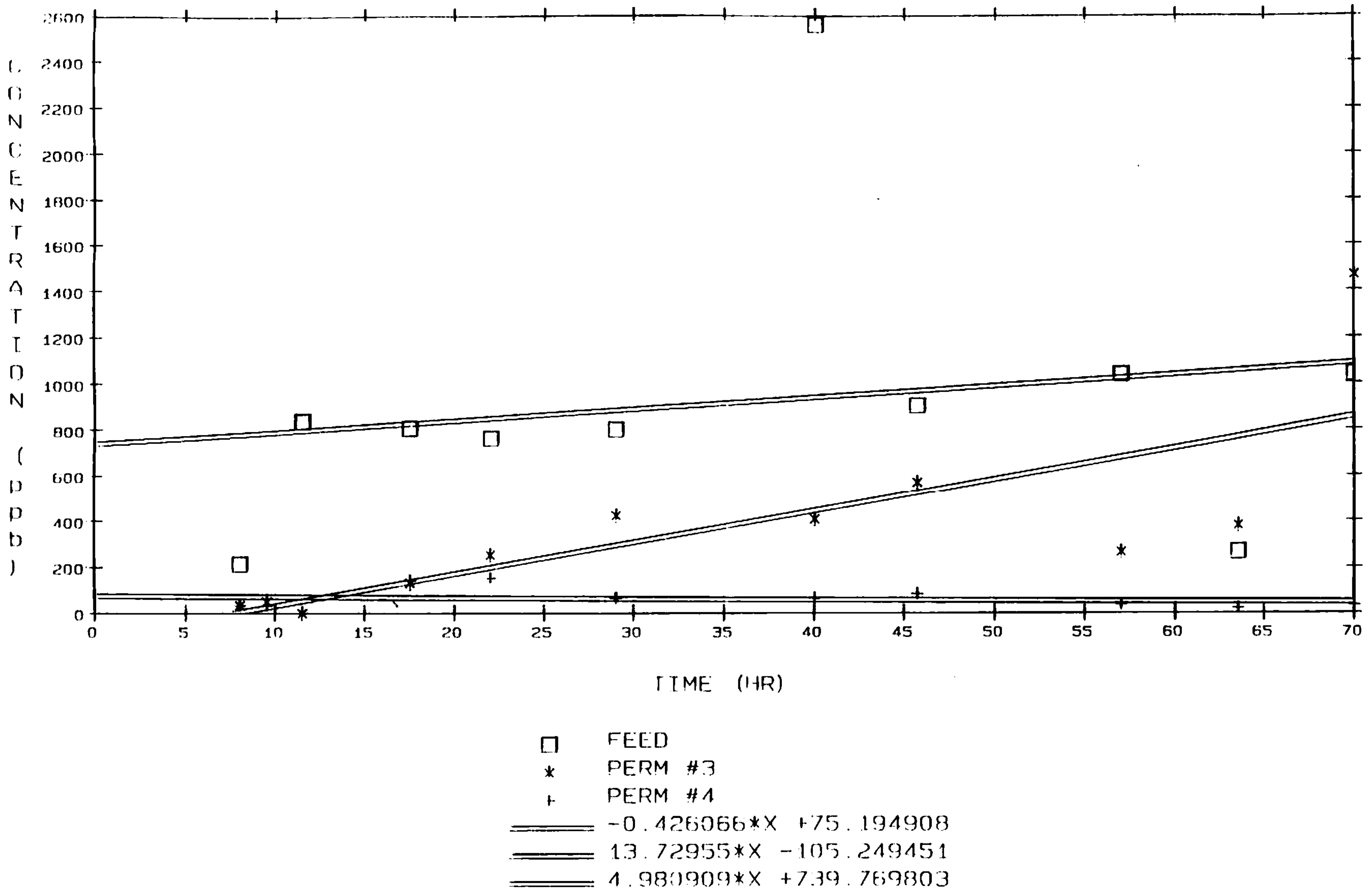
OSWEGO RO RESULTS - BENZENE

	FEED	PERM #1	PERM #2	PERM #3	PERM #4	CONC
0.8						
8.0	210.565	81.159	34.88	33.740	35.276	559.39
9.5		67.580	37.47	49.490	32.893	641.72
11.5	834.400	0.000	0.00	0.000	0.000	4222.51
17.5	803.280	639.385	1902.71	130.389	144.194	3295.24
22.0	760.630	597.970	341.27	251.880	152.230	
29.0	799.400	510.460	228.63	421.810	64.100	
40.0	2560.550	588.600	505.61	405.490	64.090	3809.80
45.7	900.500	533.810	184.49	569.310	82.700	3895.00
57.0	1038.600	277.670	241.59	264.620	37.270	2911.10
63.5	265.220	209.810	252.87	380.280	20.560	1010.30
70.0	1038.600	290.600	281.84	1465.980	34.610	

OSWEGO RO RESULTS   BENZENE



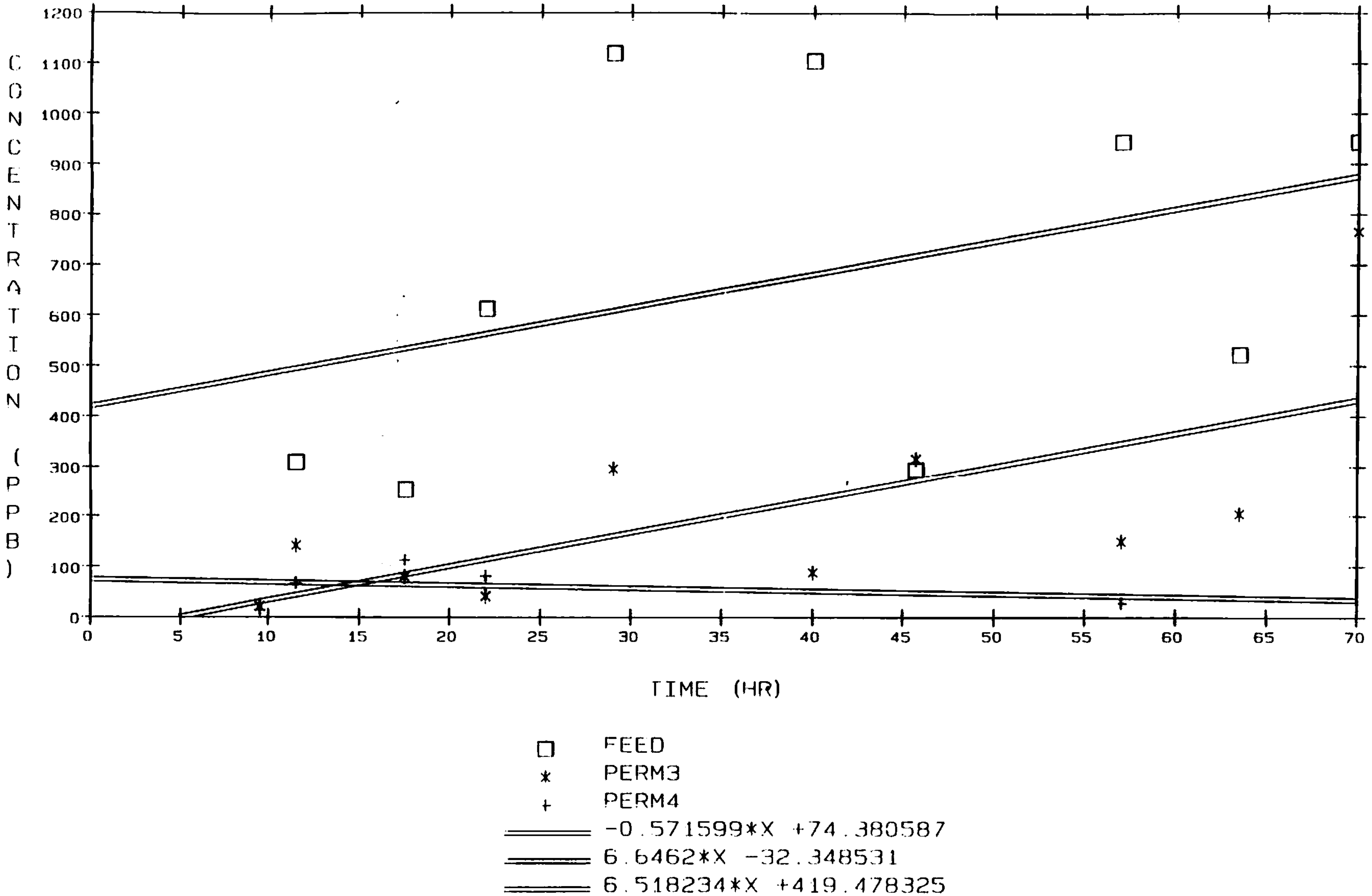
OSWEGO RO RESULTS - BENZENE



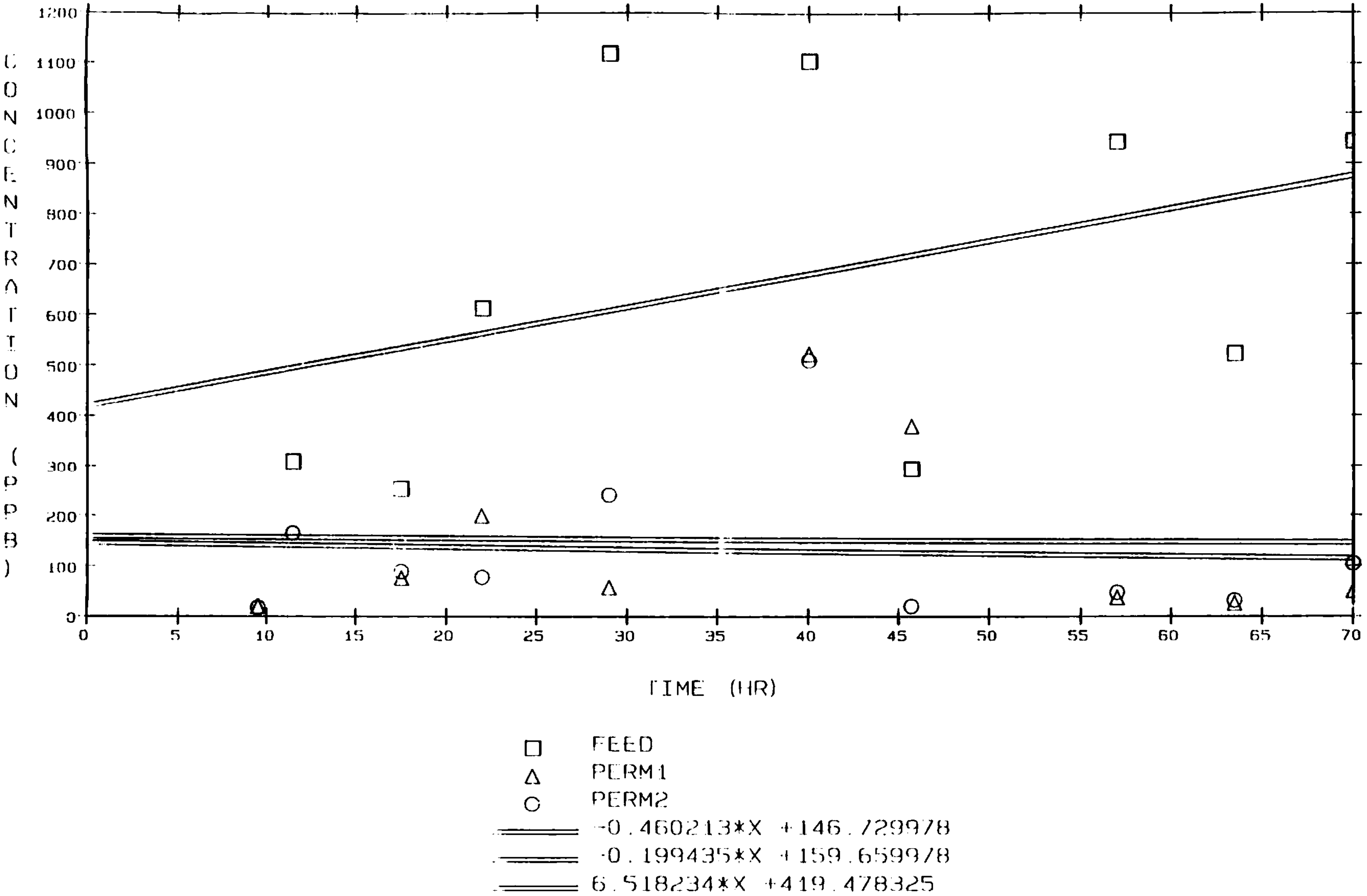
OSWEGO RO RESULTS - BROMODICHLOROMETHANE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0						
9.5		19.69	16.74	21.71	14.20	
11.5	307.85		164.94	141.27	66.96	681.55
17.5	252.26	76.09	88.40	80.06	113.21	1251.93
22.0	612.04	199.16	76.95	42.18	82.10	
29.0	1119.10	57.30	241.29	294.76		4730.50
40.0	1105.50	522.39	508.29	89.51		
45.7	292.70	377.82	19.69	314.95		5359.80
57.0	942.80	36.76	46.96	151.06	28.27	3711.10
63.5	522.05	26.49	30.85	205.39		357.90
70.0	942.80	50.60	104.89	766.14		
MEAN	677.46	151.74	129.90	210.70	60.95	
% REMOVAL		77.60	80.80	68.90	91.00	

OSWEGO RO RESULTS - BROMODICHLOROMETHANE



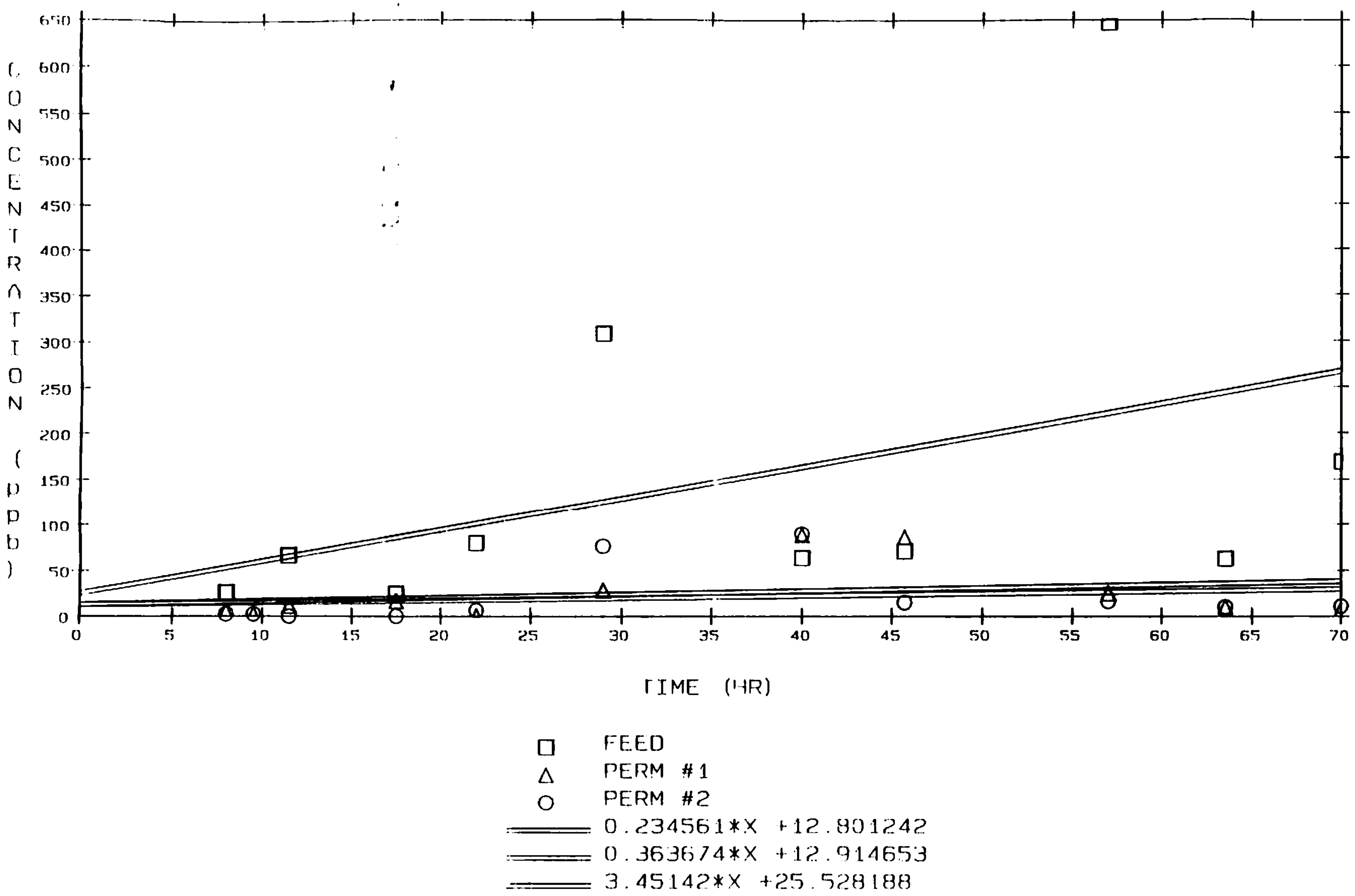
OSWEGO RO RESULTS BROMODICHLOROMETHANE



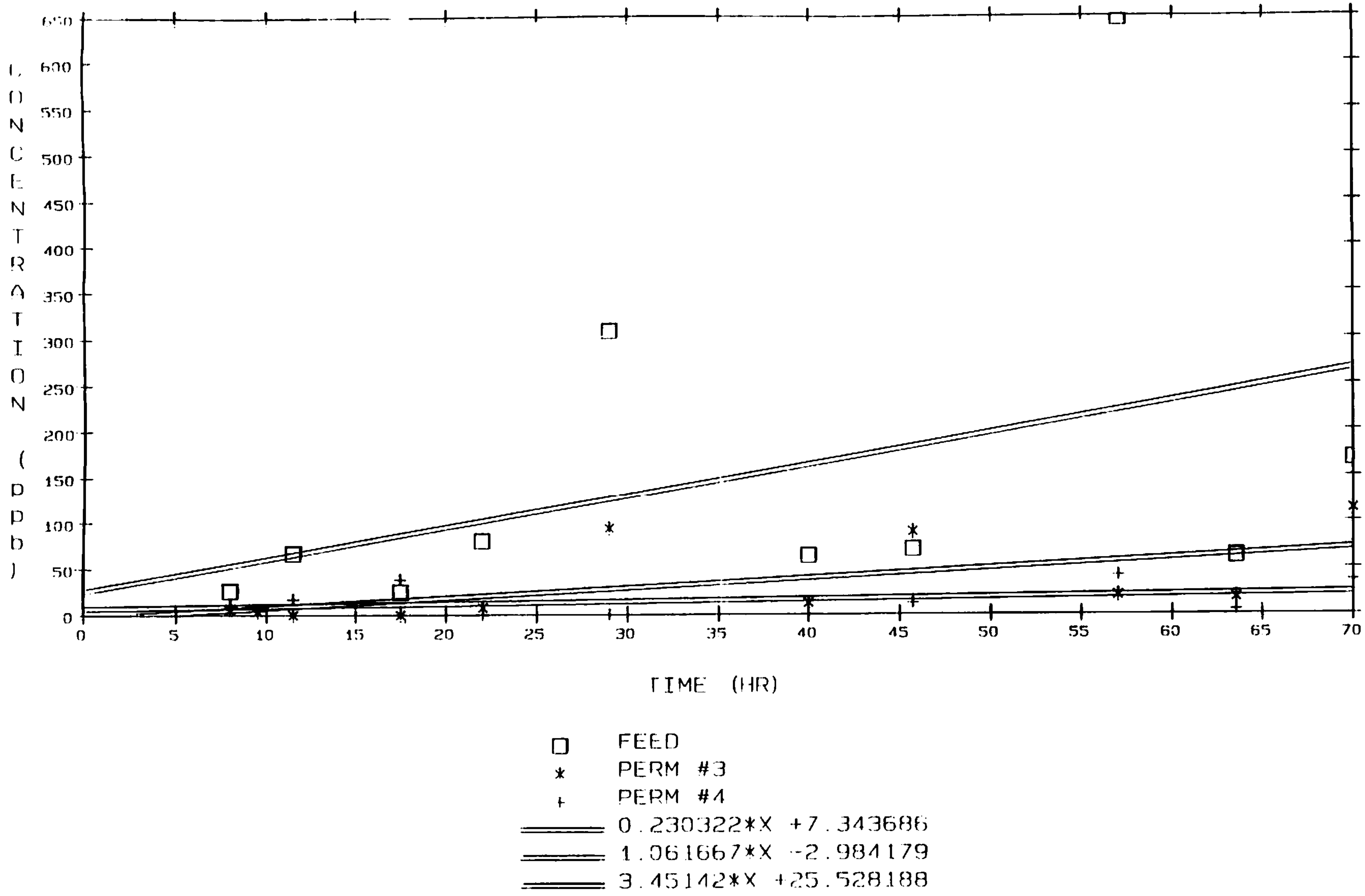
OSWEGO RO RESULTS - METHYL ISOBUTYL KETONE

	FEED	PERM #1	PERM #2	PERM #3	PERM #4	CONC
0.8						
8.0	25.379	5.056	2.682	5.461	10.788	74.29
9.5		2.644	2.287	3.988	4.882	53.32
11.5	65.630	10.496	0.000	0.000	17.040	211.72
17.5	23.930	16.070	0.000	0.000	37.945	177.95
22.0	79.030	0.000	6.120	7.720	0.000	
29.0	307.850	27.620	75.770	93.400	0.000	
40.0	62.550	87.830	89.590	12.450	0.000	834.30
45.7	70.200	85.430	14.990	89.600	12.760	772.90
57.0	647.100	24.880	16.620	20.030	41.747	1214.80
63.5	62.020	9.960	9.810	17.560	5.000	72.70
70.0	168.600	7.980	10.600	113.710	36.690	

OSWEGO RO RESULTS - METHYL ISOBUTYL KETONE



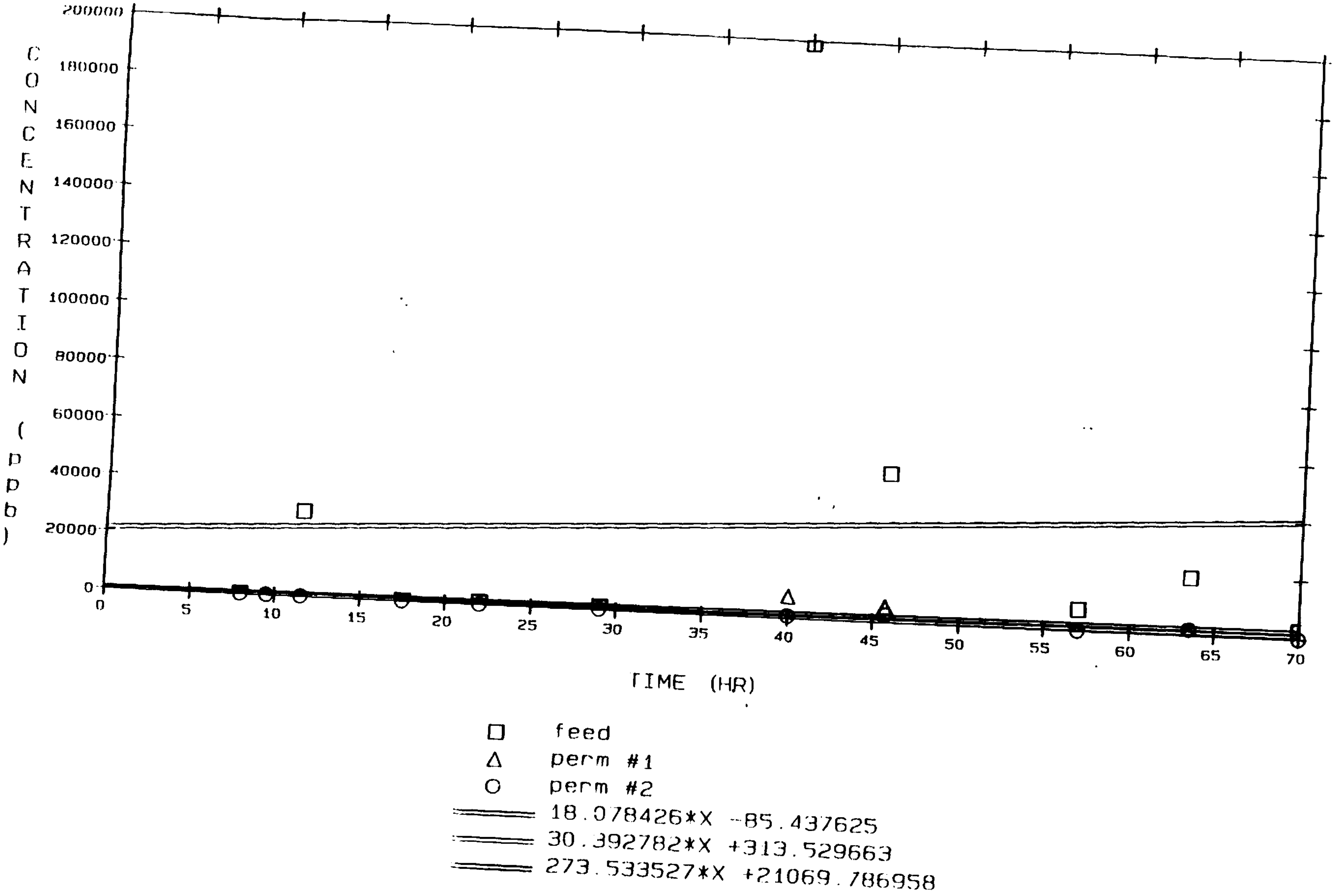
OSWEGO RO RESULTS - METHYL ISOBUTYL KETONE



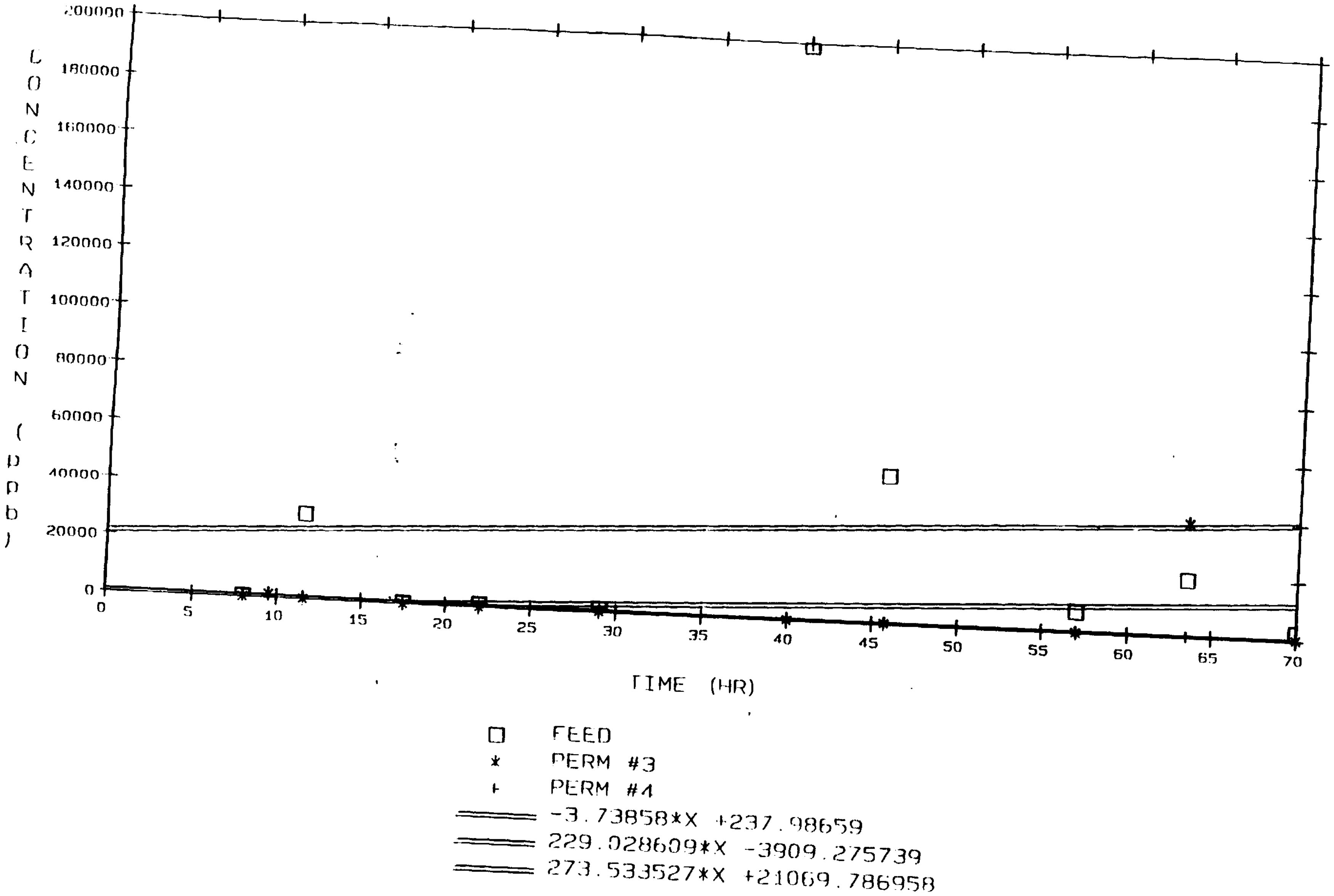
OSWEGO RO RESULTS - BROMOFORM

	FEED	PERM #1	PERM #2	PERM #3	PERM #4	CONC
0.8						
8.0	0.00	0.000	0.000	0.000	0.000	0.00
9.5		14.493	25.557	1186.590	407.660	79542.80
11.5	29053.90	28.436	55.457	46.181	607.615	660.77
17.5	0.00	47.530	0.000	75.297	0.000	112709.60
22.0	728.01	66.240	70.910	92.690	0.000	
29.0	886.25	164.600	256.770	238.310	0.000	
40.0	198965.50	7450.590	670.320	156.810	0.000	336242.00
45.7	51312.60	5307.760	2655.440	399.360	82.700	6960.20
57.0	7269.12	0.000	91.640	212.970	0.000	272100.00
63.5	19479.40	1726.960	1990.000	39727.500	122.770	109451.00
70.0	2624.00	0.000	0.000	450.250	0.000	

OSWEGO RO RESULTS BROMOFORM



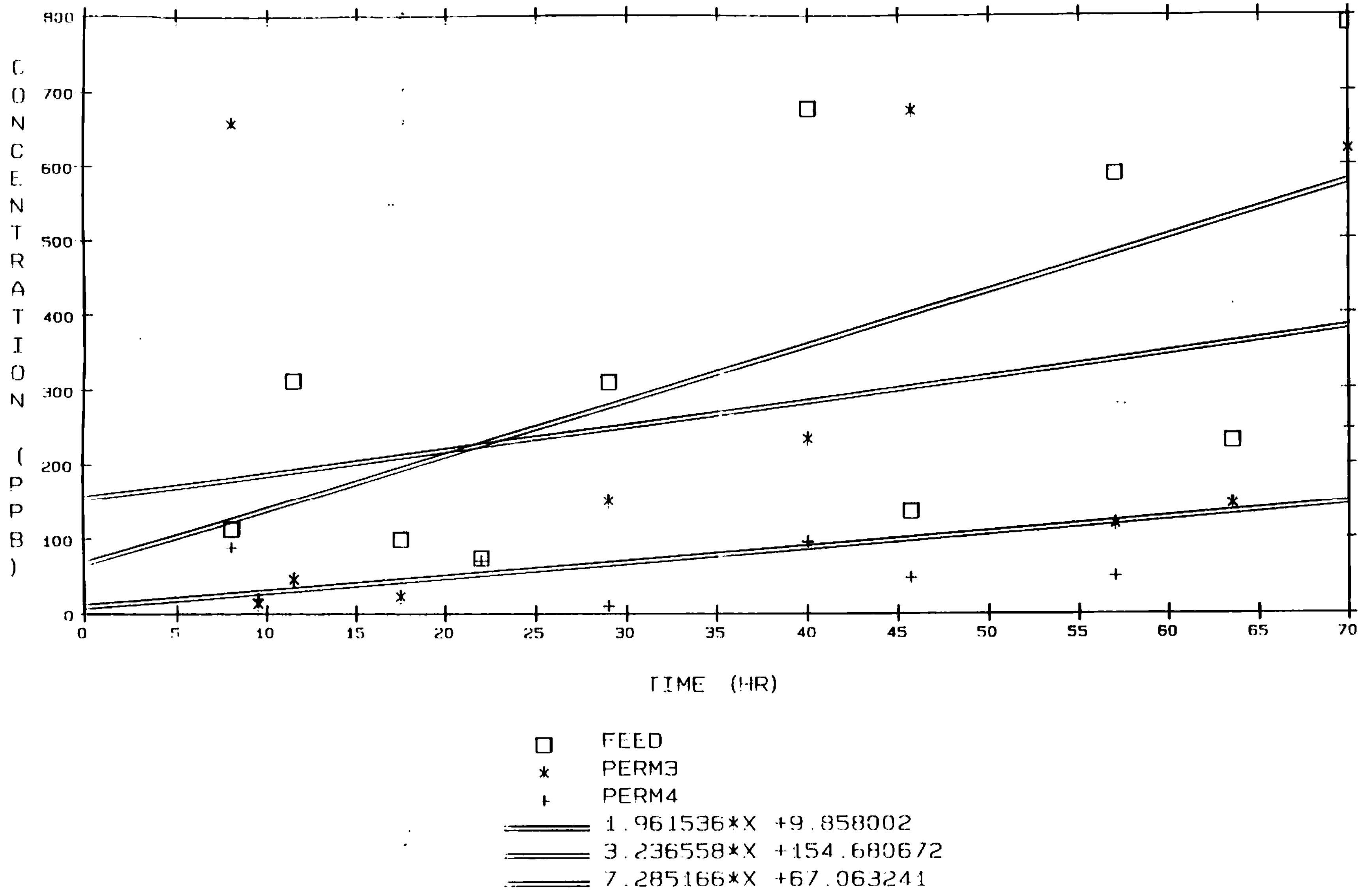
OSWEGO RO RESULTS - BROMOFORM



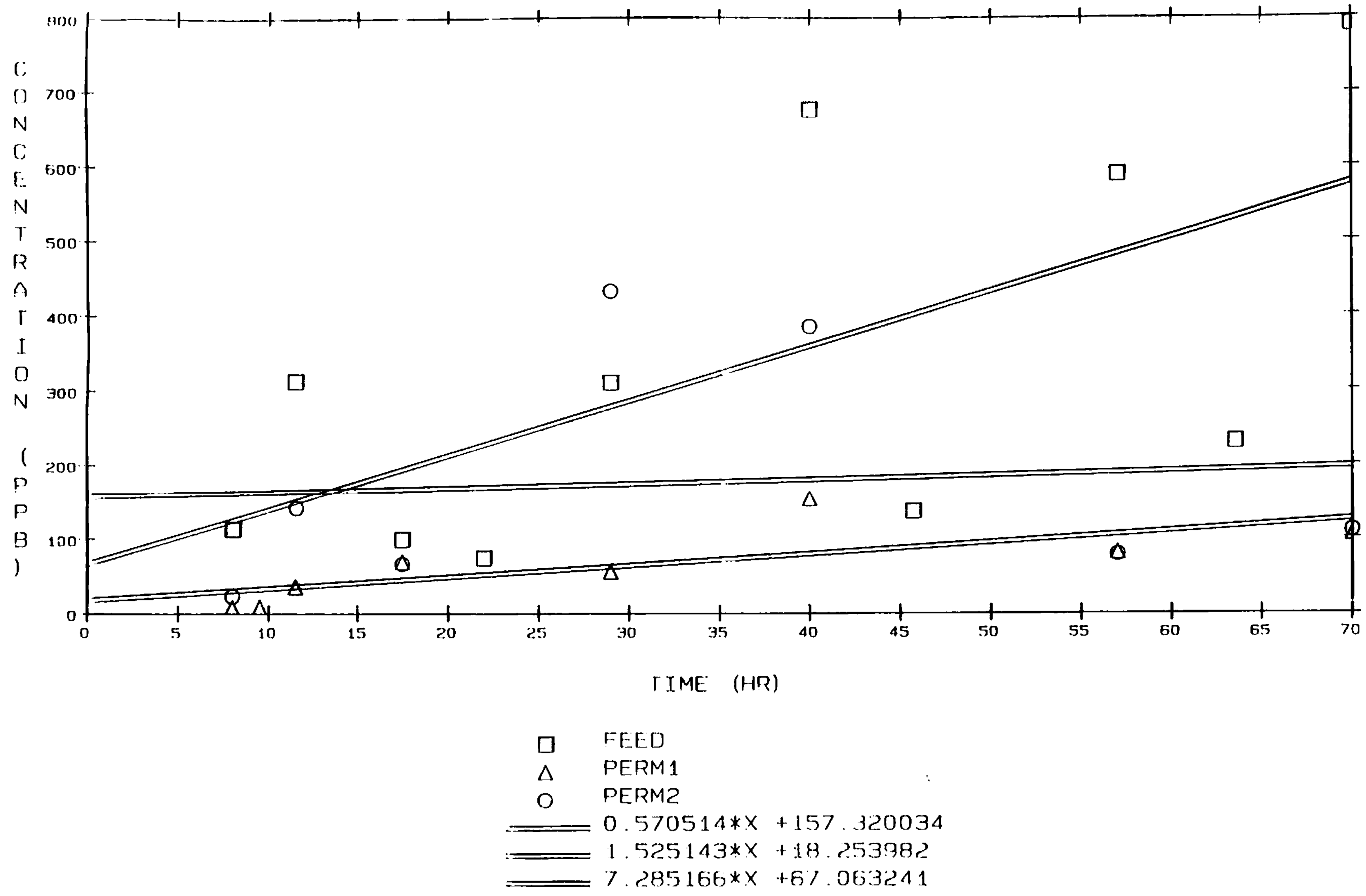
OSWEGO RO RESULTS - TETACHLOROETHANE/ENE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	conc
0.8						
8.0	113.06	7.871	22.889	657.936	89.038	366.59
9.5		8.561		13.004	20.100	311.04
11.5	311.40	35.583	141.675	46.026		101.09
17.5	98.05	68.984	65.796	23.068		606.45
22.0	73.88				70.840	
29.0	309.30	55.350	431.710	150.840	10.700	
40.0	675.75	153.300	384.370	233.980	95.110	3091.70
45.7	135.90			673.540	47.820	2772.10
57.0	588.40	80.930	78.100	119.050	49.790	1905.50
63.5	229.95			146.380		580.00
70.0	788.20	105.300	109.630	621.280	247.050	

OSWEGO RO RESULTS - TETRACHLOROETHENE (1.1.2.2)



OSWEGO RO RESULTS - TETRACHLOROETHENE (1, 1, 2, 2)

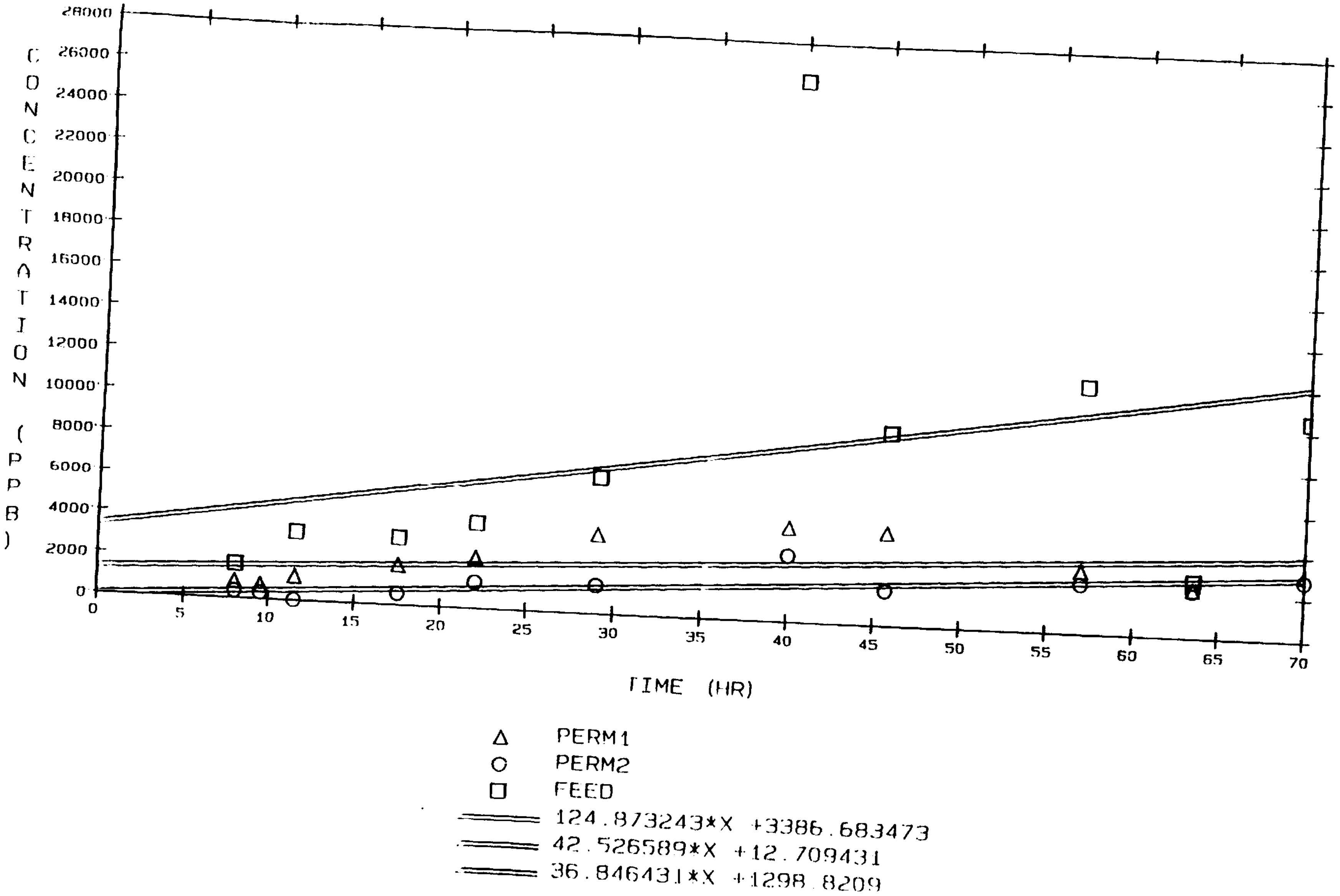


OSWEGO RO RESULTS - TOLUENE

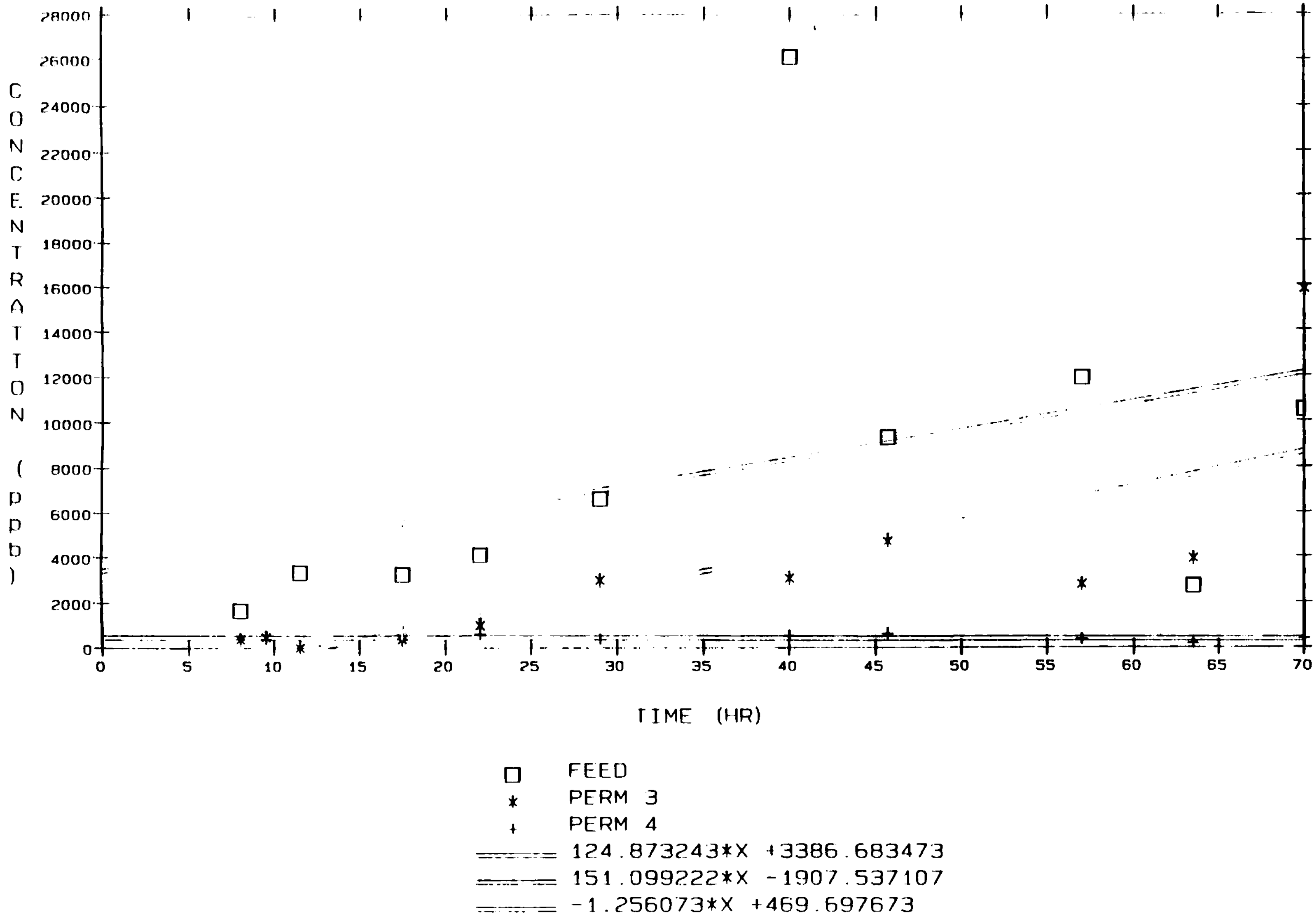
TIME(HR)	FEED	PERM1	PERM2	PERM3	PERM4	CONCENTRATE
0.8						
8.0	128.70	169.13	0.00		88.45	
9.5						
11.5	14426.00	10405.42			4745.57	14993.68
17.5	99641.80	7888.80	25117.36	34033.30	55439.43	100270.20
22.0	19981.30	34164.60	39273.20	62228.40	79914.10	
29.0	2486.45	1306.59	2399.22	1296.51	691.28	
40.0	4469.14	1853.38	1886.51	1191.60	778.20	1576.00
45.7	1907.30	2906.70	801.49	965.21	2789.12	13366.30
57.0	50145.60	19552.50	2747.66	23210.20	1117.58	1492.20
63.5	23334.94	3415.94	1883.47	2270.54	1165.33	2963.00
70.0	50145.60	5110.30	20707.60	5259.68	1557.91	

GTOLUEN

RO RESULTS AT OSWEGO - TOLUENE



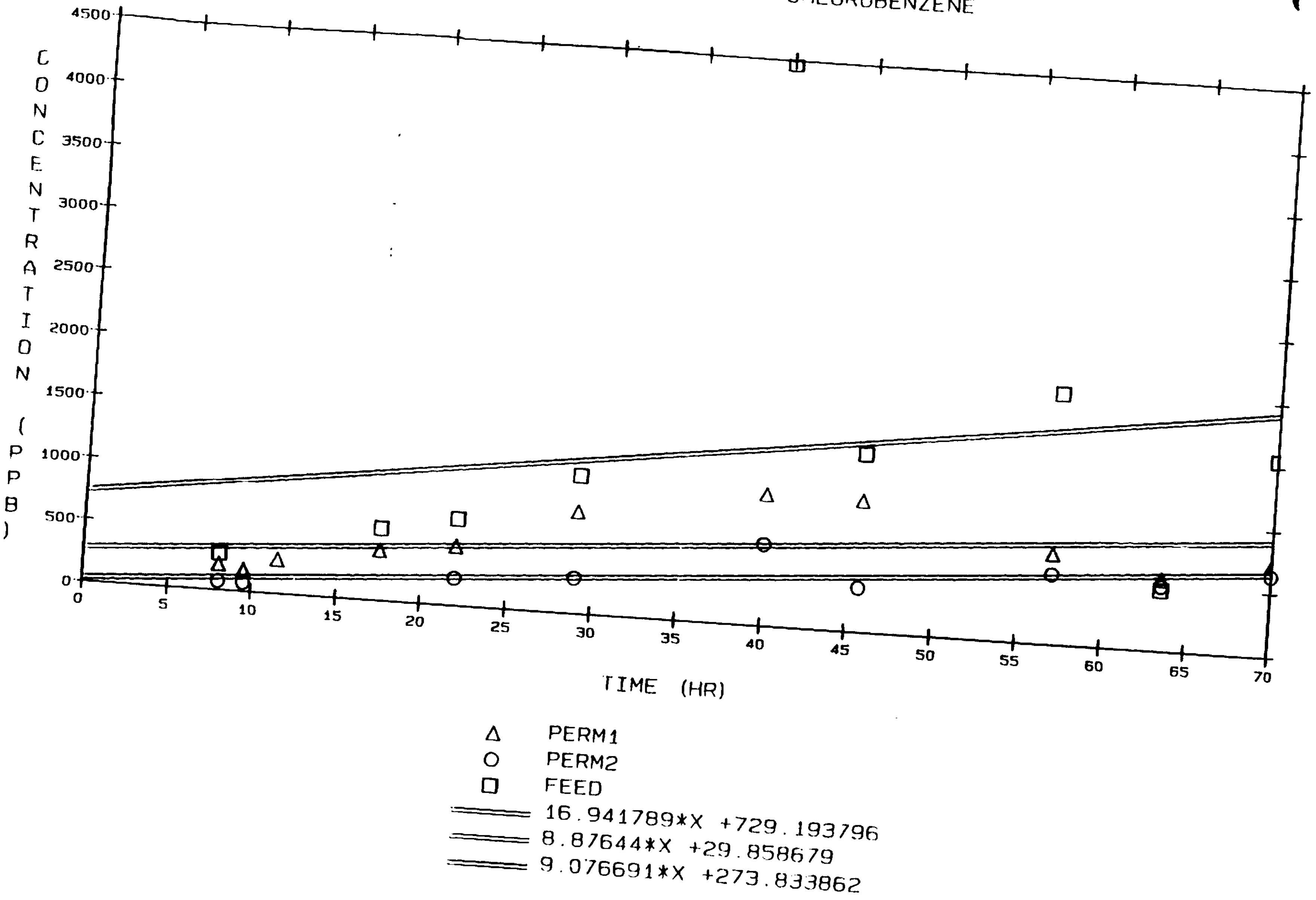
OSWEGO RO RESULTS - TOLUENE



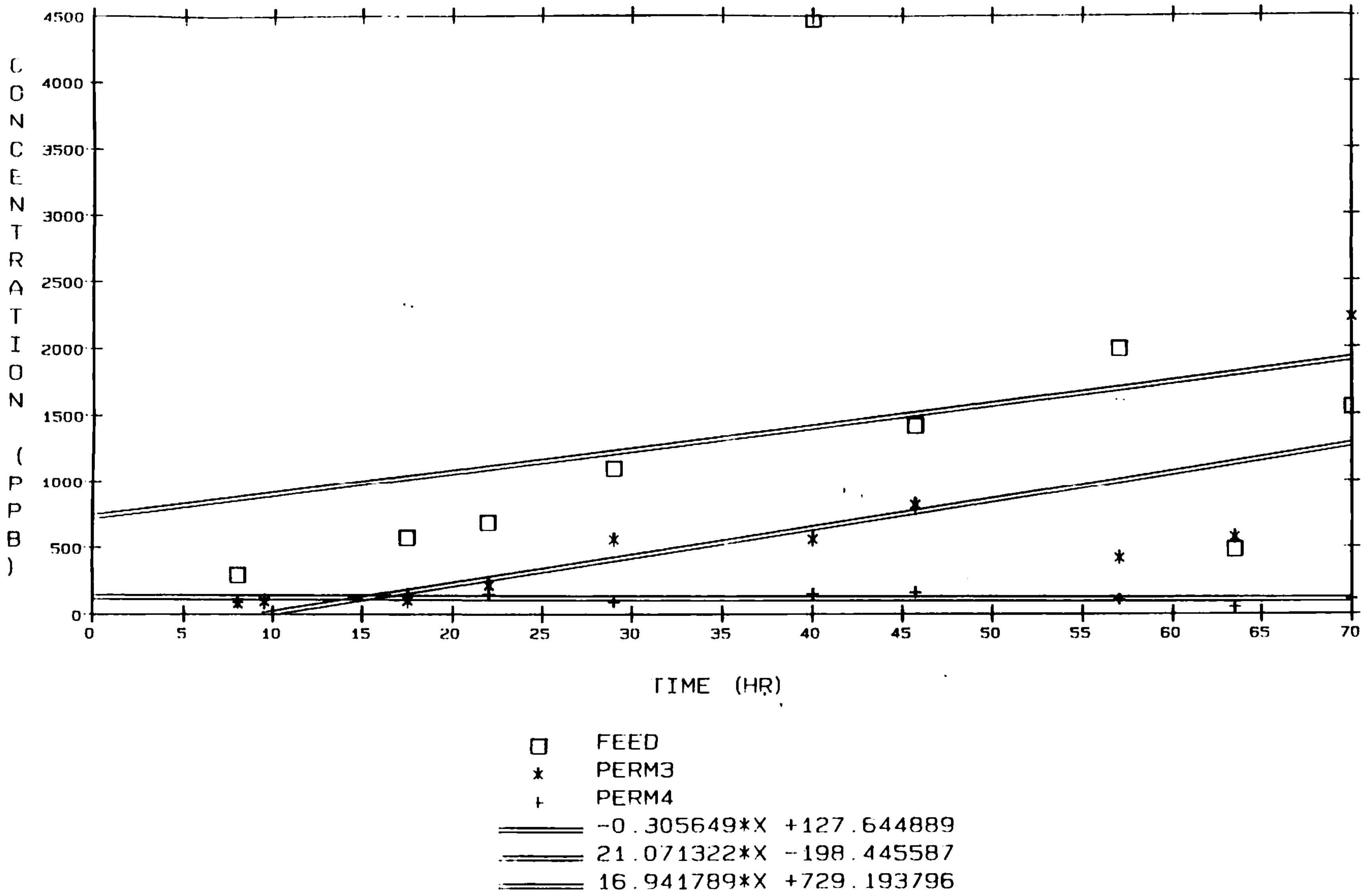
OSWEGO RO RESULTS - CHLOROBENZENE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0	289.693	202.264	72.470	80.422	93.331	546.90
9.5		164.495	67.847	98.128	109.490	702.55
11.5		266.944				101.09
17.5	567.910	395.939		102.567	139.412	1409.09
22.0	681.270	469.740	213.080	212.640	150.540	
29.0	1095.000	808.490	280.450	559.230	90.920	
40.0	4473.200	1047.810	645.540	558.090	150.040	3778.90
45.7	1413.000	1049.630	349.100	815.140	158.990	3671.50
57.0	1991.000	714.800	554.150	419.860	105.230	4526.10
63.5	478.740	566.510	511.320	574.850	53.730	1339.70
70.0	1548.300	717.510	634.480	2226.650	114.060	

RO RESULTS AT OSWEGO - CHLOROBENZENE



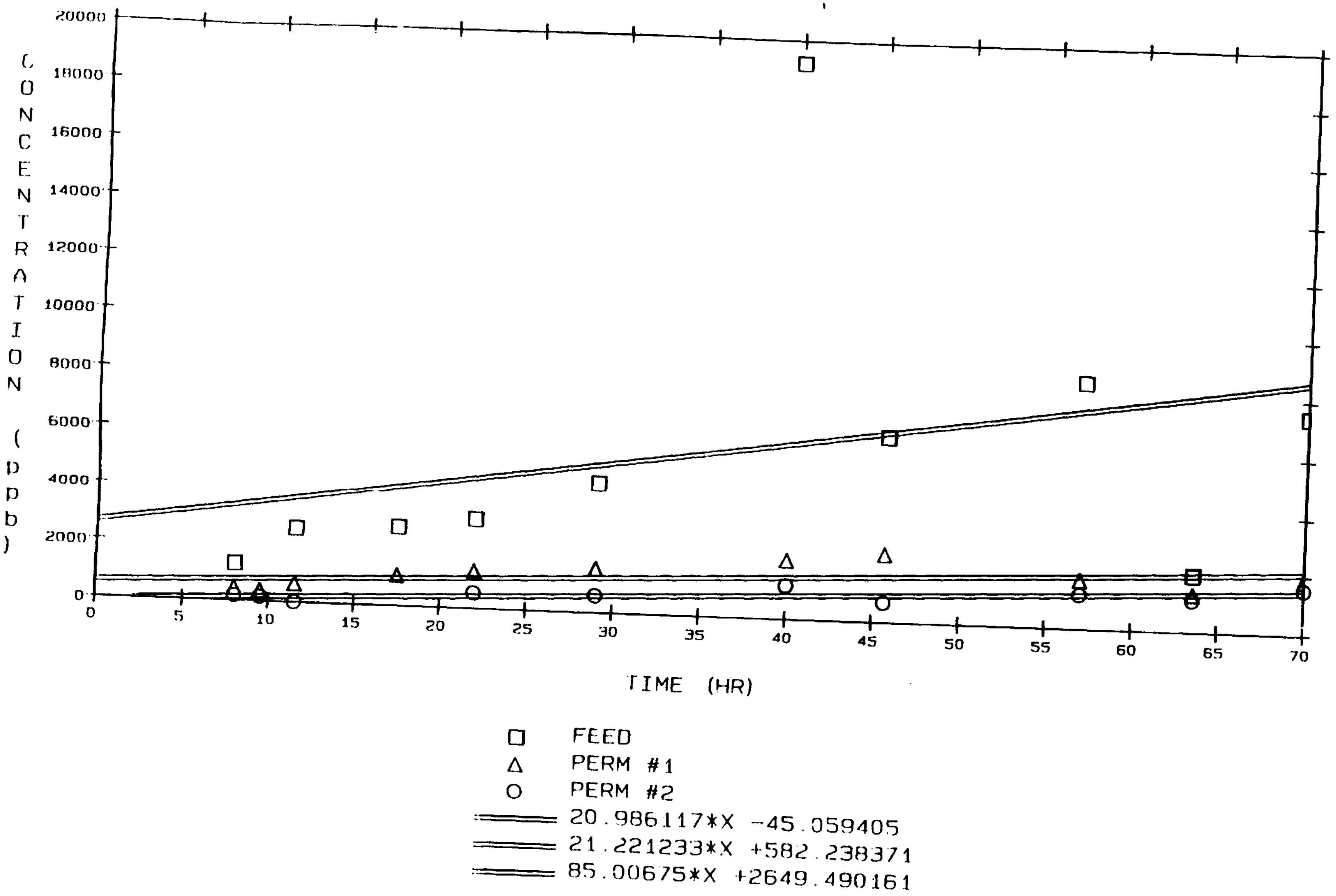
RO RESULTS AT OSWEGO - CHLOROBENZENE



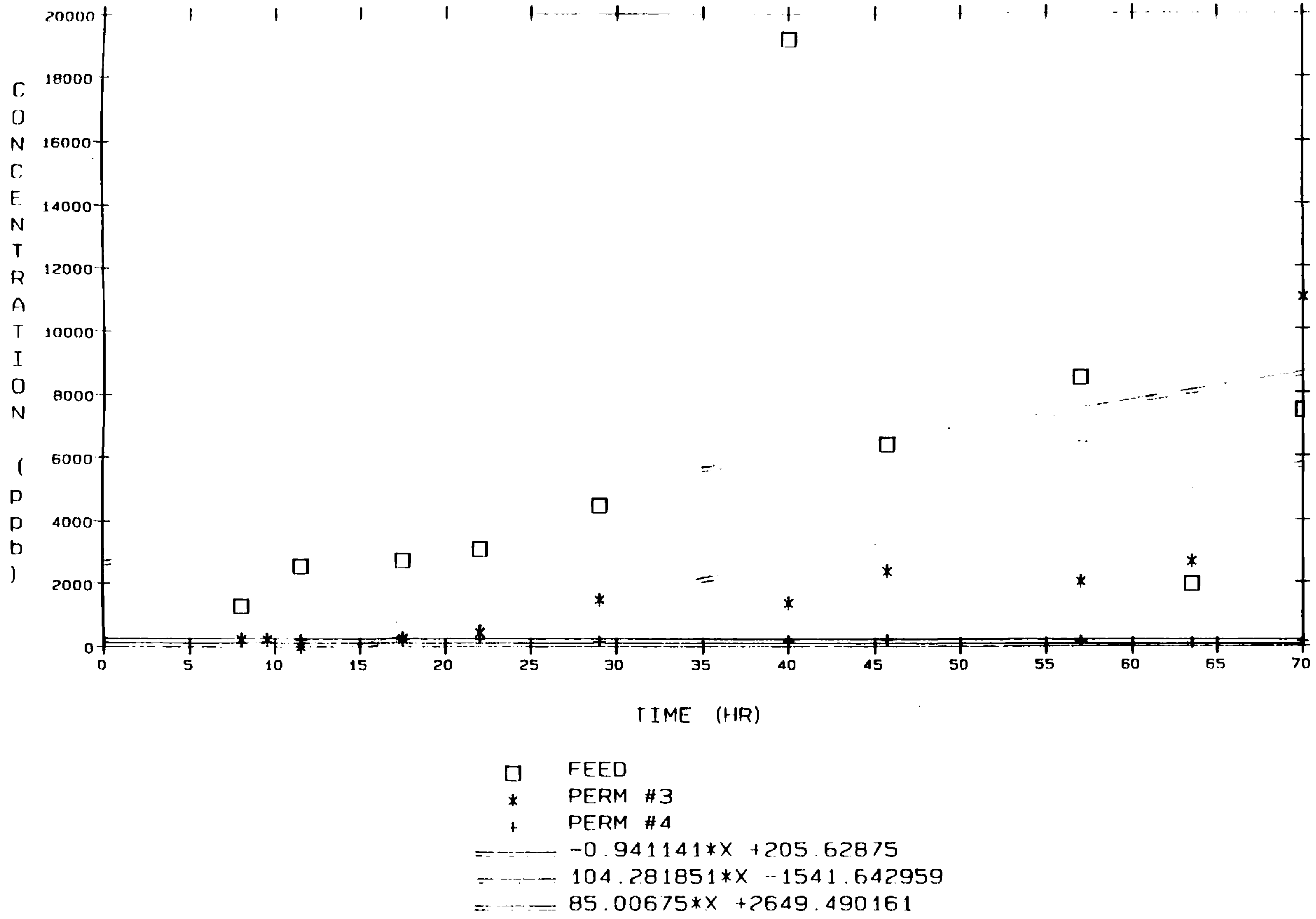
OSWEGO RO RESULTS - ETHYLBENZENE

TIME (HR)	FEED	PERM #1	PERM #2	PERM #3	PERM #4	CONC
0.8						
8.0	1265.94	424.203	162.980	224.237	138.659	2496.71
9.5		364.692	150.825	211.590	161.301	2686.62
11.5	2539.40	627.462	8.896	2.418	214.865	7419.64
17.5	2700.07	1024.400		244.510	232.167	6039.06
22.0	3057.25	1275.680	516.570	443.340	245.060	
29.0	4461.15	1513.720	577.730	1454.610	151.010	
40.0	19211.05	2002.730	1135.250	1350.410	175.070	12127.70
45.7	6376.40	2308.050	667.550	2350.260	197.940	13226.20
57.0	8470.60	1663.650	1170.010	2035.810	151.170	17824.60
63.5	1942.80	1300.420	1106.400	2669.670	79.450	664.50
70.0	7429.70	1829.990	1528.450	11025.200	163.520	

OSWEGO RO RESULTS - ETHYLBENZENE



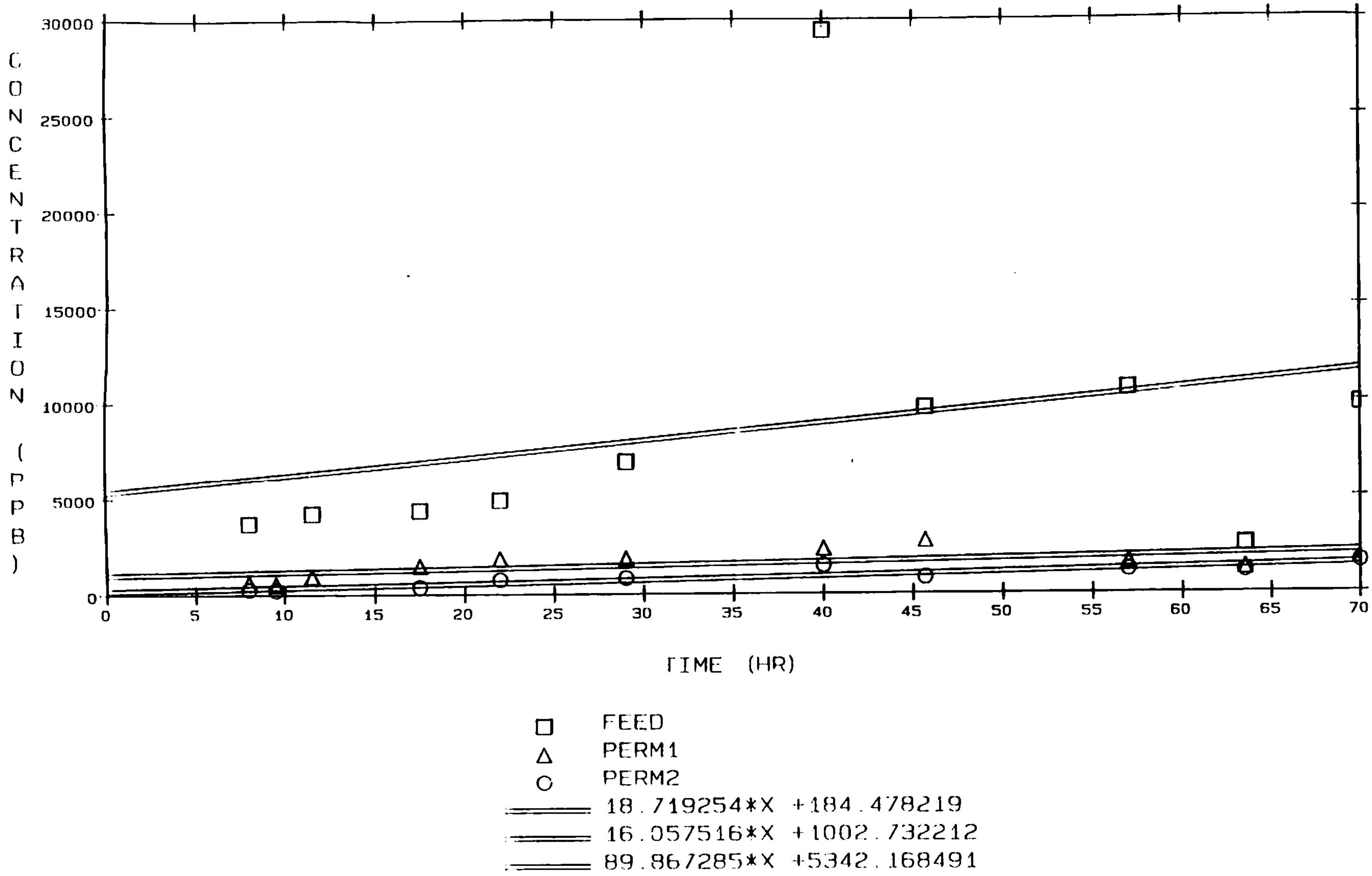
OSWEGO RO RESULTS - ETHYLBENZENE



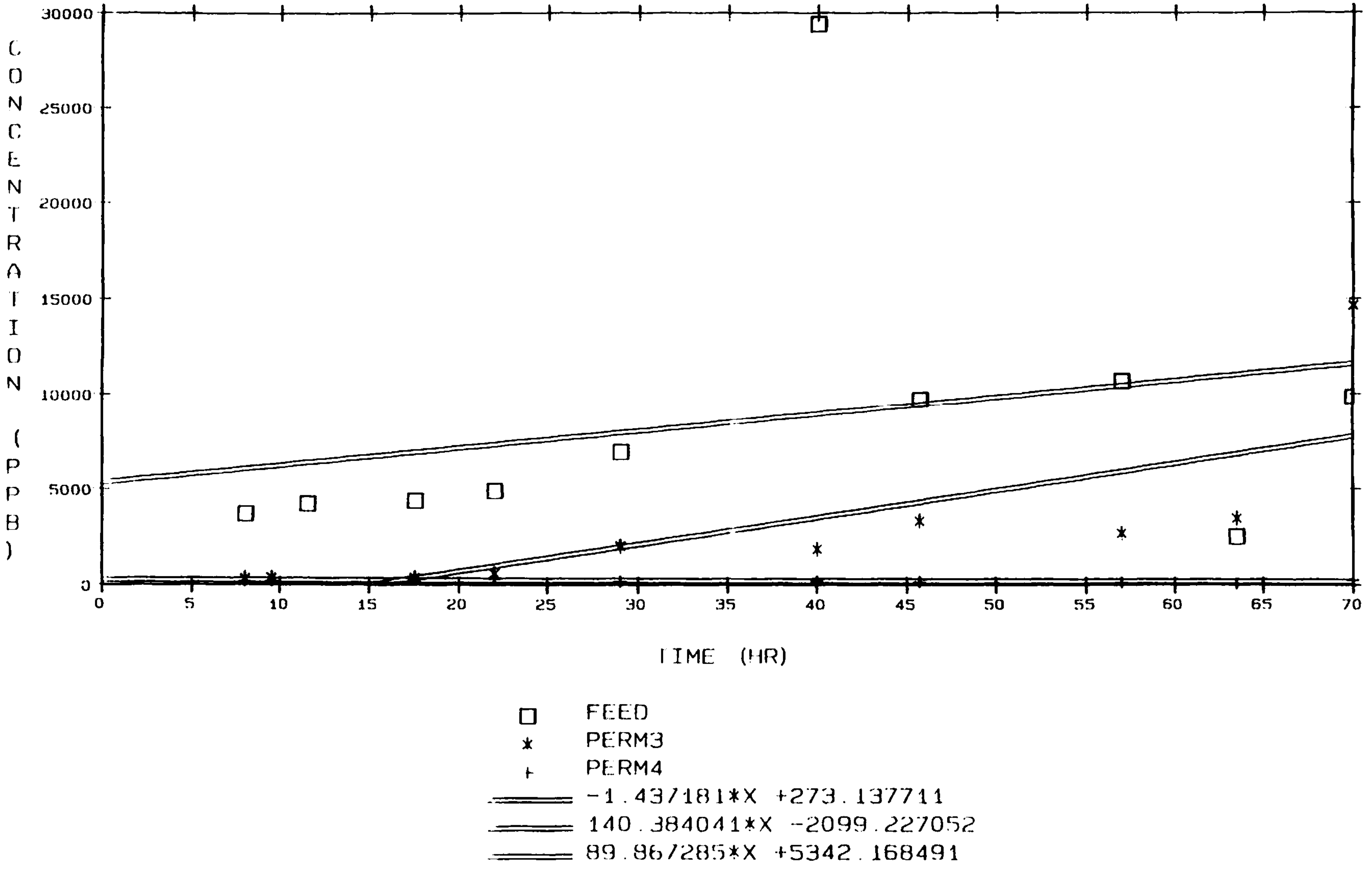
OSWEGO RO RESULTS - M,P-XYLENES

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0	3691.08	617.508	257.177	329.144	205.012	6380.11
9.5		538.490	231.839	386.622	220.067	6192.08
11.5	4196.56	925.980				12243.26
17.5	4373.42	1454.110	394.210	359.313	313.201	10122.06
22.0	4888.26	1844.410	741.800	604.290	339.280	
29.0	6913.55	1841.870	809.050	2033.630	200.000	
40.0	29393.30	2347.280	1461.090	1893.310	220.210	18410.00
45.7	9698.70	2740.080	838.060	3361.940	204.430	17206.90
57.0	10660.30	1620.410	1188.910	2715.390	164.970	23613.90
63.5	2533.88	1279.640	1128.260	3511.290	81.470	8958.60
70.0	9802.30	1820.970	1574.500	14659.900	262.190	

RO RESULTS AT OSWEGO META-XYLENE
- PARA-XYLENE



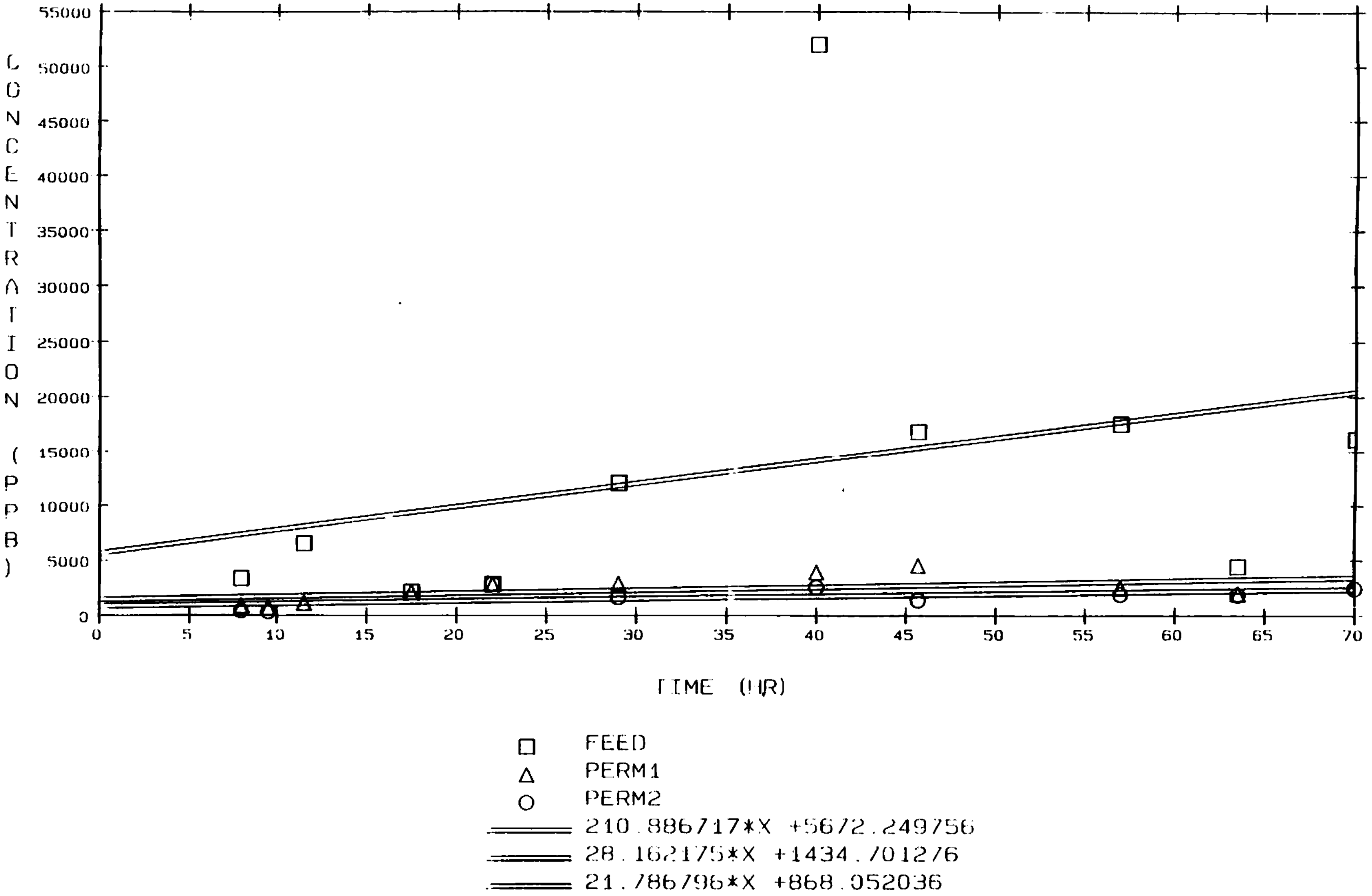
RO RESULTS AT OSWEGO - META-XYLENE
- PARA-XYLENE



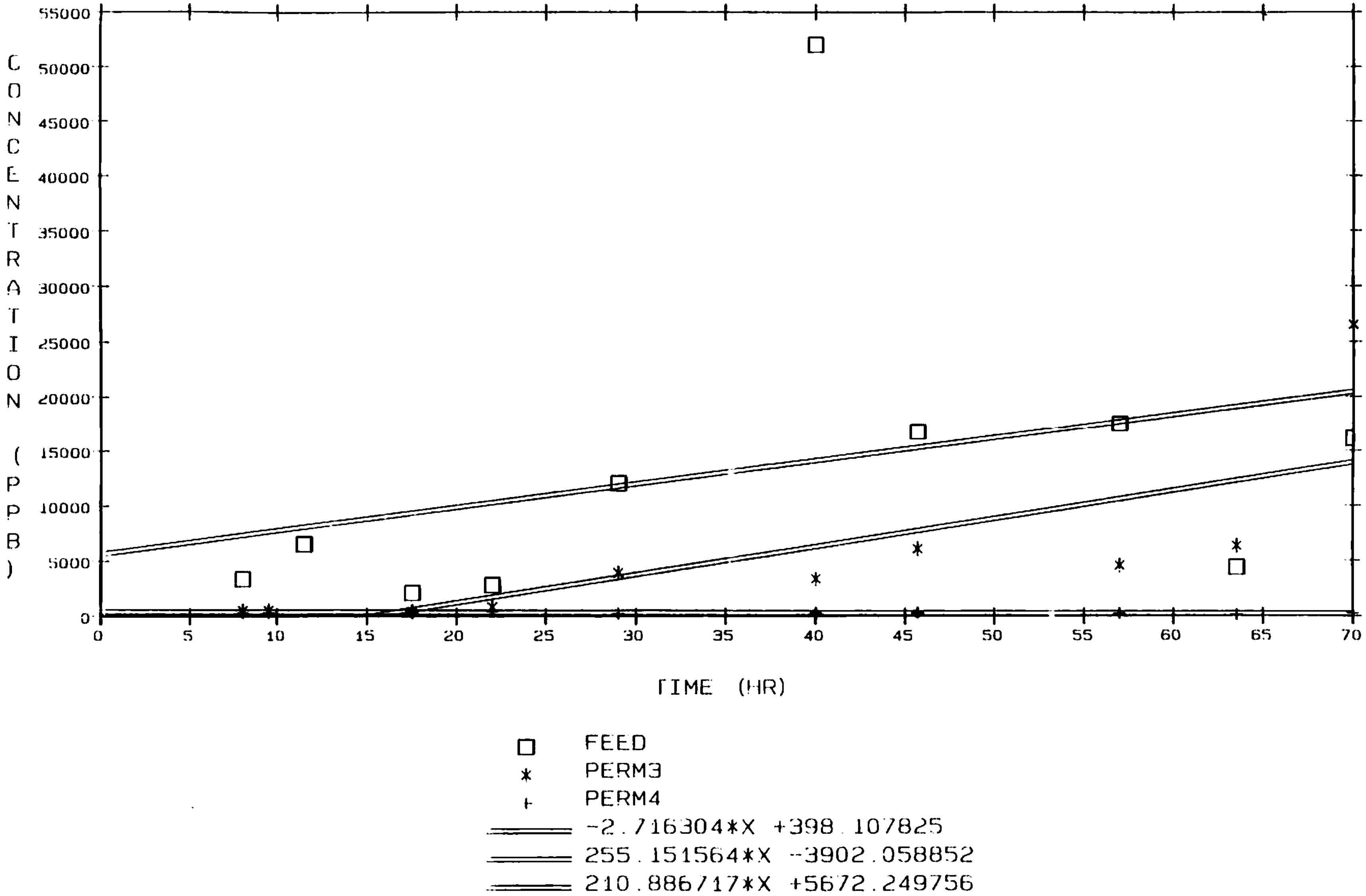
OSWEGO RO RESULTS - O-XYLENE

TIME	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0	3338.77	878.953	397.634	517.903	303.179	7610.88
9.5		749.556	331.903	553.959	317.527	7799.47
11.5	6493.04	1148.380				21040.67
17.5	2109.13	2109.130		485.466	418.167	18293.83
22.0	2819.62	2819.620	2819.620	862.380	460.300	
29.0	11992.45	2864.290	1669.910	3962.730	265.290	
40.0	52033.00	3968.920	2555.910	3404.000	310.190	34620.90
45.7	16773.10	4502.650	1390.610	6086.900	295.710	313428.90
57.0	17459.20	2491.120	1883.130	4609.640	263.190	42763.60
63.5	4433.93	1990.010	1827.480	6353.930	111.260	15818.20
70.0	16075.20	2783.290	2446.180	26558.400	252.420	

RO RESULTS AT OSWEGO - ORTHO-XYLENE



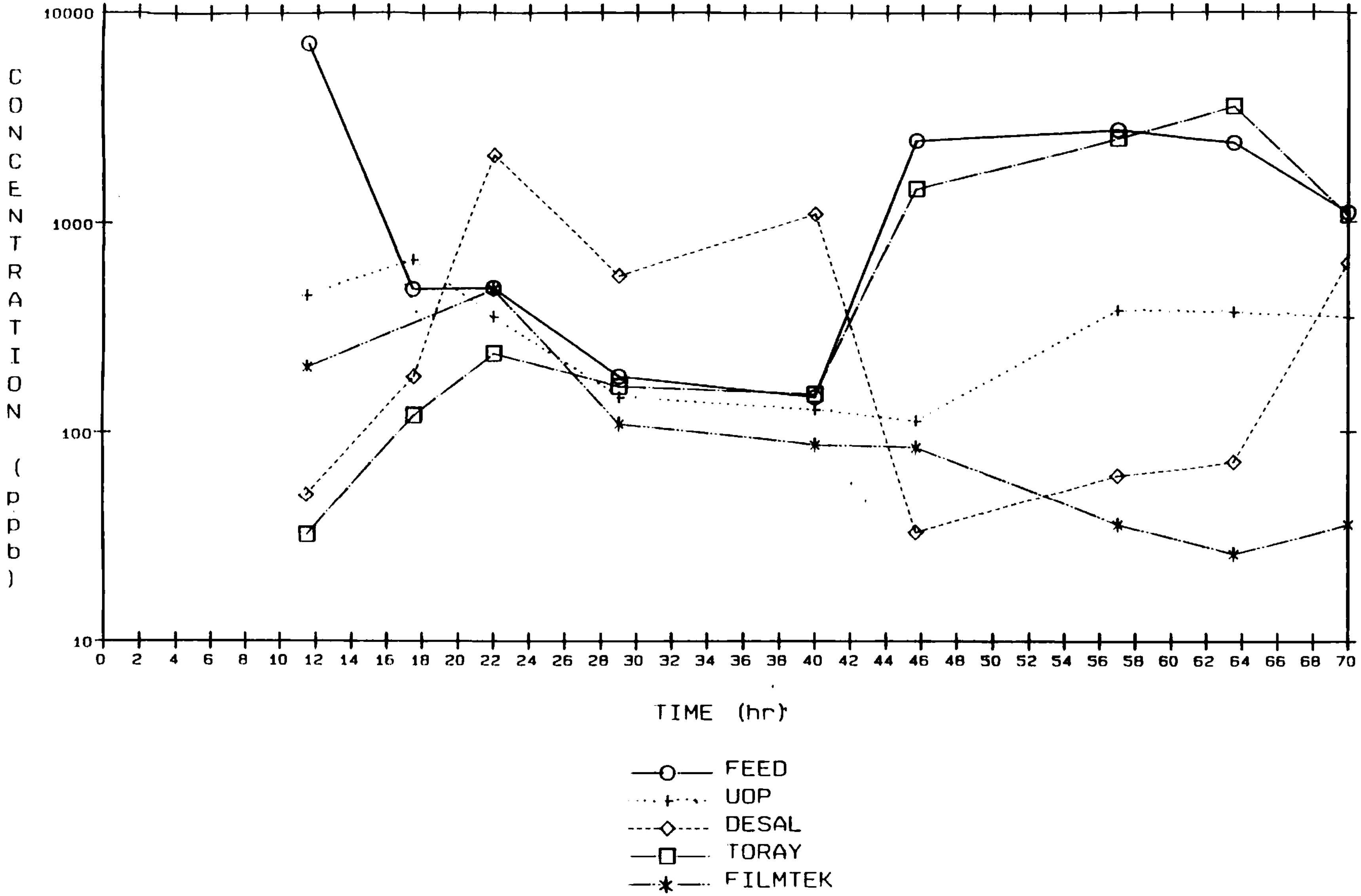
RO RESULTS AT OSWEGO - ORTHO-XYLENE



OSWEGO RO RESULTS - PHENOL

TIME (hr)	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.0						
8.0						
9.5						
11.5	7155	447.0	50.0	32.0	203.0	
17.5	475	657.0	184.0	120.0	ND	
22.0	485	353.0	2119.0	237.0	478.0	
29.0	183	146.0	555.0	164.0	109.0	
40.0	146	128.0	1100.0	151.0	87.0	
45.7	2474	113.0	33.0	1450.0	84.0	
57.0	2778	378.0	62.0	2533.0	36.0	5906
63.5	2402	369.0	72.0	3582.0	26.0	
70.0	1104	348.0	634.0	1076.0	36.0	
MEAN	1911	327.0	534.0	1038.0	122.0	
% REMOVAL		82.9	72.1	45.7	93.6	

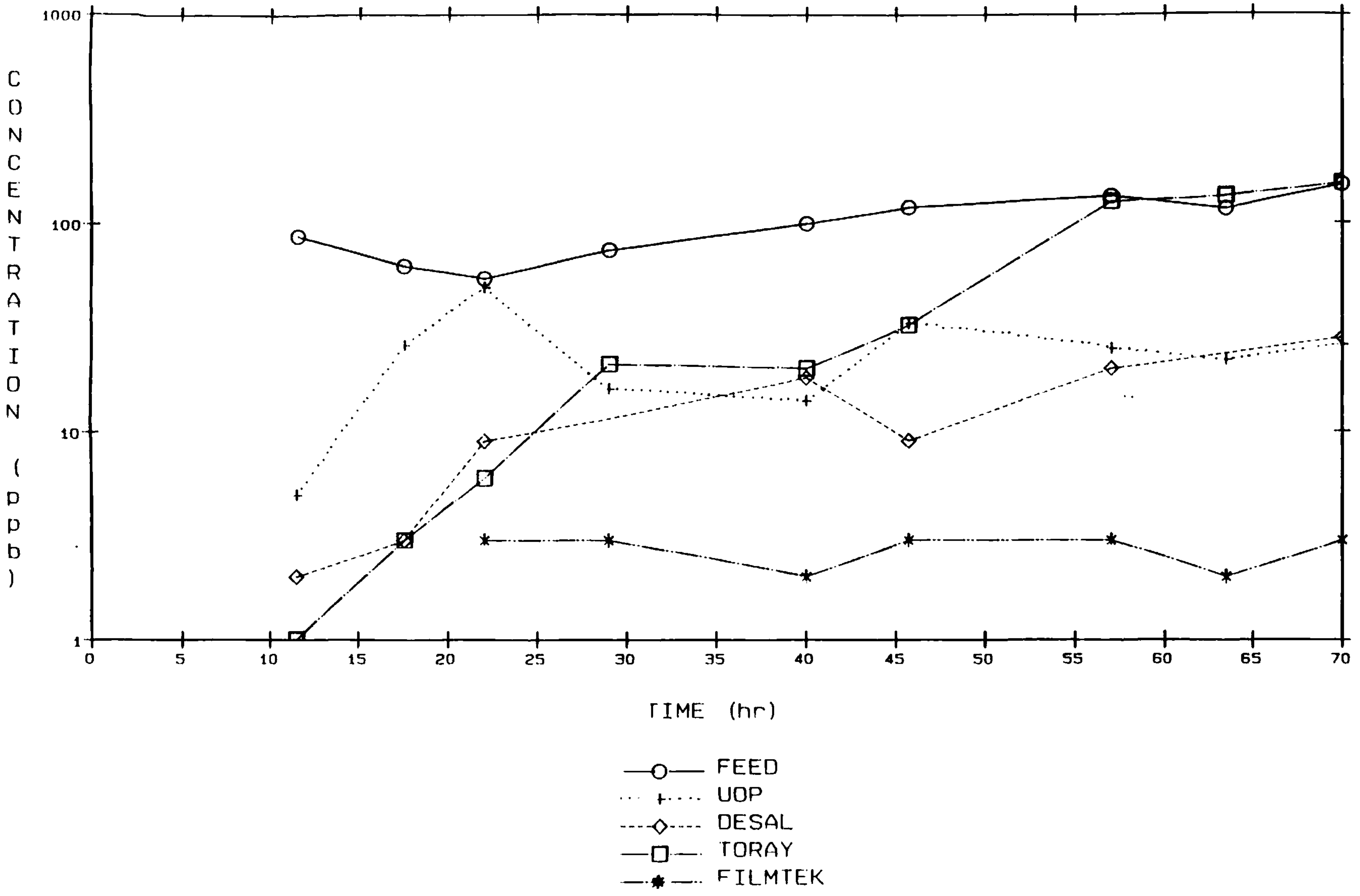
OSWEGO RO RESULTS - PHENOL



OSWEGO RESULTS - 1,2-DICHLOROBENZENE

	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0						
9.5						
11.5	87	5	2	1	ND	
17.5	62	26	3	3	ND	
22.0	54	49	9	6	3	
29.0	74	16	ND	21	3	
40.0	99	14	18	20	2	
45.7	119	33	9	32	3	
57.0	135	25	20	127	3	ND
63.5	117	22	ND	135	2	
70.0	153	26	28	156	3	
MEAN	100	24	13	56	3	
% REMOVAL		76	87	44	97	

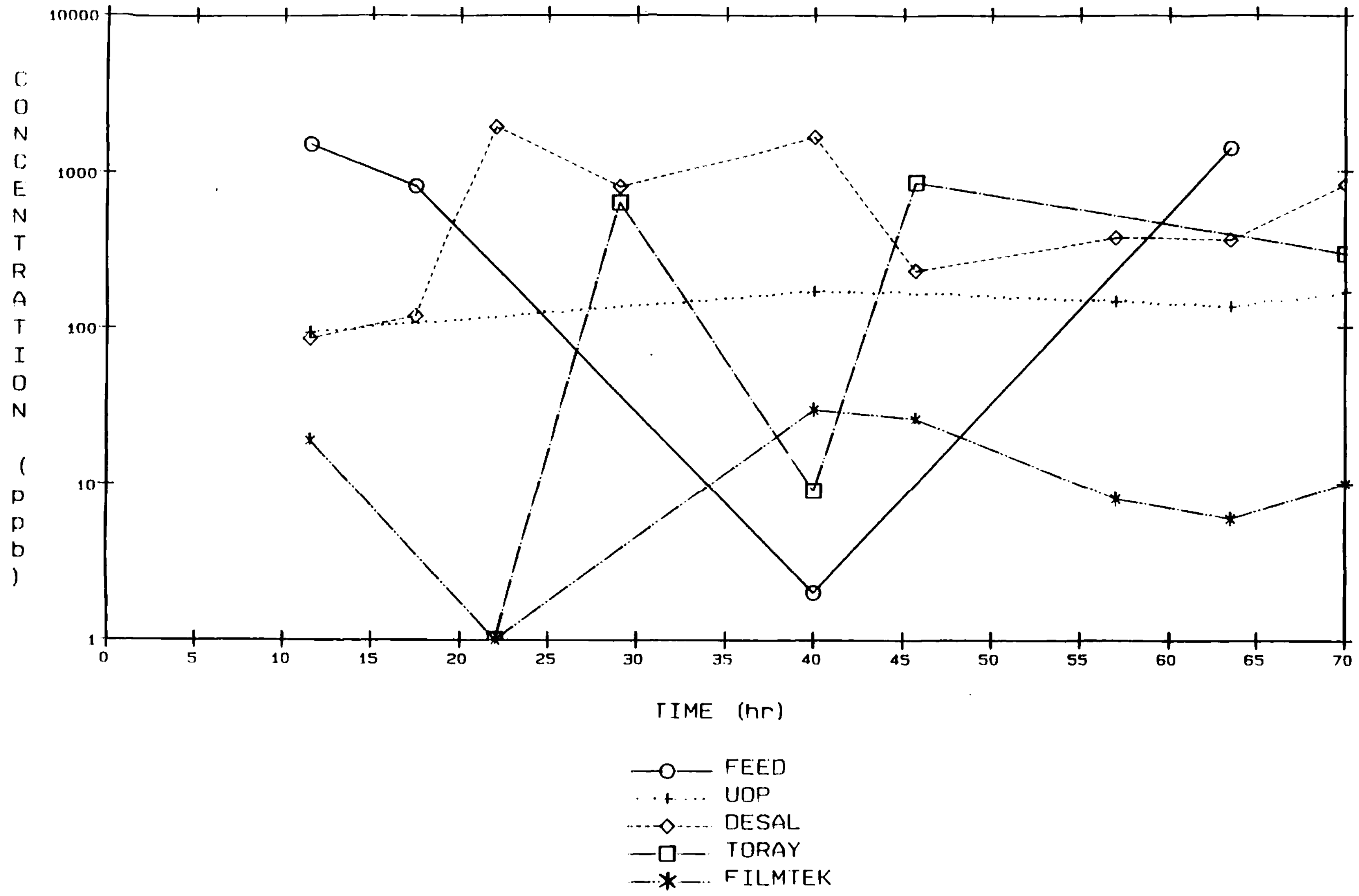
OSWEGO RO RESULTS - 1. 2-DICHLOROBENZENE



OSWEGO RESULTS - 2-METHYLPHENOL

	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0						
9.5						
11.5	1520	94.0	ND	ND	19.0	
17.5	813	ND	ND	ND	ND	
22.0	ND	ND	ND	1.0	1.0	
29.0	ND	ND	ND	635.0	ND	
40.0	2	171.0	ND	9.0	30.0	
45.7	ND	ND	ND	851.0	26.0	
57.0	ND	147.0	ND	ND	8.0	3185
63.5	1413	135.0	96.0	ND	6.0	
70.0	ND	167.0	202.0	291.0	10.0	
MEAN	937	143.0	149.0	357.0	14.0	
% REMOVAL		84.7	84.1	61.9	98.5	

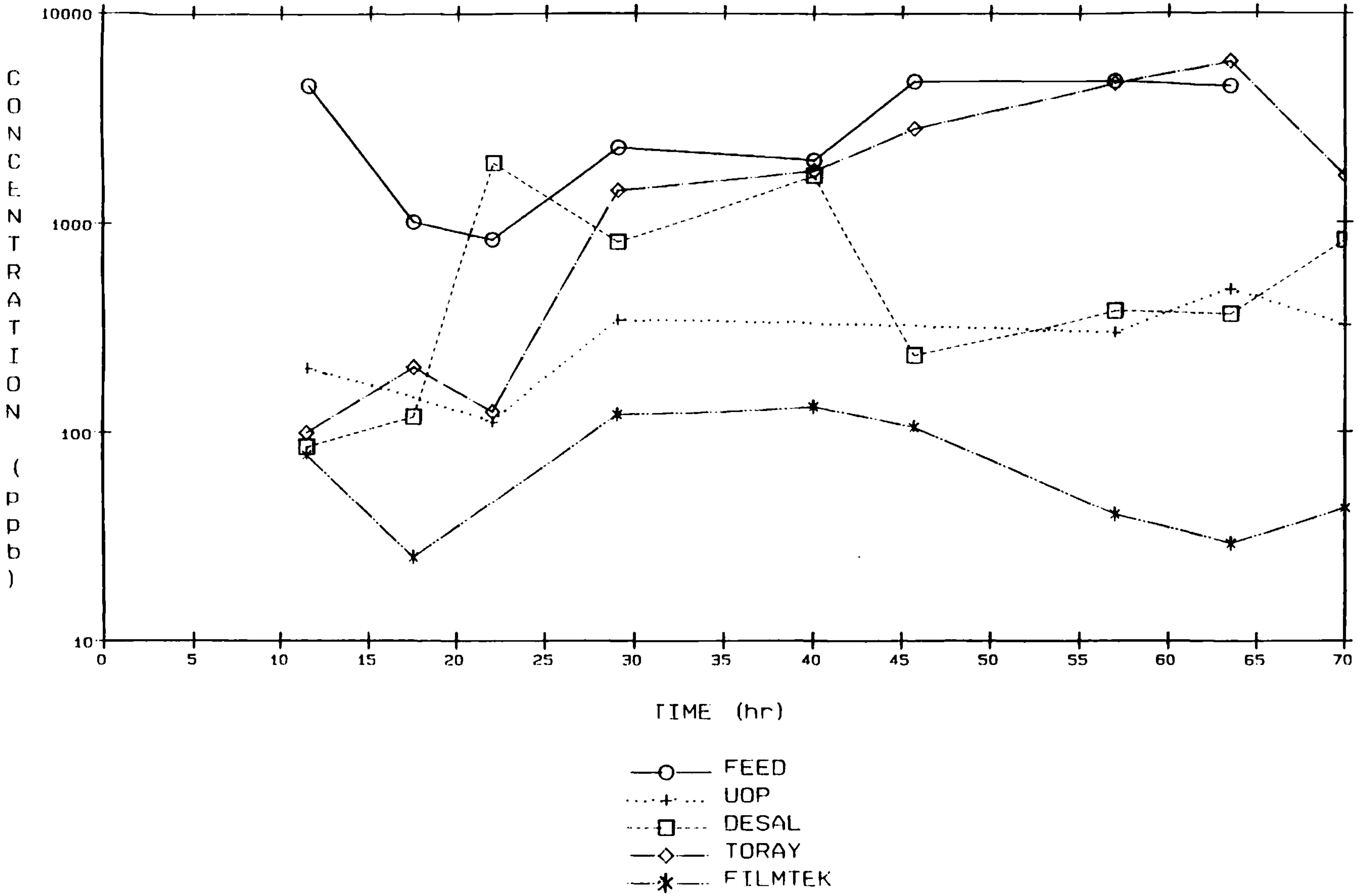
OSWEGO RESULTS - 2-METHYLPHENOL



OSWEGO RESULTS - 4-METHYLPHENOL

	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0						
9.5						
11.5	4620	201.0	85	99.0	78.0	
17.5	1008	ND	118	204.0	25.0	
22.0	825	112.0	1961	125.0	ND	
29.0	2320	342.0	807	1433.0	121.0	
40.0	2017	ND	1699	1794.0	132.0	
45.7	4797	ND	230	2854.0	105.0	
57.0	4811	297.0	376	4699.0	40.0	10736
63.5	4524	476.0	361	5883.0	29.0	
70.0	ND	322.0	817	1674.0	43.0	
MEAN	3115	292.0	717	2085.0	71.6	
% REMOVAL		90.6	77	33.1	97.7	

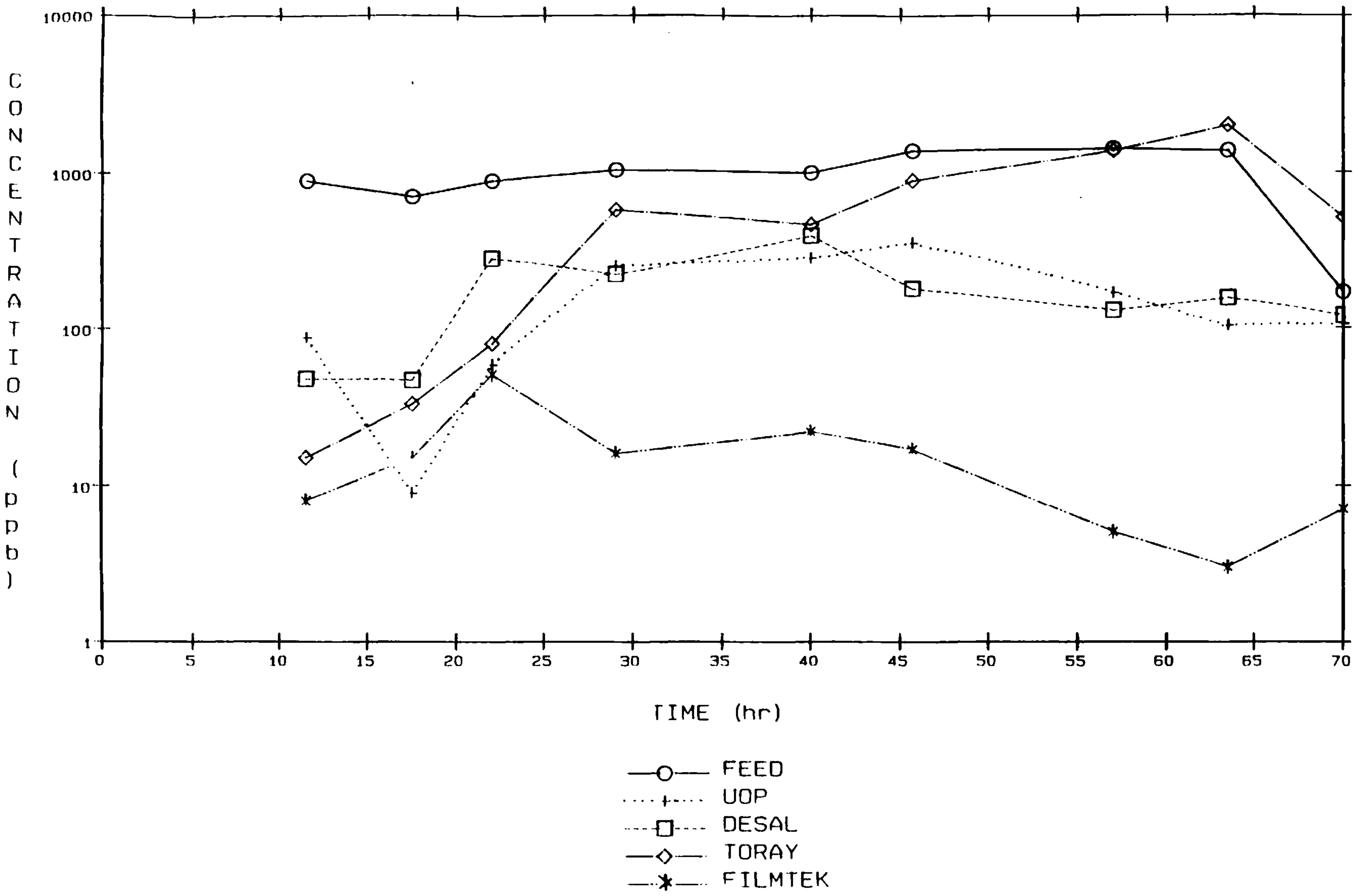
OSWEGO RESULTS - 4-METHYLPHENOL



OSWEGO RO RESULTS - 2,4-DIMETHYLPHENOL

	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0						
9.5						
11.5	902	88.0	48.0	15.0	8.0	
17.5	706	9.0	47.0	33.0	15.0	
22.0	895	59.0	279.0	80.0	51.0	
29.0	1054	251.0	222.0	579.0	16.0	
40.0	1000	284.0	392.0	463.0	22.0	
45.7	1390	353.0	178.0	891.0	17.0	
57.0	1428	170.0	130.0	1384.0	5.0	3286
63.5	1383	104.0	155.0	1992.0	3.0	
70.0	170	106.0	120.0	512.0	7.0	
MEAN	992	158.0	175.0	661.0	16.0	
% REMOVAL		84.1	82.4	33.4	98.4	

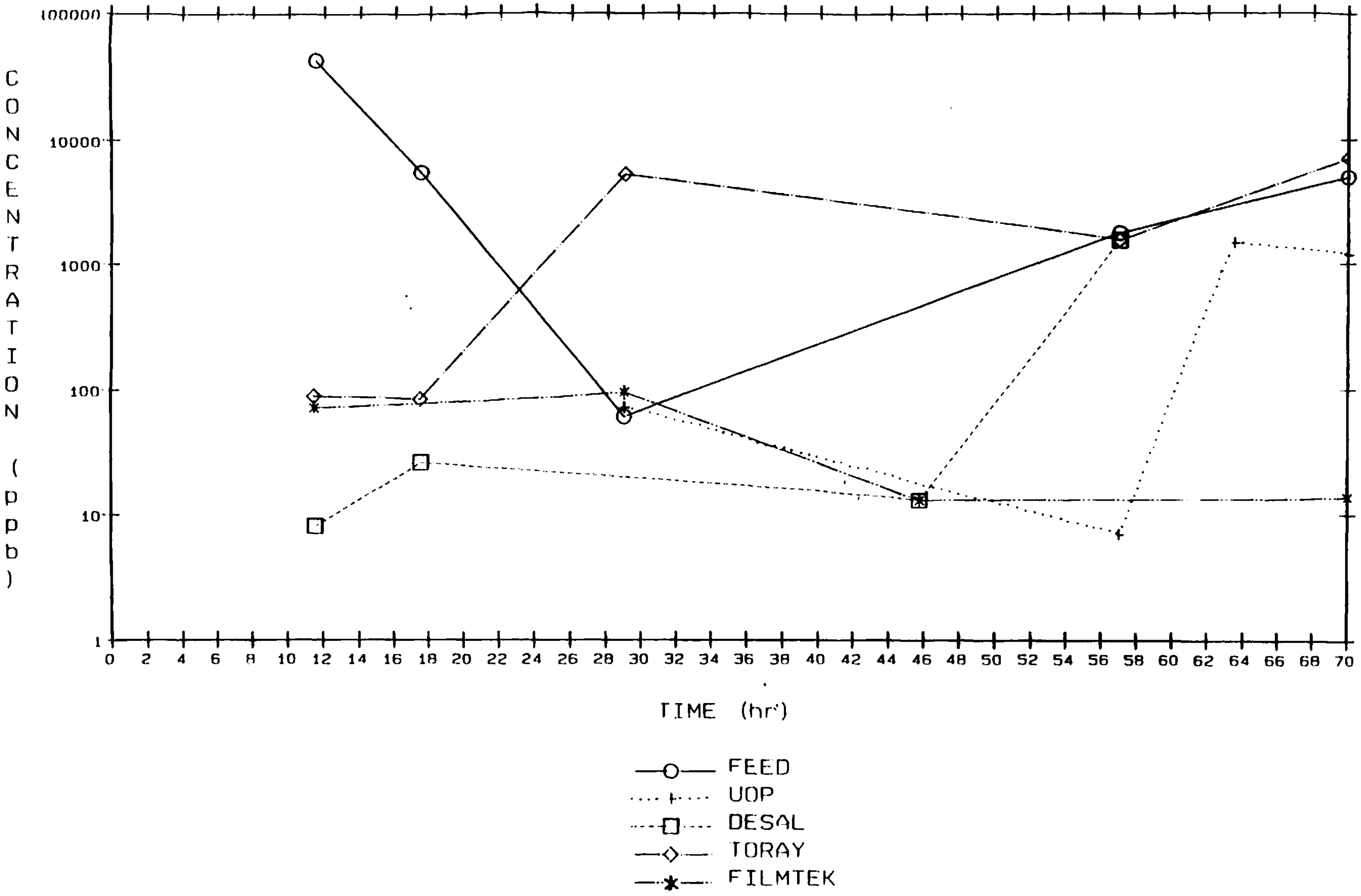
OSWEGO RESULTS - 2,4-DIMETHYLPHENOL



OSWEGO RO RESULTS - BENZOIC ACID

TIME (hr)	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.0						
8.0						
9.5						
11.5	42331	ND	8.0	87.0	71.0	
17.5	5436	ND	26.0	83.0	ND	
22.0	ND	ND	ND	ND	ND	
29.0	60	72.0	ND	5258.0	95.0	
40.0	ND	ND	ND	ND	ND	
45.7	ND	ND	13.0	ND	13.0	
57.0	1787	7.0	1549.0	1578.0	ND	21574
63.5	ND	1482.0	ND	ND	ND	
70.0	4988	1199.0	ND	7107.0	14.0	
MEAN	10920	690.0	399.0	2823.0	48.3	
% REMOVAL		93.7	96.3	74.2	99.6	

OSWEGO RESULTS BENZOIC ACID



OSWEGO RO RESULTS - BIS(2-ETHYLHEXYL)PHTHALATE

	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0						
9.5						
11.5	86	4.0	ND	8	15	
17.5	ND	101.0	ND	2	5	
22.0	14	ND	ND	1	10	
29.0	ND	2.0	ND	53	ND	
40.0	128	ND	ND	128	9	
45.7	ND	2.0	5	ND	5	
57.0	ND	4.0	2	ND	4	ND
63.5	92	3.0	18	ND	9	
70.0	ND	2.0	ND	ND	7	
MEAN	80	17.0	8	38	8	
% REMOVAL		78.8	90	52	90	

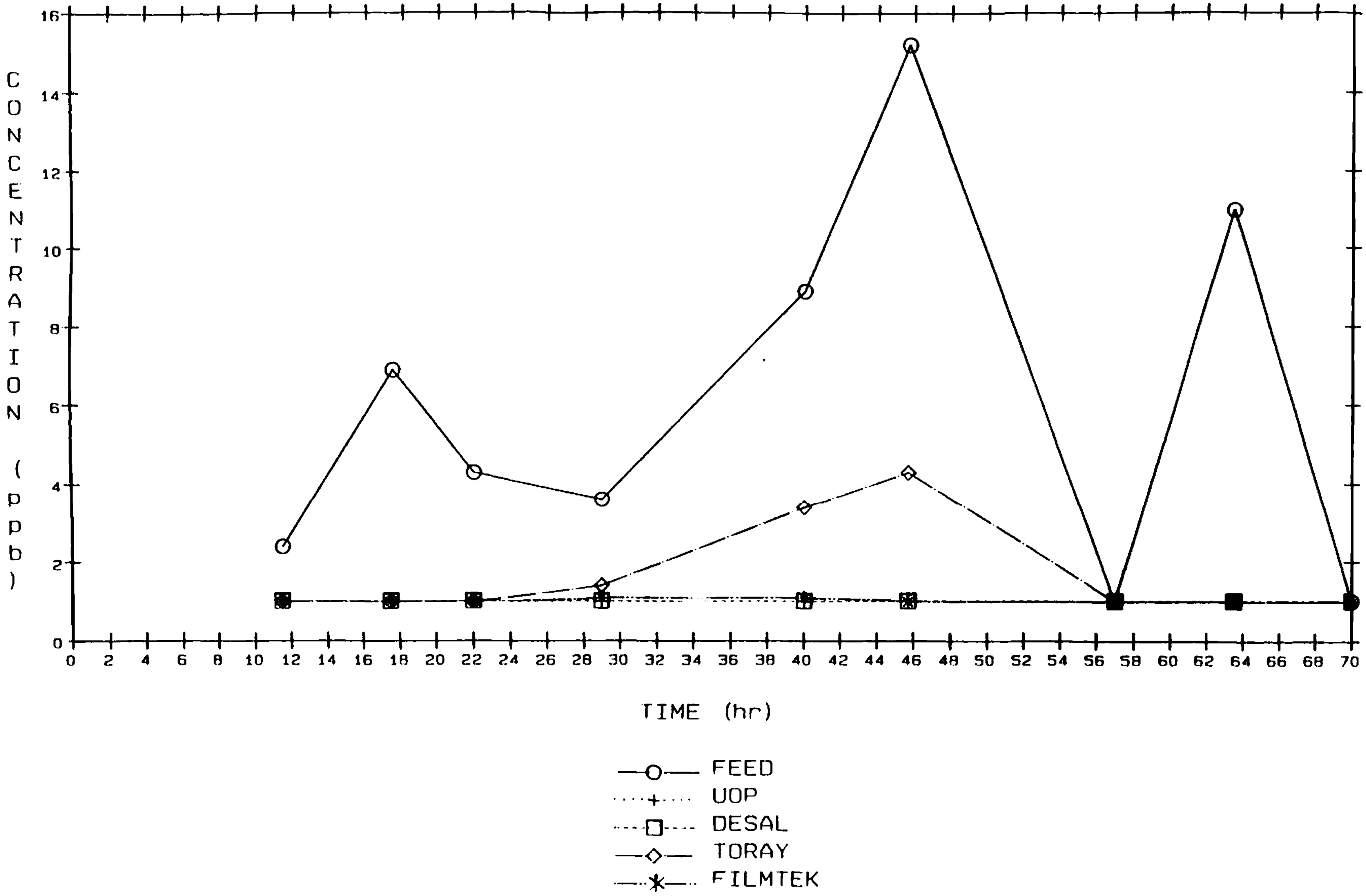
OSWEGO RO RESULTS - DI-N-OCTYLPHTHALATE

	FEED	PERM1	PERM2	PERM3	PERM4	CONC
0.8						
8.0						
9.5						
11.5	ND	19	ND	ND	3	
17.5	ND	ND	2	ND	3	
22.0	31	1	8	ND	3	
29.0	7	ND	ND	ND	ND	
40.0	ND	1	ND	ND	5	
45.7	ND	ND	3	ND	7	
57.0	ND	ND	ND	ND	3	ND
63.5	ND	3	33	ND	4	
70.0	ND	ND	ND	ND	1	

OSWEGO RESULTS - RO METALS - ANTIMONY

TIME (hr)	FEED	PERM1	PERM2	PERM3	PERM4
0.0					
8.0					
9.5					
11.5	2.4	1.0	1.0	1.0	1.0
17.5	6.9	1.0	1.0	1.0	1.0
22.0	4.3	1.0	1.0	1.0	1.0
29.0	3.6	1.0	1.0	1.4	1.1
40.0	8.9	1.0	1.0	3.4	1.1
45.7	15.2	1.0	1.0	4.3	1.0
57.0	1.0	1.0	1.0	1.0	1.0
63.5	11.0	1.0	1.0	1.0	1.0
70.0	1.0	1.0	1.0	1.0	1.0

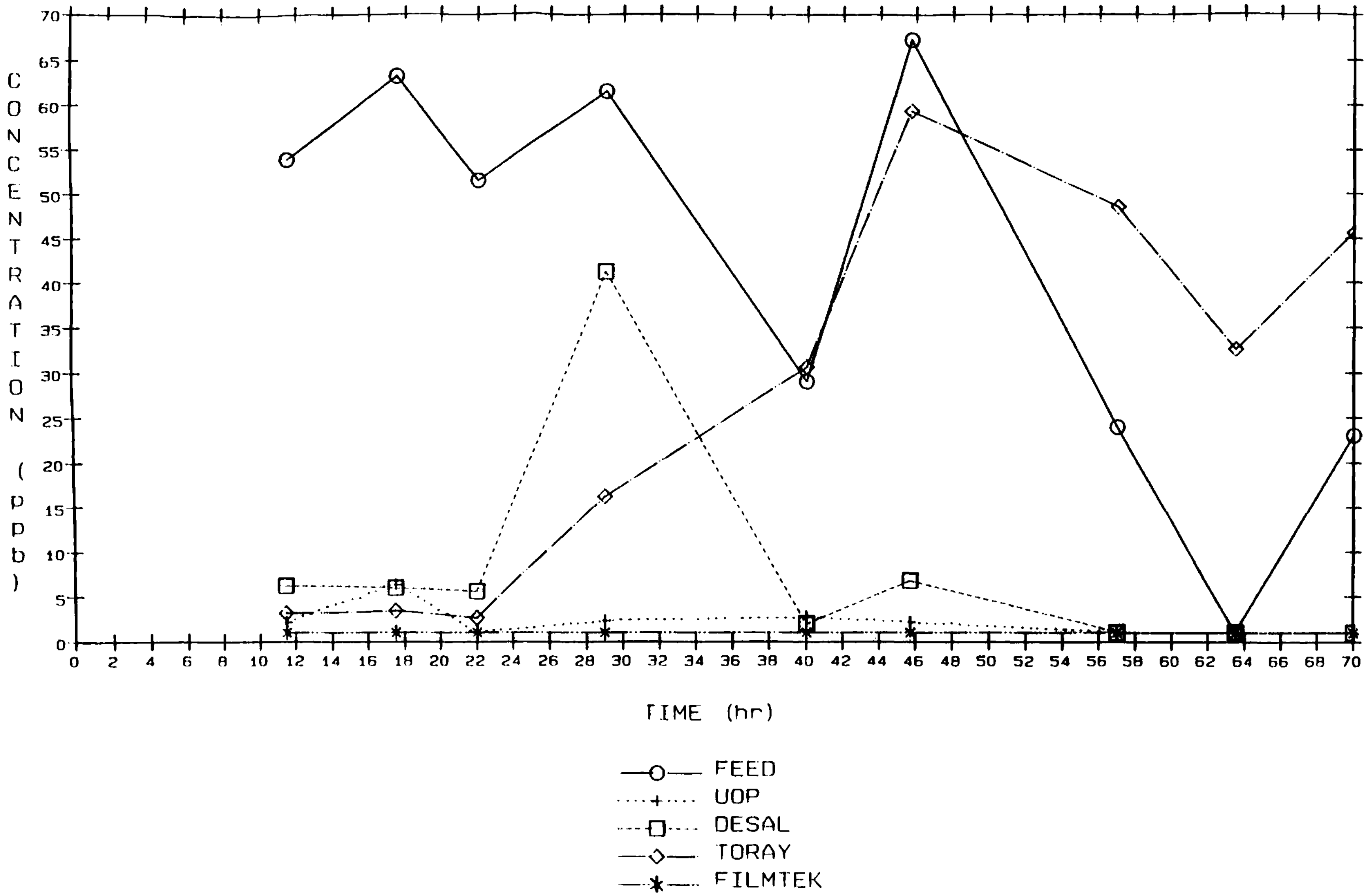
OSWEGO RESULTS - RO METALS - ANTIMONY



OSWEGO RESULTS - RO METALS - ARSENIC

TIME (hr)	FEED	PERM1	PERM2	PERM3	PERM4
0.0					
8.0					
9.5					
11.5	54.0	2.2	6.2	3.2	1.0
17.5	63.2	6.4	6.0	3.4	1.0
22.0	51.6	1.0	5.6	2.6	1.0
29.0	61.6	2.4	41.2	16.2	1.0
40.0	29.0	2.8	2.0	30.6	1.0
45.7	67.2	2.2	6.8	59.4	1.0
57.0	24.0	1.0	1.0	48.6	1.0
63.5	1.0	1.0	1.0	32.6	1.0
70.0	23.0	1.0	1.0	45.6	1.0

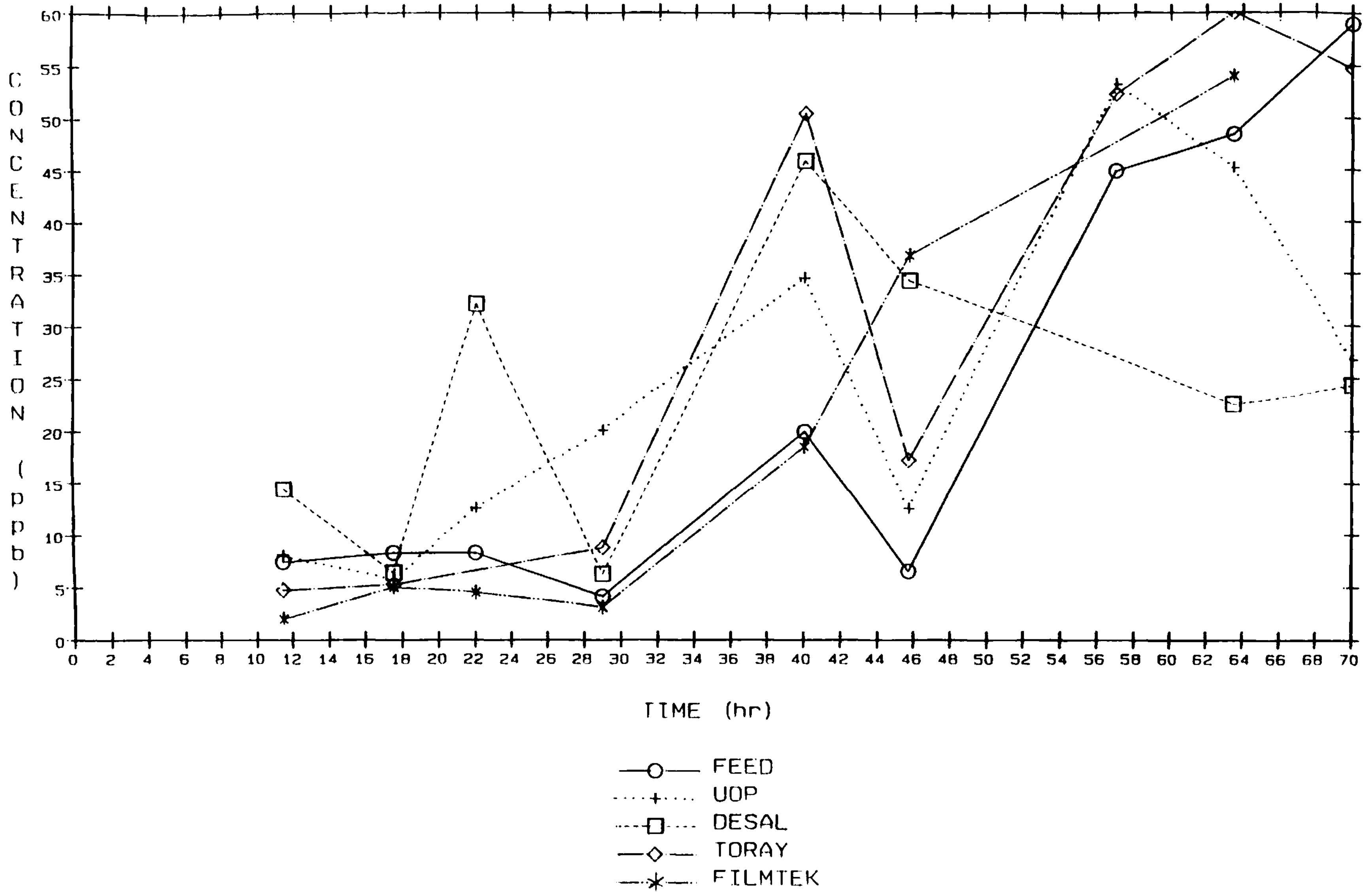
OSWEGO RESULTS - RO METALS - ARSENIC



OSWEGO RESULTS - RO METALS - LEAD

TIME (hr)	FEED	PERM1	PERM2	PERM3	PERM4
0.0					
8.0					
9.5					
11.5	7.4	8.0	14.4	4.7	2.0
17.5	8.3	5.7	6.4	5.3	5.0
22.0	8.3	12.6	32.1		4.5
29.0	4.1	20.1	6.2	8.8	3.1
40.0	19.9	34.6	45.9	50.5	18.5
45.7	6.5	12.5	34.3	17.2	36.8
57.0	44.9	53.3		52.3	
63.5	48.4	45.2	22.5	60.0	54.0
70.0	59.0	26.8	24.3	54.7	

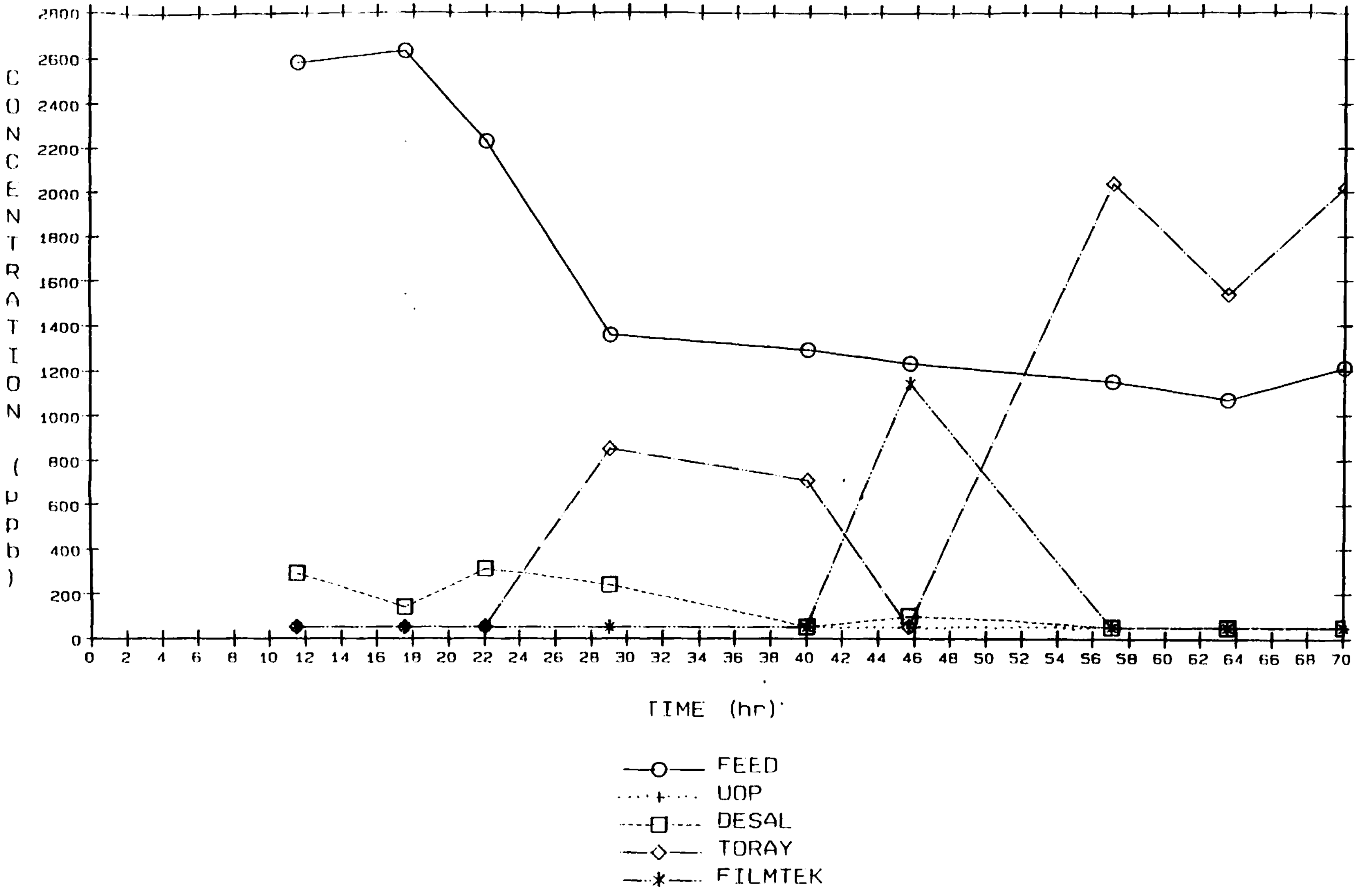
OSWEGO RESULTS - METALS RO - LEAD



OSWEGO RESULTS - RO METALS - NICKEL

TIME (hr)	FEED	PERM1	PERM2	PERM3	PERM4
0.0					
8.0					
9.5					
11.5	2580	50	290	50	50
17.5	2630	50	140	50	50
22.0	2230	50	310	50	50
29.0	1360	50	240	850	50
40.0	1290	50	50	710	50
45.7	1230	50	100	50	1140
57.0	1150	50	50	2040	50
63.5	1070	50	50	1540	50
70.0	1210	50	50	2020	50

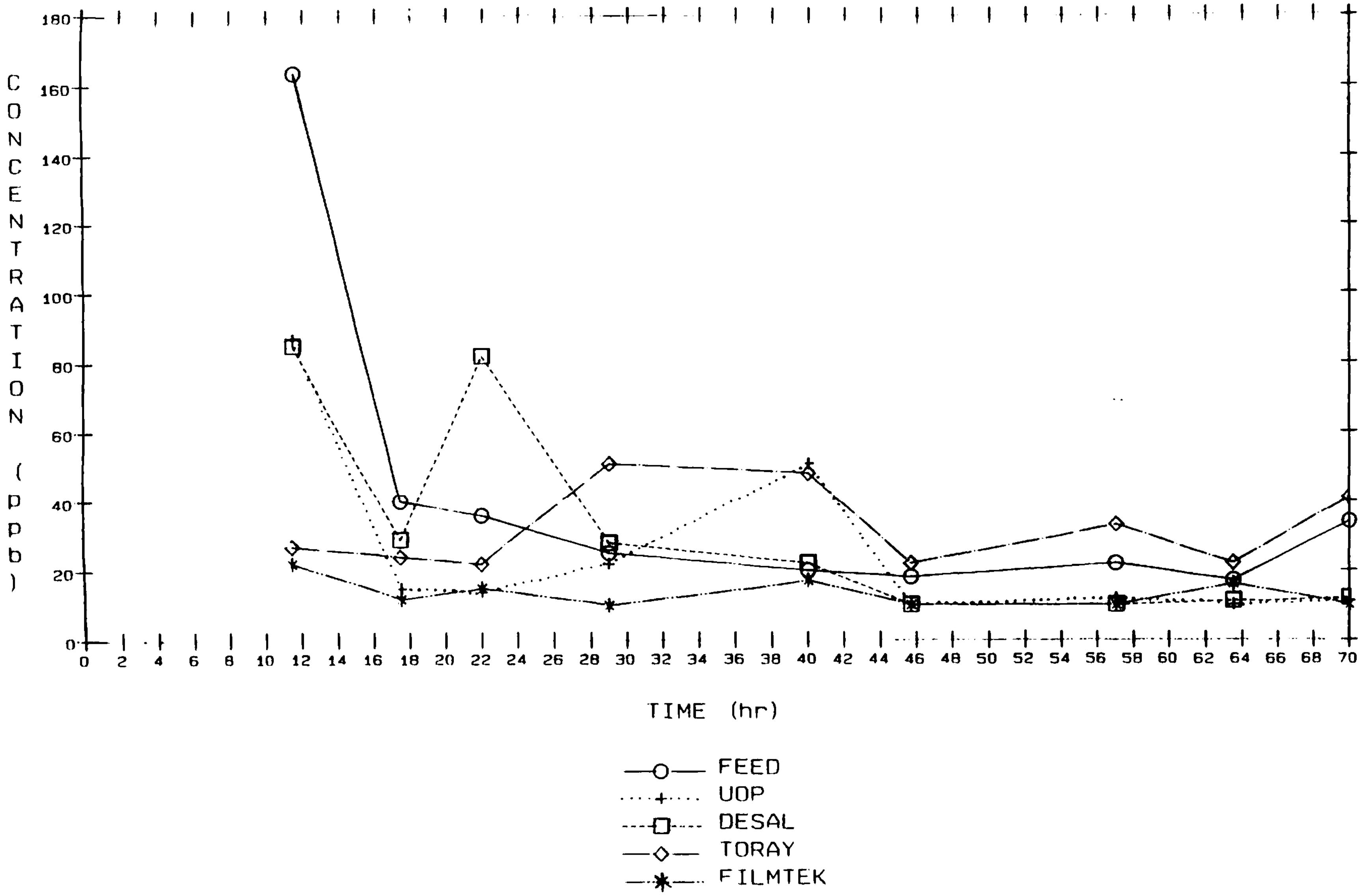
OSWEGO RESULTS - RO METALS NICKEL



OSWEGO RESULTS - RO METALS - ZINC

TIME (hr)	FEED	PERM1	PERM2	PERM3	PERM4
0.0					
8.0					
9.5					
11.5	164	87.0	85.0	27.0	22.0
17.5	40.0	15.0	29.0	24.0	12.0
22.0	36.0	14.0	82.0	22.0	15.0
29.0	25.0	22.0	28.0	51.0	10.0
40.0	20.0	51.0	22.0	48.0	17.0
45.7	18.0	10.0	10.0	22.0	10.0
57.0	22.0	12.0	10.0	33.0	10.0
63.5	17.0	10.0	11.0	22.0	16.0
70.0	34.0	11.0	12.0	41.0	10.0

OSWEGO RESULTS - RO METALS - ZINC



APPENDIX B

VOLATILE RESULTS

AVERAGE RUNS 6,8,9
UV/03/H202 pH10
LEACHATE

	DOSE UNITS	0.00	0.34	0.69	1.38	2.76
	COMPOUND TIME(MIN)	0	15	30	60	120
1	STANDARD	106.31	109.31	179.64	197.53	123.87
2	METHYLENE CHLORIDE	471.00	637.54	832.12	331.26	1.00
3	ACETONE					
4	1,1-DICHLOROETHENE	158.31	153.16	102.16	61.92	23.47
5	1,1-DICHLOROETHANE	436.76	1772.79	199.66	66.01	12.17
6	t-1,2-DICHLOROETHENE	2711.32	1854.18	194.90	56.68	16.77
7	CHLOROFORM	0.00	0.00	0.00	0.00	0.00
8	1,2-DICHLOROETHANE	856.36	802.62	634.01	446.97	71.61
9	1,1,1-TRICHLOROETHANE	227.00	195.62	66.71	30.69	4.16
10	CARBON TETRACHLORIDE	0.00	0.00	0.00	0.00	0.00
11	BROMODICHLOROMETHANE	0.00	0.00	0.00	0.00	0.00
12	1,2 DICHLOROPROPANE	0.00	0.00	0.00	0.00	0.00
13	c-1,3-DICHLOROPROPENE	0.00	0.00	0.00	0.00	0.00
14	TRICHLOROETHENE	53.16	77.50	57.17	45.66	3.85
15	BENZENE	353.22	256.39	33.08	12.92	1.43
16	TETRACHLOROETHENE	0.00	0.00	17.43	16.29	0.00
17	METHYL ISOBUTYL KETONE	34.47	67.91	26.87	24.68	1.15
18	BROMOFORM	0.00	0.00	0.00	0.00	0.00
19	1,1,2,2-TETRACHLOROETHANE	229.39	197.12	114.30	98.84	1.78
20	TOLUENE	2739.74	1911.22	94.74	20.92	3.66
21	CHLOROBENZENE	418.64	504.87	36.97	10.88	0.34
22	ETHYLBENZENE	1992.16	1428.78	69.50	13.17	1.04
23	M-,P- XYLENE	3848.84	2745.11	78.70	6.78	0.89
24	O-XYLENE	5364.50	3802.42	155.19	11.07	2.33
	TOTAL VOC (PPB)	19894.87	16407.22	2713.49	1254.74	145.66
	LOG(C/CO)	0.00	-0.08	-0.87	-1.20	-2.14

VOLATILE RESULTS

RUN#7
UV/03 pH10

	LEACHATE	DOSE UNITS	0.00	0.34	0.69	1.38	2.76
#	COMPOUND	TIME(MIN)	0	15	30	60	120
1	STANDARD		105.69	100.77	139.85	202.62	126.78
2	METHYLENE CHLORIDE		204.01	620.73	1240.02	424.12	1.00
3	ACETONE						
4	1,1-DICHLOROETHENE		118.31	118.93	195.22	59.64	0.00
5	1,1-DICHLOROETHANE		401.27	410.06	394.54	76.83	15.76
6	t-1,2-DICHLOROETHENE		3690.09	993.68	376.68	61.71	14.90
7	CHLOROFORM						0.00
8	1,2-DICHLOROETHANE		701.32	804.12	846.97	473.76	109.58
9	1,1,1-TRICHLOROETHANE		261.93	124.76	159.33	54.47	3.13
10	CARBON TETRACHLORIDE					0.00	0.00
11	BROMODICHLOROMETHANE					0.00	0.00
12	1,2 DICHLOROPROPANE					0.00	0.00
13	c-1,3-DICHLOROPROPENE					0.00	0.00
14	TRICHLOROETHENE		0.00	22.93	57.97	49.81	7.40
15	BENZENE		469.04	125.05	43.72	13.21	1.88
16	TETRACHLOROETHENE		0.00	0.00	10.34	14.74	0.00
17	METHYL ISOBUTYL KETONE		47.95	13.07	26.14	24.51	2.26
18	BROMOFORM						
19	1,1,2,2-TETRACHLOROETHANE		344.43	108.34	68.91	63.67	4.20
20	TOLUENE		3620.40	762.99	122.46	18.71	3.91
21	CHLOROBENZENE		704.00	187.69	34.38	12.26	0.00
22	ETHYLBENZENE		2263.51	439.21	55.99	6.13	1.10
23	M-,P- XYLENE		4635.69	697.32	78.33	4.80	1.32
24	O-XYLENE		6158.46	1293.61	169.64	9.35	2.43

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	23620.41	6722.487	3880.64	1367.732	168.848
L[illegible]/CO)	0.00	-0.55	-[illegible]	-1.24	-2.15

VOLATILE RESULTS

RUN#10
03/H202 pH10

	LEACHATE	DOSE UNITS	0.00	0.39	0.78	1.57	3.14
#	COMPOUND	TIME(MIN)	0	15	30	60	120
1	STANDARD		82.22	70.13	121.48	125.89	172.63
2	METHYLENE CHLORIDE		0.00	339.44	497.38	360.38	1.00
3	ACETONE						
4	1,1-DICHLOROETHENE		120.87	81.32	83.28	64.89	67.47
5	1,1-DICHLOROETHANE		366.03	239.42	224.12	104.94	37.05
6	t-1,2-DICHLOROETHENE		2765.57	927.66	332.23	73.83	37.31
7	CHLOROFORM						0.00
8	1,2-DICHLOROETHANE		707.15	630.63	595.14	464.24	203.48
9	1,1,1-TRICHLOROETHANE		174.61	97.72	60.36	25.10	18.15
10	CARBON TETRACHLORIDE					0.00	0.00
11	BROMODICHLOROMETHANE					0.00	0.00
12	1,2 DICHLOROPROPANE					0.00	0.00
13	c-1,3-DICHLOROPROPENE				0.00	0.00	0.00
14	TRICHLOROETHENE		0.00	0.00	39.66	37.04	14.33
15	BENZENE		454.22	165.48	51.59	17.35	3.22
16	TETRACHLOROETHENE		0.00	0.00	19.51	16.37	0.00
17	METHYL ISOBUTYL KETONE		22.82	62.46	20.57	14.33	0.85
18	BROMOFORM					0.00	0.00
19	1,1,2,2-TETRACHLOROETHANE		206.74	3288.87	77.66	59.93	3.95
20	TOLUENE		4116.37	1379.28	248.29	35.89	1.96
21	CHLOROBENZENE		747.45	294.20	72.89	13.32	0.00
22	ETHYLBENZENE		3402.57	872.02	204.15	16.24	1.10
23	M-,P- XYLENE		6714.07	1397.52	307.80	20.33	1.73
24	O-XYLENE		8619.33	2090.89	504.47	34.67	2.58

ALL CONCENTRATIONS IN PPB

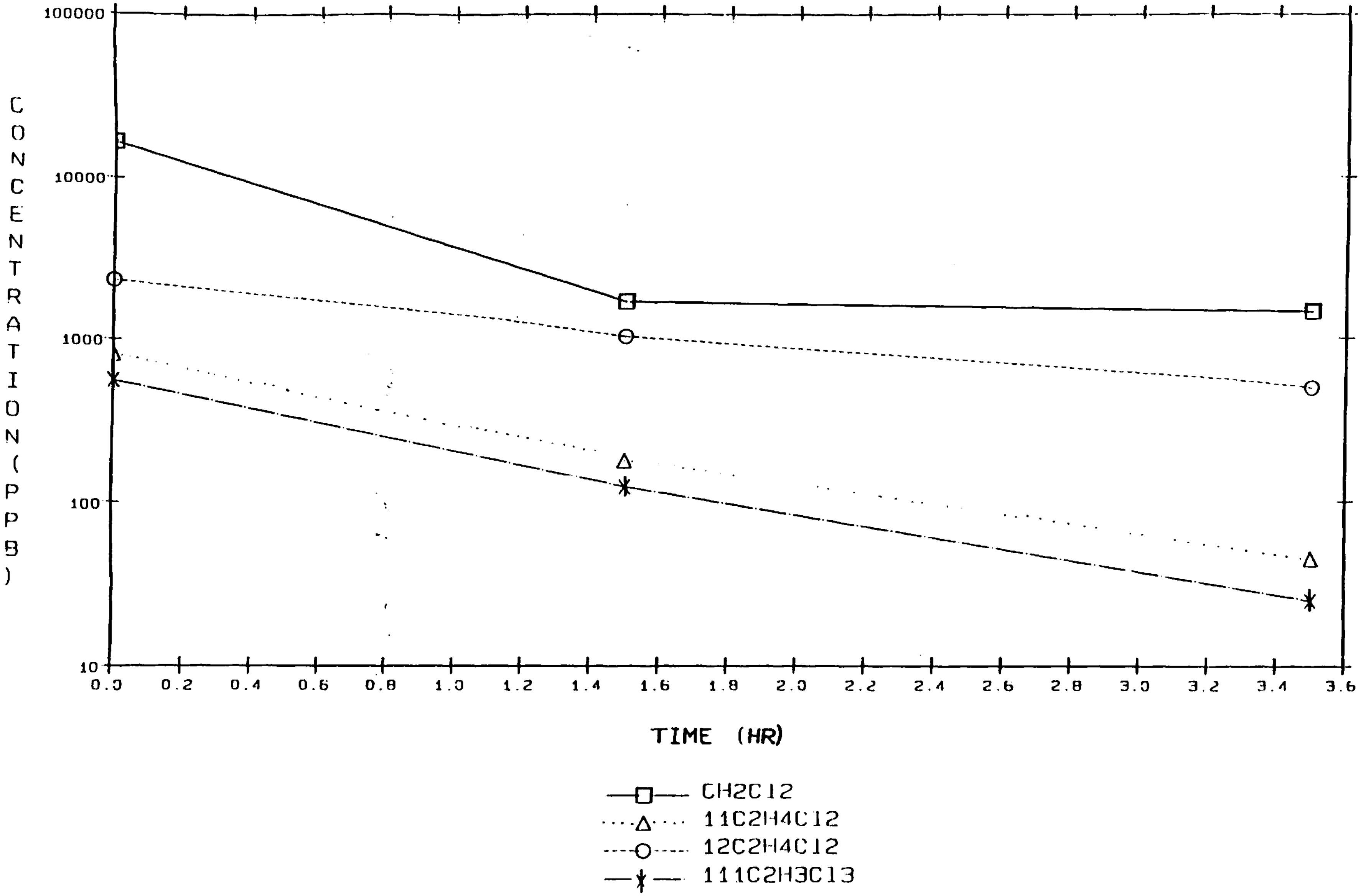
TOTAL VOC (PPB)	28417.8	11866.91	3339.094	1358.848	394.176
LOG(C/CO)	0.00	-0.38	-0.93	-1.32	-1.86

APPENDIX C

RUN 11 UV (FLOWTHROUGH) - RO

COMPOUND	UV FEED	UV EFFLUENT	PERNEATE
DICHLOROMETHANE	16765.6	1670.9	1445.7
ACETONE	27268.1	9531.4	2036.3
1.1-DICHLOROETHANE	806.1	178.2	45.0
1.1-DICHLOROETHENE	746.5	124.9	30.0
1.2-DICHLOROETHANE	2289.8	1018.5	496.5
t-1.2-DICHLOROETHENE	10514.8	318.8	1017.1
1.1.1-TRICHLOROETHANE	552.8	122.9	25.1
TRICHLOROETHENE	401.6	60.9	52.0
BENZENE	914.6	60.0	52.9
BROMODICHLOROMETHANE	623.2	56.5	0.0
1.2-DICHLOROPROPANE	74.3	18.6	0.0
METHYL ISOBUTYL KETON	113.6	13.7	8.6
BROMOFORM	32016.1	226.1	0.0
TETRACHLOROETHANE/ENE	475.6	45.2	27.7
TOLUENE	3508.3	75.5	277.9
CHLOROBENZENE	768.2	41.1	117.6
ETHYLBENZENE	2832.0	171.8	0.0
m,p-XYLENE	4566.5		226.2
o-XYLENE	7479.2	1222.2	294.3
PHENOL	7632.0	121.0	58.0
2-METHYLPHENOL	1619.0	20.0	15.0
4-METHYLPHENOL	5027.0	67.0	49.0
NITROBENZENE			25.0
2,4-DIMETHYLPHENOL	812.0	6.0	6.0
BENZOIC ACID	31526.0	46.0	0.0

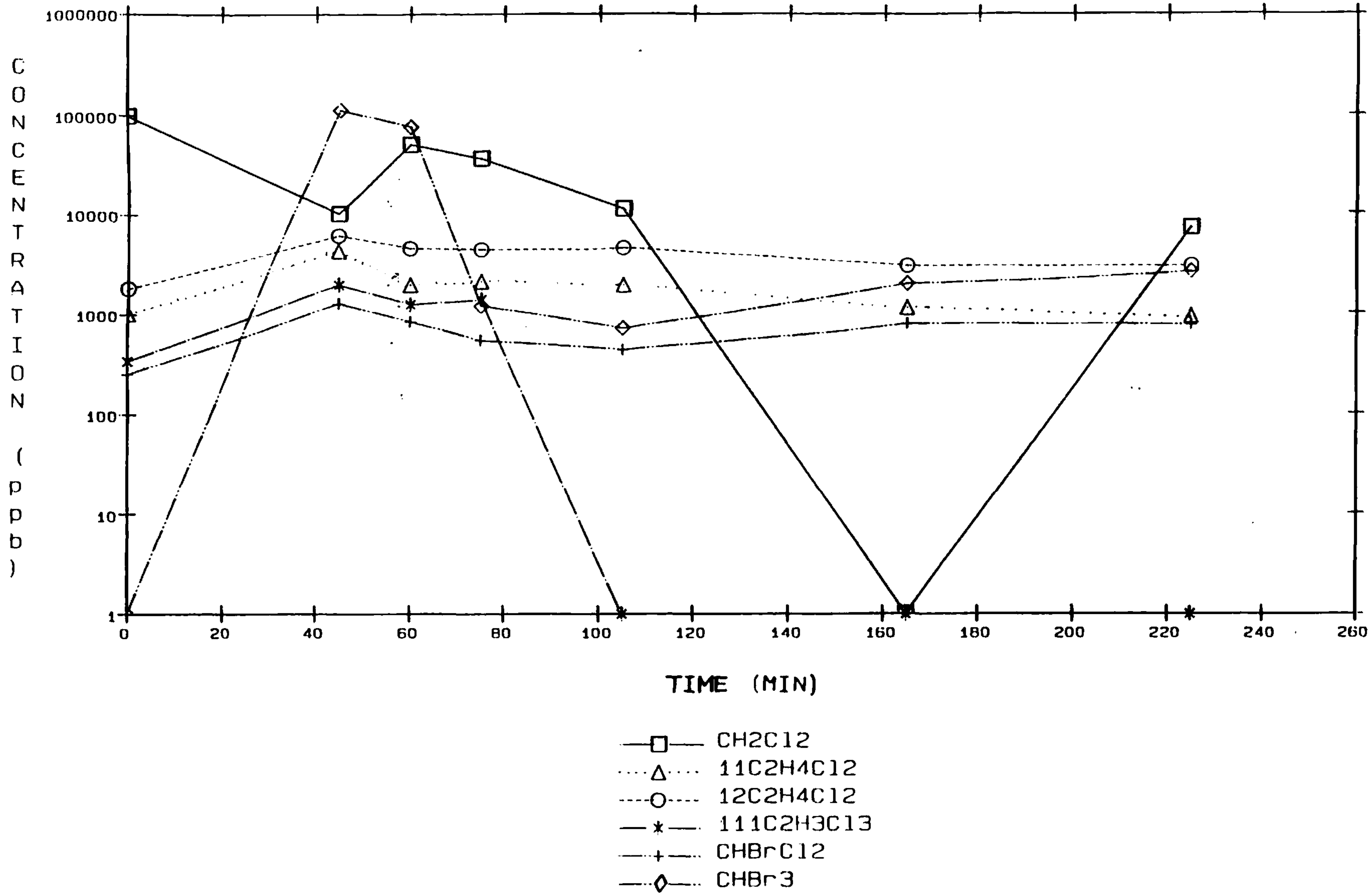
OSWEGO UV (FLOW THROUGH) -RO #1 HALOGENATED ALKANES



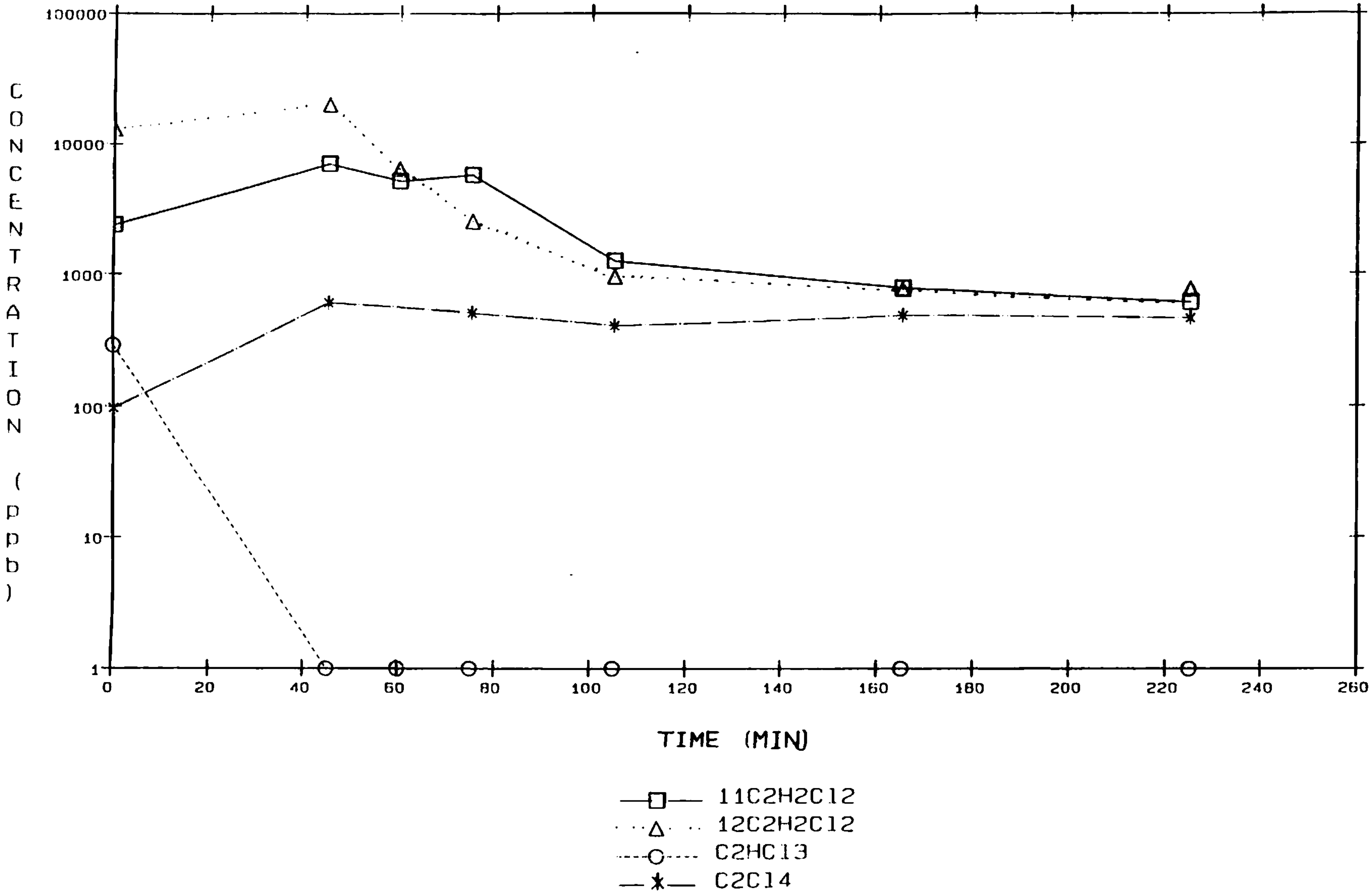
RUN 12 - RO (CONCENTRATE) - UV (BATCH)

COMPOUND	RO FEED	RO CONCENTRATE	15 MIN	30 MIN	60 MIN	120 MIN	180 MIN
DICHLOROMETHANE	99641.9	10027.2	50178.6	36117.3	11221.5	1.0	7204.2
ACETONE	29715.9	1.0	100310.6	11624.6	1.0	1.0	1.0
1.1-DICHLOROETHANE	1009.2	4180.3	1922.5	2071.5	1931.8	1131.3	924.6
1.1-DICHLOROETHENE	2383.2	7052.9	5107.7	5722.6	1258.5	773.2	601.5
1.2-DICHLOROETHANE	1794.3	5997.9	4460.4	4402.2	4555.4	2954.4	2934.7
t-1.2-DICHLOROETHENE	13104.6	20228.8	6369.3	2526.2	945.3	757.5	758.9
1.1.1-TRICHLOROETHANE	340.4	1907.5	1225.7	1377.5	1.0	1.0	1.0
TRICHLOROETHENE	288.3	1.0	1.0	1.0	1.0	1.0	1.0
BENZENE	803.3	3295.2	773.6	435.5	175.2	115.1	92.9
BROMODICHLOROMETHANE	252.3	1251.9	833.1	536.4	436.1	789.6	766.8
METHYL ISOBUTYL KETON	23.9	178.0	124.8	216.0	197.8	197.4	176.7
BROMOFORM	1.0	113709.6	75976.2	1188.0	717.2	1961.2	2584.1
TETRACHLOROETHANE/ENE	98.1	606.5		504.5	405.4	481.5	460.6
TOLUENE	3196.4	9474.5	1758.5	581.3	2151.5	1713.1	386.4
CHLOROBENZENE	567.1	1409.1	670.6	387.6	134.1	118.2	1.0
ETHYLBENZENE	2700.1	6039.1	1074.4	233.3	48.1	37.3	6.9
m.p-XYLENE	4373.4	10122.1	1734.6	1.0	1.0	1.0	1.0
o-XYLENE	7049.0	18293.8	3666.7	1.0	4.0	1.0	1.0
PHENOL	475.0		24864.0	13895.0	4740.0	0.0	56.0
2-METHYLPHENOL	813.0		549.0	1436.0	360.0	50.0	0.0
4-METHYLPHENOL	1008.0		538.0	11044.0	322.0	64.0	22.0
NITROBENZENE					269.0	142.0	133.0
ISOPHORONE	26.0		125.0	129.0	50.0	50.0	34.0
2.4-DIMETHYLPHENOL	706.0		2693.0	998.0	146.0	0.0	0.0
BENZOIC ACID	5436.0		67585.0	128330.0	40076.0	11513.0	55721.0

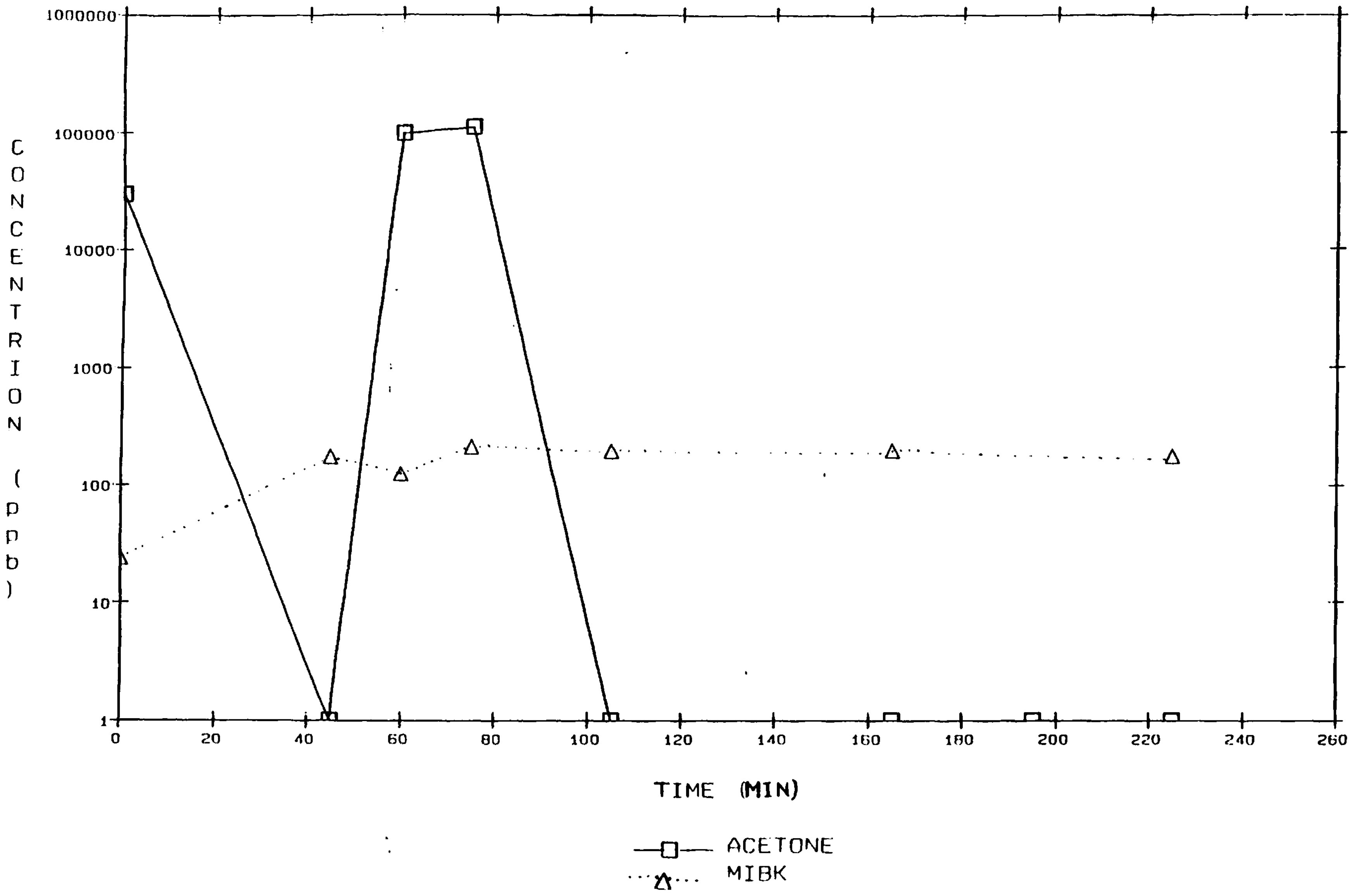
OSWEGO RO (CONC) - UV (BATCH) #12 HALAGONATED ALKANES



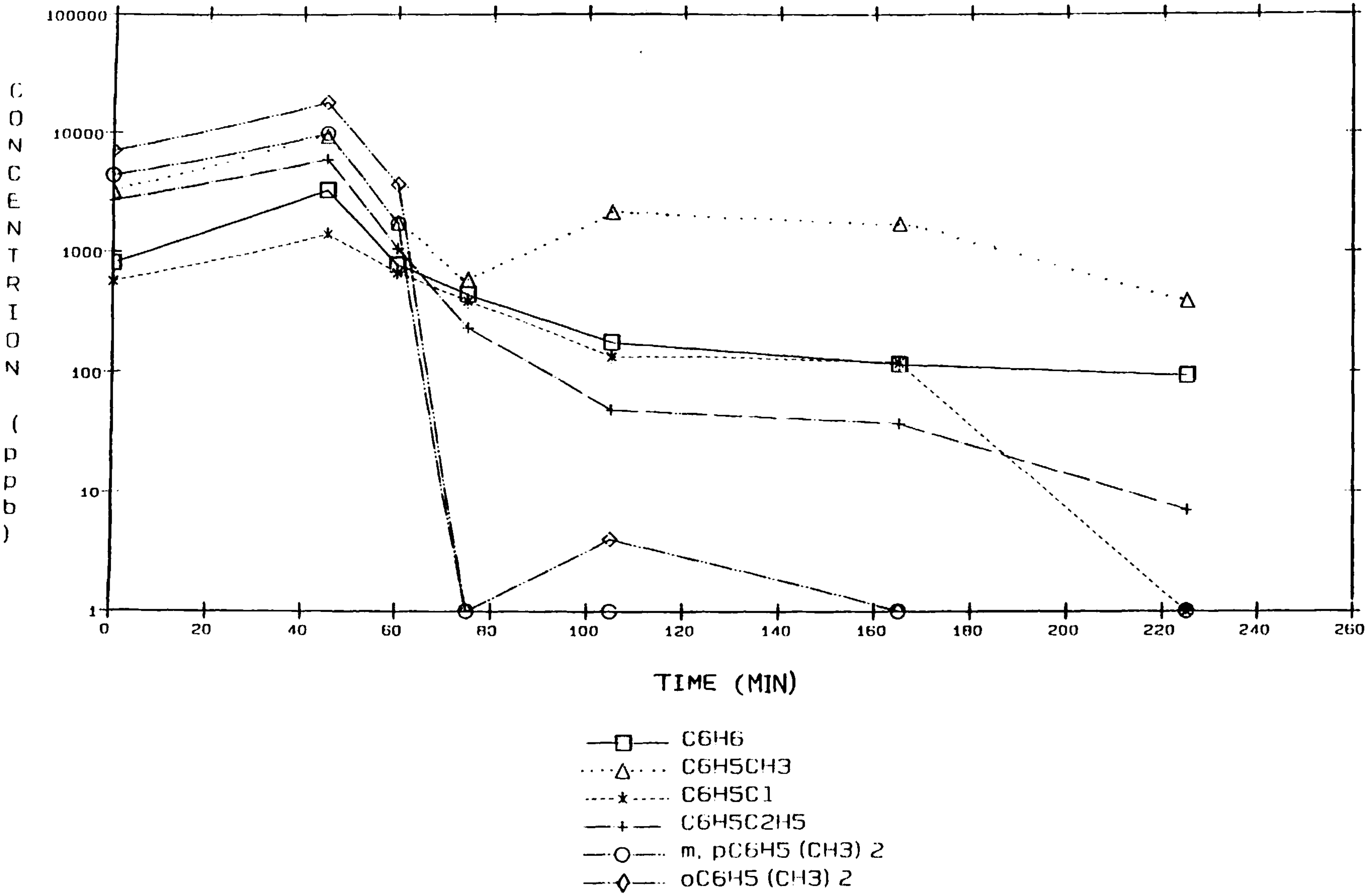
OSWEGO RD (CONC) - UV (BATCH) #12ALKENES



OSWEGO RO (CONC) - UV (BATCH) #12KETONES



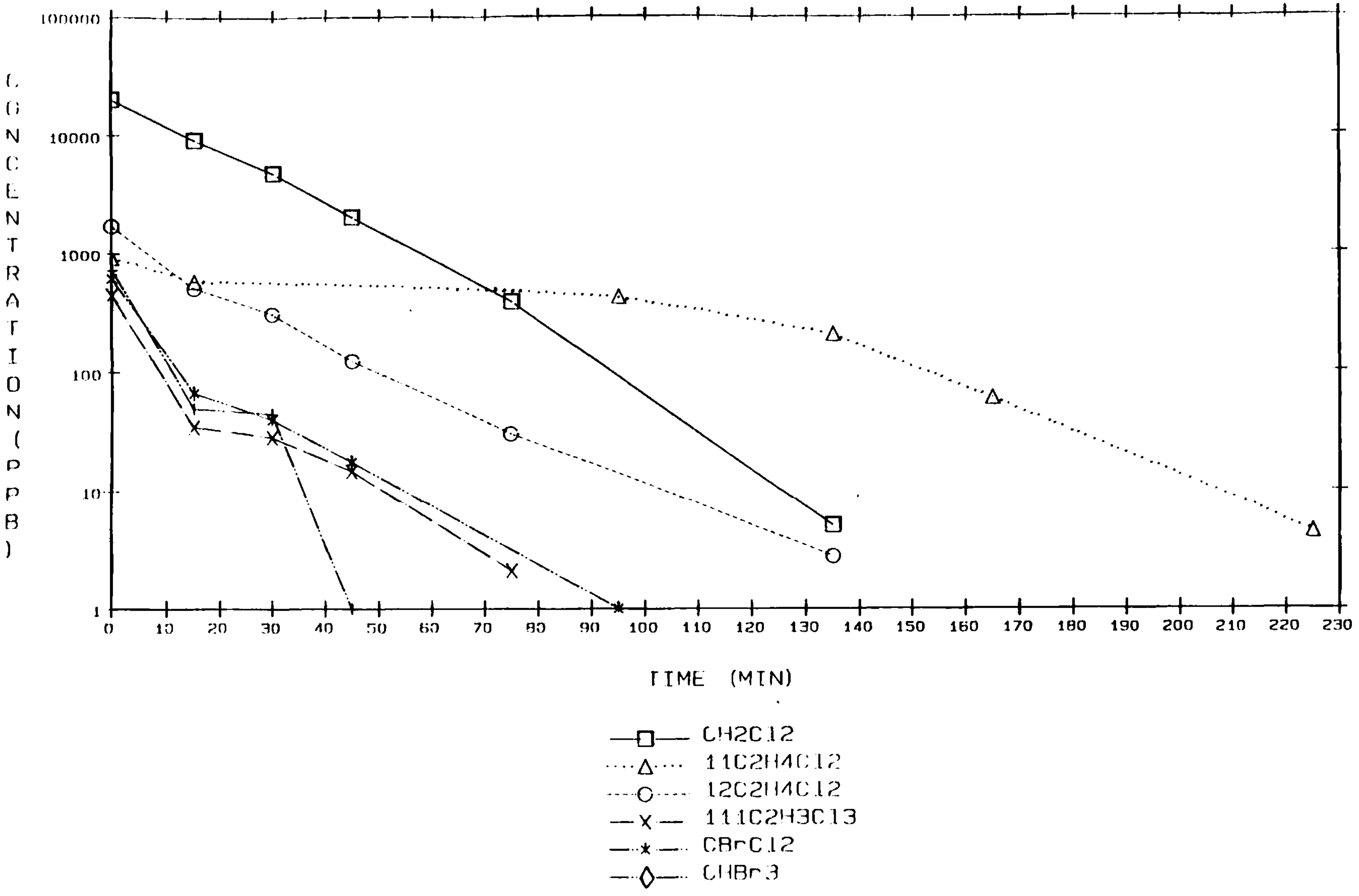
OSWEGO RD (CONC) - UV (BATCH) #12 AROMATICS



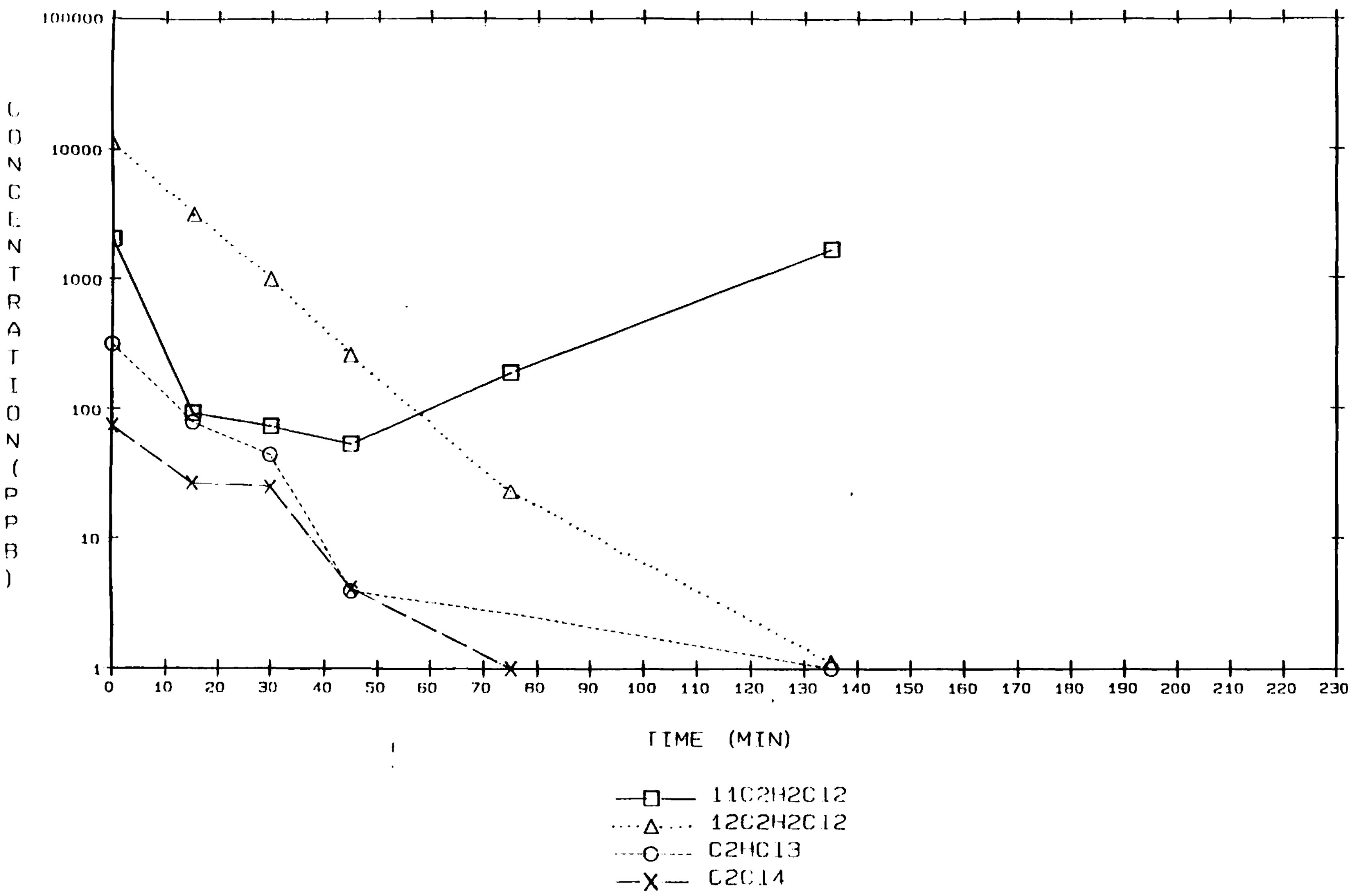
RUN 13 RO (PERMEATE) - UV (BATCH)

COMPOUND	RO FEED	RO PERMEATE	15 MIN	30 MIN	60 MIN	120 MIN
DICHLOROMETHANE	19881.3	9245.7	4795.9	2019.0	388.2	5.0
ACETONE	18953.1					
1,1-DICHLOROETHANE	918.9	584.5	426.0	205.8	59.6	4.4
1,1-DICHLOROETHENE	2034.3	92.6	72.6	53.1	18.3	24.2
1,2-DICHLOROETHANE	1700.8	509.9	305.1	123.3	30.1	2.7
t-1,2-DICHLOROETHENE	11129.4	3200.3	986.1	257.5	22.9	1.1
1,1,1-TRICHLOROETHANE	445.1	34.8	28.2	14.6	2.1	
TRICHLOROETHENE	314.6	79.0	44.1	3.9		1.0
BENZENE	760.6	153.7	49.7	9.8	1.7	0.8
BROMODICHLOROMETHANE	612.0	66.9	39.8	17.5	1.0	1.0
METHYL ISOBUTYL KETON	79.0	13.2	13.1	1.0		
BROMOFORM	728.0	49.7	44.6	1.0	1.0	1.0
TETRACHLOROETHANE/ENE	73.9	26.5	24.7	4.1	1.0	
TOLUENE	4081.4	6571.2	1886.6	423.6	61.0	2.2
CHLOROBENZENE	681.3	155.9	61.1	11.2	2.4	1.0
ETHYLBENZENE	3057.3	310.1	87.0	17.5	1.6	1.0
m,p-XYLENE	4888.3	434.2	113.6	25.3	2.6	1.0
o-XYLENE	8145.3	701.1	190.2	42.9	4.0	1.0
PHENOL	485.0	322.0	107.0	7.0	0.0	0.0
2-METHYLPHENOL		5.0	27.0	2.0	0.0	0.0
4-METHYLPHENOL	825.0	137.0	76.0	6.0	0.0	0.0
NITROBENZENE			31.0	11.0	2.0	0.0
2,4-DIMETHYLPHENOL	895.0	76.0	9.0	0.0	0.0	0.0
BENZOIC ACID		599.0	83.0	20.0	0.0	0.0
NAPTHALENE	14.0	2.0	0.0	0.0	0.0	0.0

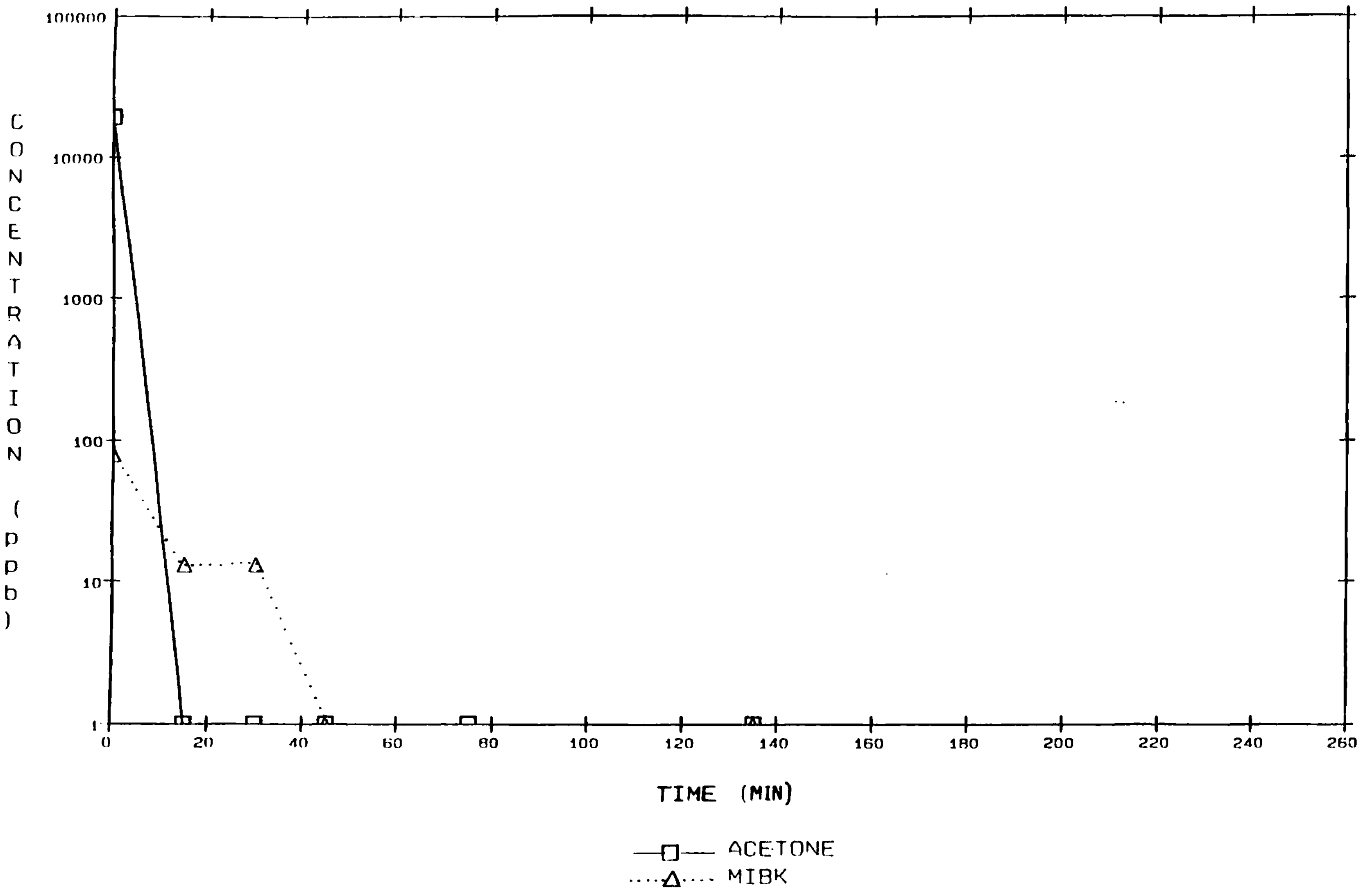
RO (PERM) -UV (BATCH) #3 - HALOGRNATED ALKANES



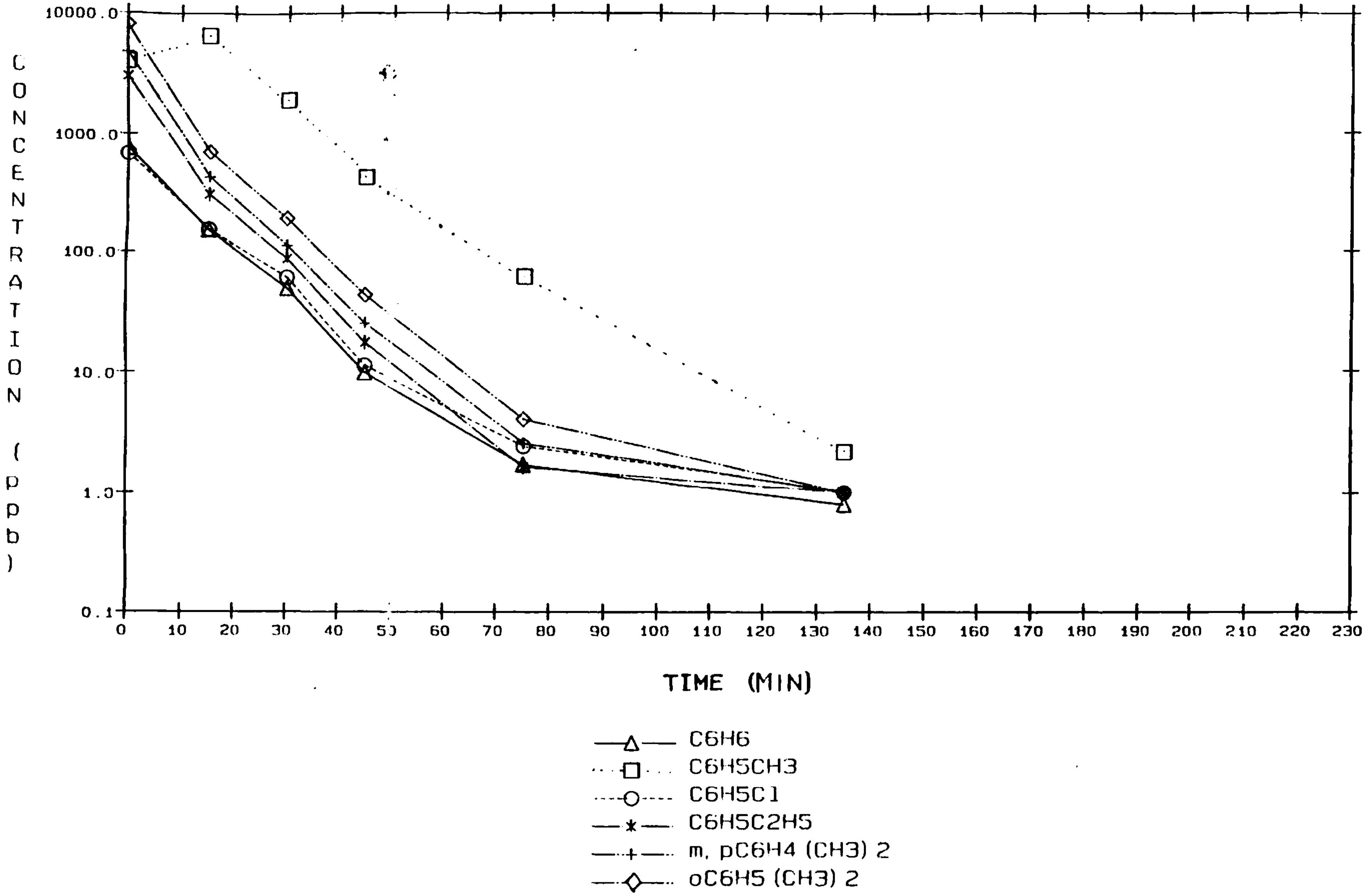
RO (PERM) -UV (BATCH) #3 HALOGENATED ALKENES



OSWEGO RD (PERM) - UV (BATCH) #3 KETONES



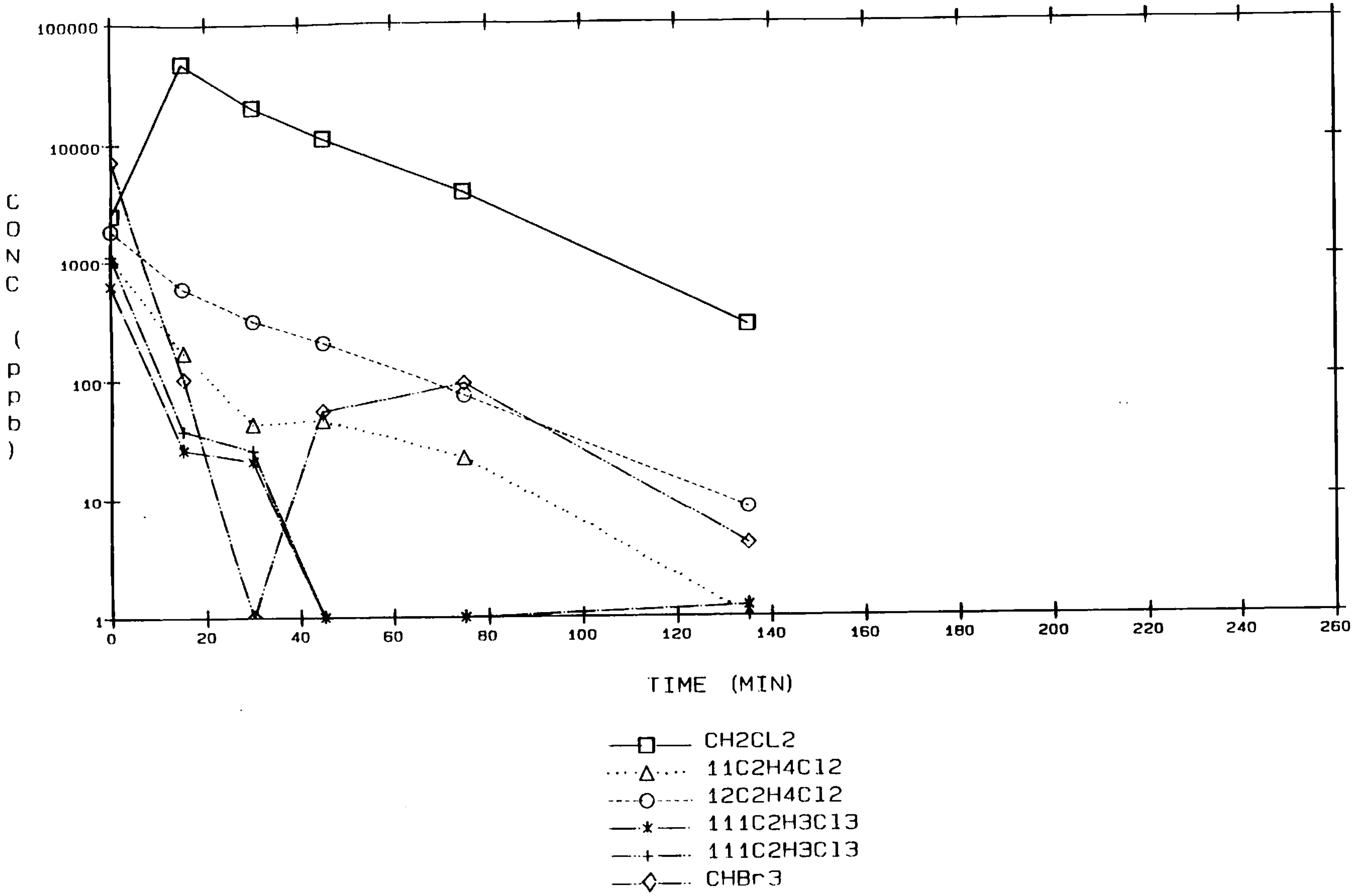
OSWEGO - RO (PERM) - UV (BATCH) #3 AROMATICS



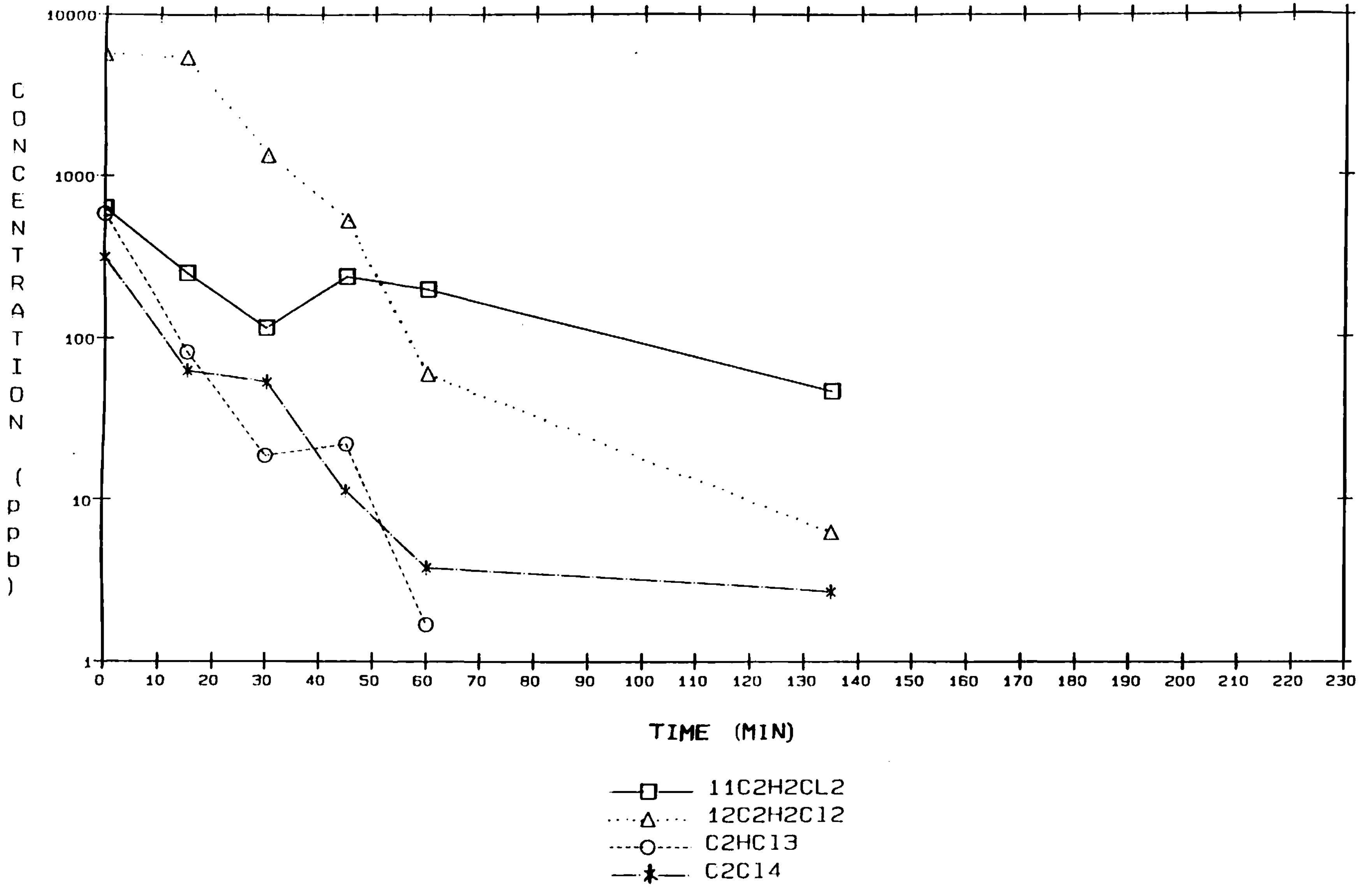
RUN 14 RO (PERMEATE) - UV (BATCH)

	RO FEED	RO PERMEATE	15 MIN	30 MIN	60 MIN	120 MIN
DICHLOROMETHANE	2486.5	47492.6	19871.2	10943.9	3818.7	280.4
ACETONE	7814.8	14395.7	12331.7	12586.0	11195.0	6195.0
1,1-DICHLOROETHANE	1068.5	170.9	42.9	45.9	22.0	1.0
1,1-DICHLOROETHENE	628.6	248.9	114.3	234.4	196.0	46.3
1,2-DICHLOROETHANE	1837.8	587.4	313.6	205.6	74.6	8.3
t-1,2-DICHLOROETHENE	5694.0	5421.7	1342.7	522.5	59.4	6.3
1,1,1-TRICHLOROETHANE	623.4	26.0	20.8	1.0	1.0	1.2
TRICHLOROETHENE	580.3	81.0	18.9	22.2	1.7	0.0
BENZENE	799.4	211.6	39.7	17.4	2.2	0.8
BROMODICHLOROMETHANE	1119.1	38.0	25.6	1.0	1.0	1.0
METHYL ISOBUTYL KETON	307.8	8.6	1.0	1.0	1.0	1.0
BROMOFORM	7269.1	103.1	1.0	54.8	93.2	4.0
TETRACHLOROETHANE/ENE	309.3	62.8	53.2	11.3	3.8	2.6
TOLUENE	6593.1	966.5	211.7	65.3	7.5	2.5
CHLOROBENZENE	1095.0	204.1	48.8	17.6	1.7	1.0
ETHYLBENZENE	4462.2	458.6	85.1	30.4	2.9	0.2
m,p-XYLENE	6913.6	662.7	198.3	68.5	4.0	0.3
o-XYLENE	11992.5	1032.1	198.3	68.5	6.2	1.0
PHENOL	183.0	221.0	82.0	0.0	1.0	1.0
2-METHYLPHENOL			21.0			
4-METHYLPHENOL	2320.0	179.0	55.0	0.0	0.0	0.0
NITROBENZENE			32.0	11.0	4.0	0.0
2,4-DIMETHYLPHENOL	1054.0	44.0	4.0	0.0	0.0	0.0
BENZOIC ACID	60.0	15.0	2.0		23.0	

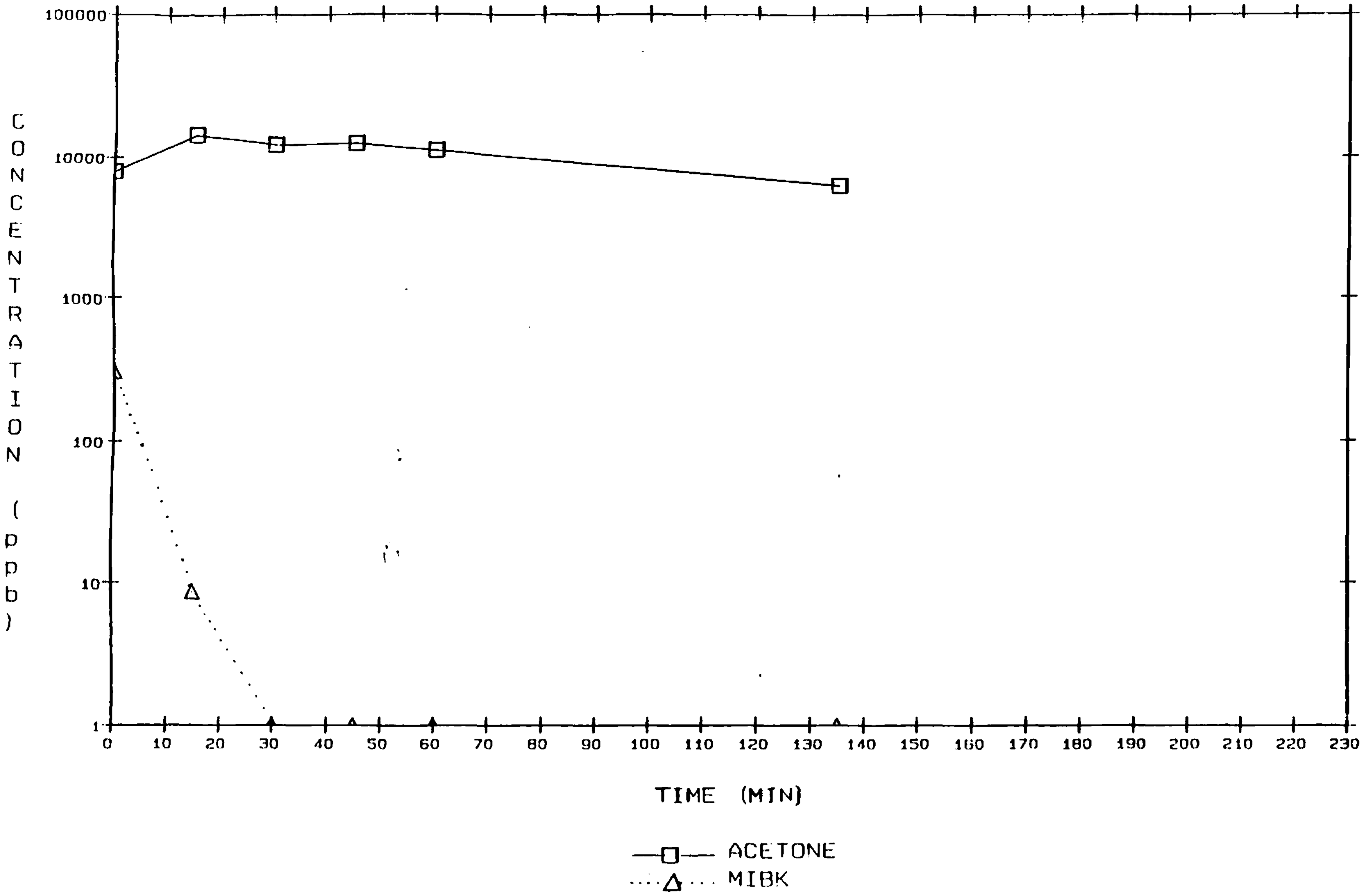
OSWEGO RD (PERM) - UV (BATCH) #4 HALOGENATED ALKANES



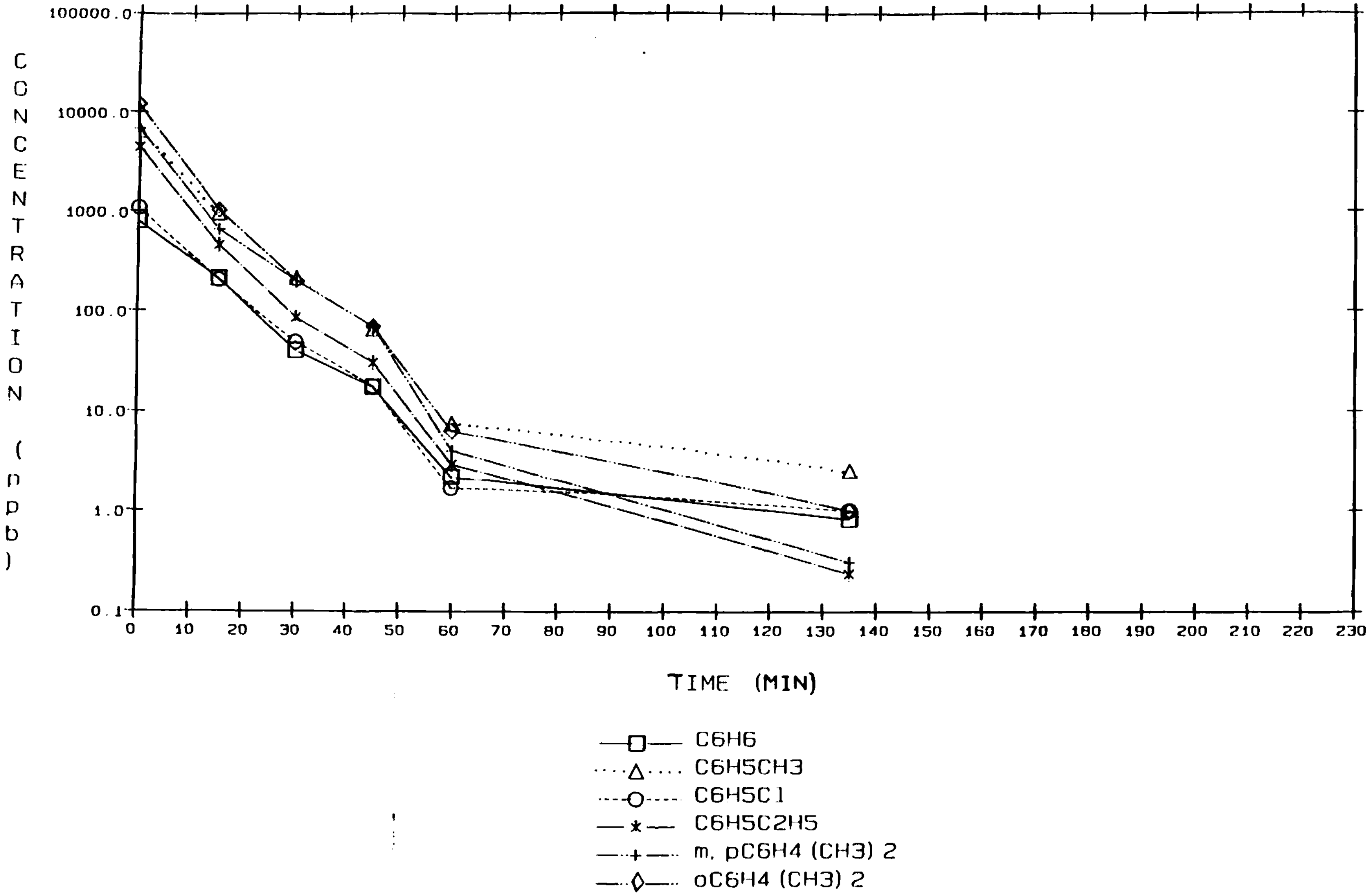
OSWEGO RO (PERM) - UV (BATCH) #4 HALOGENATED ALKENES



OSWEGO RO (PERM) - UV (BATCH) #4 KETONES



OSWEGO RO (PERM) - UV (BATCH) #4 AROMATICS



RUN 15 RO (PERM) - UV (FLOWTHROUGH)

COMPOUND	RO FEED	UV FEED	UV EFFLUENT
DICHLOROMETHANE	1907.3	243.8	0.0
ACETONE	14230.5	2565.8	O
1.1-DICHLOROETHANE	749.1	169.0	3.1
1.1-DICHLOROETHENE	722.0	32.8	8.6
1.2-DICHLOROETHANE	1787.6	490.5	41.7
t-1.2-DICHLOROETHENE	19082.3	5195.7	4.4
1.1.1-TRICHLOROETHANE	777.1	42.0	2.2
TRICHLOROETHENE	163.5	23.9	0.7
BENZENE	900.5	208.9	9.4
BROMODICHLOROMETHANE	292.7	17.4	0.0
METHYL ISOBUTYL KETON	70.2	9.3	0.0
BROMOFORM	51312.6	0.0	0.0
TETRACHLOROETHANE/ENE	135.9	39.4	1.7
TOLUENE	9316.1	1767.3	1.5
CHLOROBENZENE	1413.0	368.5	0.7
ETHYLBENZENE	6376.4	836.1	0.2
m,p-XYLENE	9698.7	1104.9	0.2
o-XYLENE	16773.1	1891.0	0.0
PHENOL	2474.0	571.0	0.0
4-METHYLPHENOL	4797.0	915.0	0.0
2,4-DIMETHYLPHENOL	1390.0	210.0	0.0

RUN 16 RO (PERM) - UV (FLOWTHROUGH)

COMPOUND	RO FEED	UV FEED	UV EFFLUENT
DICHLOROMETHANE	4469.1	765.7	79.9
ACETONE	68767.5	4345.1	3313.7
1,1-DICHLOROETHANE	3611.8	346.4	8.5
1,1-DICHLOROETHENE	987.1	87.5	0.0
1,2-DICHLOROETHANE	6931.3	918.7	107.3
t-1,2-DICHLOROETHENE	26956.6	5657.6	20.0
1,1,1-TRICHLOROETHANE	1388.4	83.1	13.5
TRICHLOROETHENE	274.4	37.0	0.0
BENZENE	2560.6	2773.9	9.4
BROMODICHLOROMETHANE	1105.5	26.7	0.0
METHYL ISOBUTYL KETON	62.6	8.6	0.0
BROMOFORM	19865.5	39.3	0.0
TETRACHLOROETHANE/ENE	675.8	164.6	1.0
TOLUENE	26145.2	2561.0	24.1
CHLOROBENZENE	4473.2	501.0	0.0
ETHYLBENZENE	19211.1	1072.2	1.0
m,p-XYLENE	29393.3	1421.9	0.0
o-XYLENE	52033.0	2451.3	1.0
PHENOL	146.0	150.0	6.0
4-METHYLPHENOL	2017.0	0.0	0.0
2,4-DIMETHYLPHENOL	1000.0	418.0	0.0
BENZOIC ACID			15.0

RUN 17: RO(PERM) - UV(FLOWTHROUGH)

COMPOUND	RO FEED	UV FEED	UV EFFLUENT
DICHLOROMETHANE	50145.6	5440.4	1279.4
ACETONE	31671.6	16826.4	14529.5
1.1-DICHLOROETHANE	1178.5	1091.5	0.0
1.1-DICHLOROETHENE	0.0	907.8	0.0
1.2-DICHLOROETHANE	2346.8	2162.1	1301.4
t-1.2-DICHLOROETHENE	62576.8	33366.6	1670.0
1.1.1-TRICHLOROETHANE	1748.5	831.5	208.1
TRICHLOROETHENE	281.4	206.2	103.1
BENZENE	1038.6	847.5	94.3
BROMODICHLOROMETHANE	942.8	796.4	474.2
METHYL ISOBUTYL KETON	647.1	77.5	37.1
BROMOFORM	7296.1	850.6	720.0
TETRACHLOROETHANE/ENE	588.4	319.6	268.7
TOLUENE	11909.3	8866.6	315.5
CHLOROBENZENE	1991.0	1376.4	169.0
ETHYLBENZENE	8470.6	6195.4	203.9
m.p-XYLENE	10660.3	8080.1	119.6
o-XYLENE	17459.2	14642.4	525.6
PHENOL	2778.0	2294.0	1.0
2-METHYLPHENOL		1241.0	13.0
4-METHYLPHENOL	4811.0	4147.0	5.0
2.4-DIMETHYLPHENOL	1428.0	1446.0	0.0
BENZOIC ACID	1787.0	6920.0	0.0

RUN 20: RO(PERM) - UV(FLOWTHROUGH)

COMPOUND	RO FEED	UV FEED	UV EFFLUENT
DICHLOROMETHANE	18129.2	8497.4	922.7
ACETONE	16938.2	16332.6	11987.2
1,1-DICHLOROETHANE	765.0	5202.0	328.8
1,1-DICHLOROETHENE	604.8	0.0	0.0
1,2-DICHLOROETHANE	1589.8	1539.3	1191.0
t-1,2-DICHLOROETHENE	30280.7	25349.3	1391.6
1,1,1-TRICHLOROETHANE	1046.1	766.0	180.1
TRICHLOROETHENE	197.5	92.8	69.3
BENZENE	724.8	591.7	52.4
BROMODICHLOROMETHANE	585.9		171.6
METHYL ISOBUTYL KETON	259.8	98.3	38.0
BROMOFORM	26020.4	55992.3	11443.0
TETRACHLOROETHANE/ENE	318.1	584.3	125.4
TOLUENE	7970.5	6232.1	222.3
CHLOROBENZENE	1294.3	944.2	58.9
ETHYLBENZENE	5596.6	4113.1	94.8
m,p-XYLENE	7631.0	5400.4	54.8
o-XYLENE	12888.7	9330.9	153.3
PHENOL	2551.3	76.0	1.0
4-METHYLPHENOL	4710.7	453.0	4.0
NITROBENZENE	1386.5		210.0
2,4-DIMETHYLPHENOL	1400.3	766.0	0.0
BENZOIC ACID	595.7		19.0

ROUN 21 RO (CONCENTRATE) - UV (BATCH)

COMPOUND	RO FEED	RO CONCENTRATE	15 MIN	30 MIN	60 MIN	120 MIN
DICHLOROMETHANE	50145.6	5200.3	3386.0	6890.1	4922.9	3466.2
ACETONE	31671.6	68709.8	73537.6	81905.3	93759.8	97809.1
1.1-DICHLOROETHANE	1178.5	1759.7	1552.3	1519.7	1007.1	495.1
1.1-DICHLOROETHENE	1.0	154.9	171.7	1.0	1.0	1.0
1,2-DICHLOROETHANE	2346.8	3974.0	4023.1	4184.7	3509.9	2594.2
t-1,2-DICHLOROETHENE	62576.8	29494.9	16671.0	7621.4	533.4	348.2
1,1,1-TRICHLOROETHANE	1748.5	1323.8	855.5	618.3	556.7	336.6
TRICHLOROETHENE	281.4	144.2	1.0	1.0	154.2	162.4
BENZENE	1038.6	1789.6	1153.9	433.8	167.8	120.0
BROMODICHLOROMETHANE	942.8	498.0	327.3	402.0	558.5	265.2
METHYL ISOBUTYL KETON	168.6	124.4	217.2	249.3	88.4	72.1
BROMOFORM	2624.0	220231.7	1669.1	1959.7	1425.5	1564.1
TETRACHLOROETHANE/ENE	788.2	1.0	596.4	1150.6	365.4	1.0
TOLUENE	10493.3	15985.1	9405.1	2268.8	120.5	78.8
CHLOROBENZENE	1548.3	1956.6	1260.9	513.5	101.7	1.0
ETHYLBENZENE	7429.7	8922.1	5333.8	998.7	51.4	6.8
m,p-XYLENE	9802.3	12263.2	7352.7	1287.8	32.3	4.1
o-XYLENE	16075.2	21627.8	13693.3	11331.1	259.0	1.0
PHENOL	1104.0	7926.0				
2-METHYLPHENOL		4115.0				
4-METHYLPHENOL		12417.0				
NITROBENZENE						
2,4-DIMETHYLPHENOL	170.0	3184.0				
BENZOIC ACID	4988.0	15042.0				

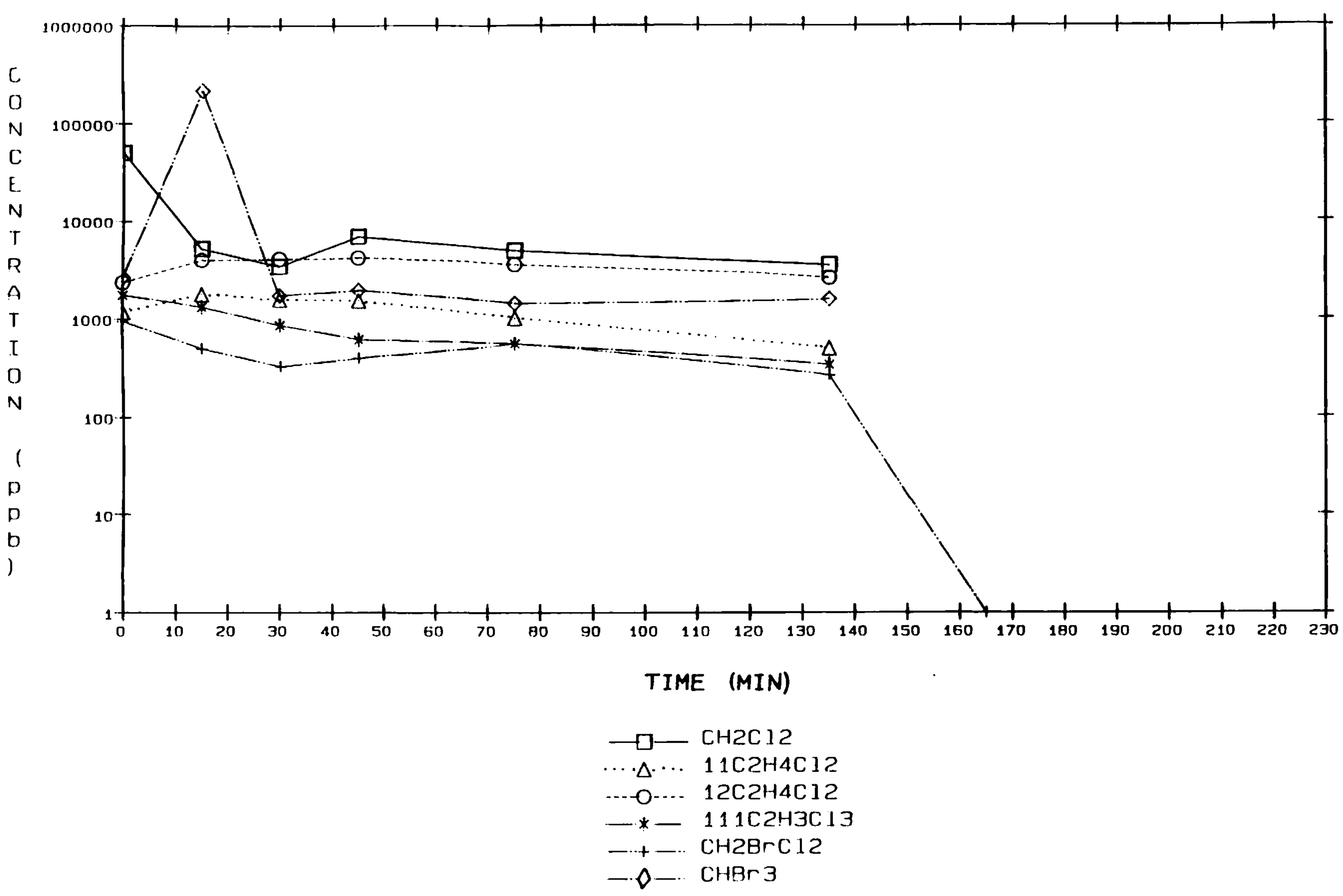
RUN 18: RO(PERM) - UV(FLOWTHROUGH)

COMPOUND	RO FEED	UV FEEF	UV EFFLUENT
DICHLOROMETHANE	18129.2	8497.4	1321.6
ACETONE	16938.2	16332.6	11230.3
1,1-DICHLOROETHANE	765.0	5202.0	533.8
1,1-DICHLOROETHENE	604.8	0.0	0.0
1,2-DICHLOROETHANE	1589.8	1539.3	1393.0
t-1,2-DICHLOROETHENE	30280.7	25349.3	2357.0
1,1,1-TRICHLOROETHANE	1046.1	766.0	375.5
TRICHLOROETHENE	197.5	92.8	108.3
BENZENE	724.8	591.7	117.5
BROMODICHLOROMETHANE	585.9		706.4
METHYL ISOBUTYL KETON	259.8	98.3	93.6
BROMOFORM	26020.4	55992.3	26345.2
TETRACHLOROETHANE/ENE	318.1	584.3	386.3
TOLUENE	7970.5	6232.1	465.6
CHLOROBENZENE	1294.3	944.2	193.5
ETHYLBENZENE	5596.6	4113.1	198.7
m,p-XYLENE	7631.0	5400.4	162.2
o-XYLENE	12888.7	9330.9	434.2
PHENOL	2551.3	76.0	227.0
4-METHYLPHENOL	4710.7	453.0	257.0
NITROBENZENE	1386.5		181.0
2,4-DIMETHYLPHENOL	1400.3	766.0	41.0
BENZOIC ACID	595.7		1619.0

RUN 19 RO (PERM) - UV (FLOWTHROUGH)

COMPOUND	RO FEED	UV FEED	UV EFFLUENT
DICHLOROMETHANE	18129.2	8497.4	1329.4
ACETONE	16938.2	16332.6	15385.8
1,1-DICHLOROETHANE	765.0	5202.0	409.6
1,1-DICHLOROETHENE	604.8	0.0	0.0
1,2-DICHLOROETHANE	1589.8	1539.3	1409.0
t-1,2-DICHLOROETHENE	30280.7	25349.3	1138.4
1,1,1-TRICHLOROETHANE	1046.1	766.0	318.2
TRICHLOROETHENE	197.5	92.8	50.1
BENZENE	724.8	591.7	722.3
BROMODICHLOROMETHANE	585.9		598.5
METHYL ISOBUTYL KETON	259.8	98.3	43.0
BROMOFORM	26020.4	55992.3	1153.0
TETRACHLOROETHANE/ENE	318.1	584.3	379.5
TOLUENE	7970.5	6232.1	365.3
CHLOROBENZENE	1294.3	944.2	58.0
ETHYLBENZENE	5596.6	4113.1	81.9
m,p-XYLENE	7631.0	5400.4	120.7
o-XYLENE	12888.7	9330.9	146.1
PHENOL	2551.3	76.0	22.0
4-METHYLPHENOL	4710.7	453.0	0.0
NITROBENZENE	1386.5		0.0
2,4-DIMETHYLPHENOL	1400.3	766.0	4.0
BENZOIC ACID	595.7		666.0

OSWEGO RD (CONC) - UV (BATCH) #2| HALAGONATED ALKANES



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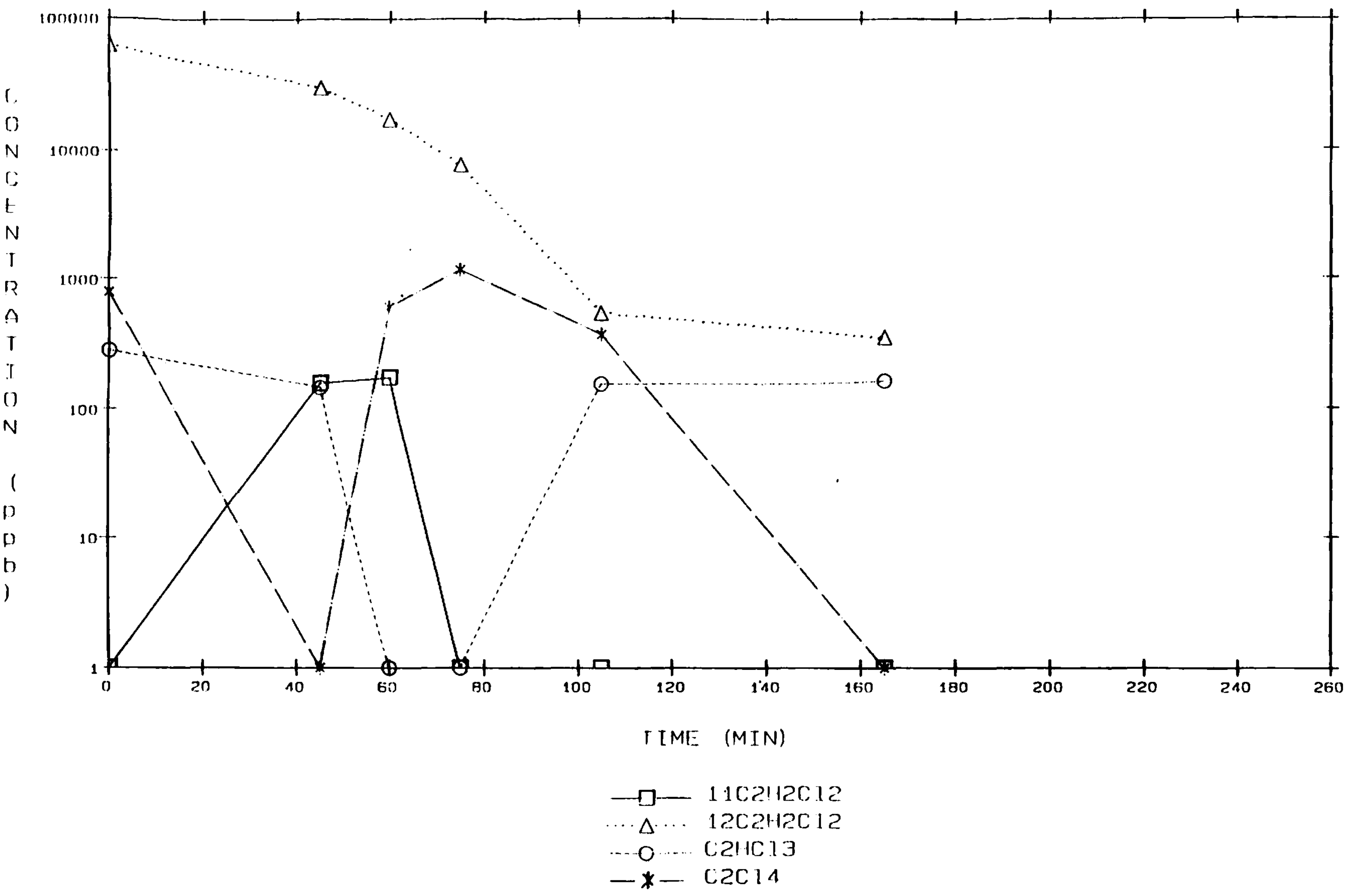
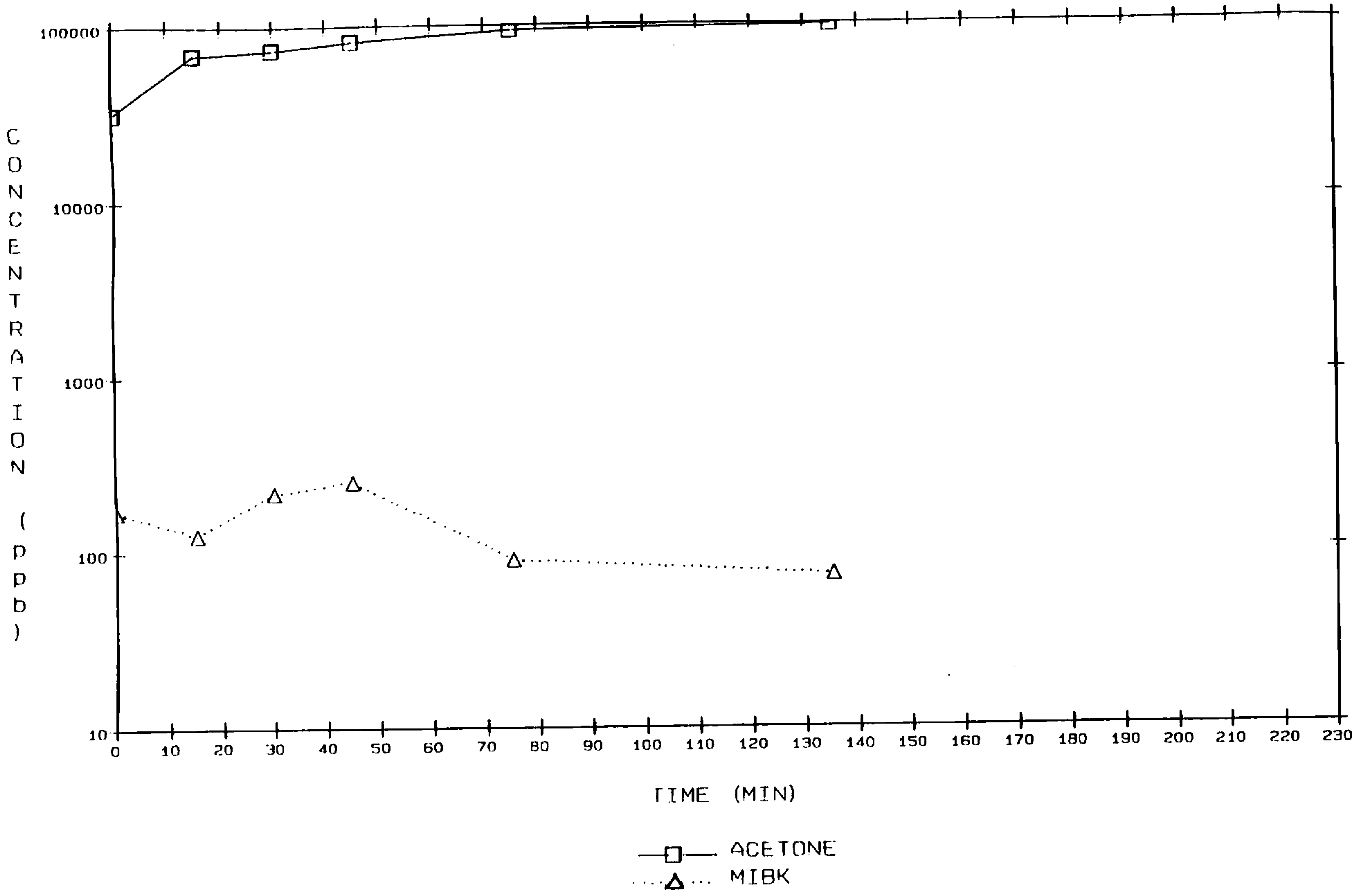
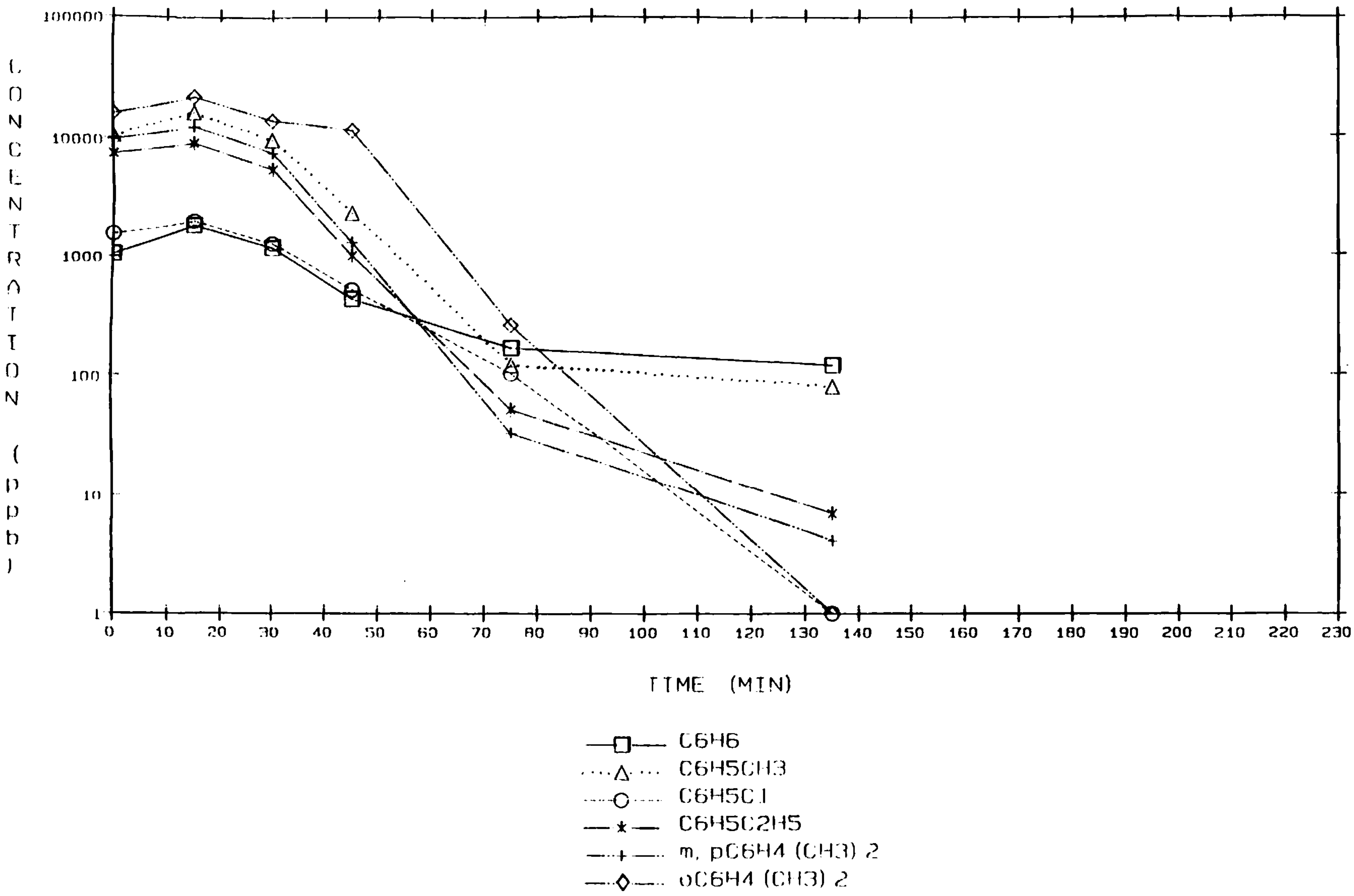


OSWEGO RO (CONC) - uV (BATCH) #21 KETONES



OSWEGO RD (CONC) - UV (BATCH) #2/ AROMATICS



APPENDIX B

SOLARCHEM REPORT

Solarchem

LEACHATE REMEDIATION

AT THE

OSWEGO SUPERFUND SITE

USING

RAYOX - A SECOND GENERATION

ENHANCED OXIDATION PROCESS

Prepared For : Mr. Harry Whittaker
Environmental Emergencies Division
Environment Canada

Prepared By : Solarchem Enterprises Inc.
Richmond Hill, Ontario Canada

January 1989

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I. INTRODUCTION

In co-operation with Environment Canada, Solarchem Inc. has completed a series of demonstration runs using one configuration of its pilot scale **RAYOX** enhanced oxidation equipment to treat leachate from the EPA Superfund site at Oswego, New York. The objectives of the work were:

- to demonstrate the utility of the **RAYOX** system as a stand alone process in the treatment of a multi-contaminant leachate/groundwater stream containing approximately 30ppm of VOC's, and
- to evaluate **RAYOX** as a pre- or post-treatment adjunct to reverse osmosis (RO) in an identical remediation situation.

Consistent with experience to date, the **RAYOX** unit was started-up during the second week of August 1988 and ran without incident through mid September depending on the availibility of site leachate, RO concentrate and/or permeate.

Key conclusions arising from these demonstration runs confirmed that:

- o **RAYOX** reliably achieved greater than 99% removal (2-3 orders of magnitude reduction) of VOC's from the subject water on a stand alone basis
- o **RAYOX**-treated leachate and permeate met the current EPA maximum monthly average indirect discharge standards for organic chemicals discharged to a local POTW
- o <u>in the configuration tested</u>, **RAYOX** was most efficient (moles of contaminant removed per unit of oxidant input) at processing higher concentration streams, and
- o if used in tandem, **RAYOX** should logically proceed RO and employ concentrate recycle.

This report is provided as a stand alone Addendum, and as an Appendix to, the Environment Canada report to Roy F. Weston Ltd., site managers at the Oswego site. As such, its purpose is to interpret the **RAYOX** results in light of Solarchem's unique understanding of <u>second generation</u> enhanced oxidation processes. Because limitations occasioned by

- slow analytical turnaround
- pretreated (iron reduced) feedstock availability, and
- late trial RO malfunction

precluded any practical on-site optimization of the RAYOX processing variables, the data presented herein are, for all intents and purposes, based on an application of a fixed dosage of oxidant input per unit of time in both batch and continuous flow modes.

In the sections of this report which follow, we provide an overview of enhanced oxidation, an outline of the trial conditions and test results observed, as well as our conclusions based on an interpretation of the study findings.

II. BACKGROUND TO THE ENHANCED OXIDATION PROCESS

In enhanced oxidation processes, the principal oxidizing agents are radicals. These oxidizing agents have much greater oxidizing power than their precursors, which generally perform the role of oxidant source rather than oxidizing agent. Typical oxidant sources are ozone and hydrogen peroxide. On occasion, less used oxidant sources are appropriate, e.g. hypochlorite or ferrous sulphate.

The synergistic effect of UV and O_3 has been known for many years, with one of the first interpretations being given by Prengle and co-workers(1) in 1976. The principles of this synergistic effect are now fairly widely understood and agreed upon by investigators studying photooxidation mechanisms. A recent discussion of the topic is given in papers by Glaze(2) and Peyton(3).

Table 1 gives some of the reactions by which waterborne contaminants can be oxidized. Thermodynamics tells us that virtually any organic contaminant, in the presence of an oxidizing source will, given enough time, be fully mineralized to CO_2, H_2O (and Cl^- in the case of a chlorinated compound). However, the oxidation rates for such processes are typically too slow to be of broad utility for wastewater treatment.

However, if the contaminated water stream with the oxidant source is also exposed to short wavelength ultraviolet light (λ<300nm), and particularly to light closely matched to the absorption spectrum of the contaminant compounds therein, then several additional decomposition reactions are initiated which greatly increase the rate of oxidation of the contaminant.

Many contaminants, which absorb UV light and are represented by R_1R_2 in Table 1, dissociate into fragments called radicals. These racidals typically react very rapidly with oxygen to form peroxy radicals (e.g. $HCOO_2\cdot$) which themselves can participate, in a complex way, with the oxidation of the contaminants present. Alternatively, they can decompose directly into simpler molecular fragments.

TABLE 1

OXIDATION REACTIONS

Direct Oxidation

$$R \xrightarrow{O_3/H_2O_2/O_2} \boxed{\begin{array}{l}\text{Oxygenated}\\ \text{Intermediates}\end{array}} \xrightarrow{O_3/H_2O_2/O_2} CO_2 + H_2O$$

Photooxidation

$$R_1R_2 \longrightarrow {}^1R_1R_2^* \xrightarrow{\text{dissociation}} R_1\cdot + R_2\cdot$$

Where R_1 & R_2 are radical species such as: H, Cl, alkyl, aryl, acetyl, etc.

$$R\cdot + O_2 \longrightarrow RO_2\cdot \xrightarrow{\text{dissociation}} \boxed{\begin{array}{c}\text{Smaller molecular}\\ \text{fragments}\end{array}} \xrightarrow{h\nu/O_3/H_2O_2/O_2} CO_2 + H_2$$

$${}^1R_1R_2^* \longrightarrow {}^3R_1R_2^* \xrightarrow{\text{dissociation}} R_1\cdot + R_2\cdot$$

$${}^3R_1R_2^* \xrightarrow{O_3/H_2O_2/O_2} \boxed{\begin{array}{l}\text{Oxygenated}\\ \text{Intermediates}\end{array}} \xrightarrow{h\nu/O_3/H_2O_2/O_2} CO_2 + H_2O$$

Photolysis of Ozone

$$O_3 \xrightarrow[H_2O]{h\nu} 2HO\cdot + O_2$$

Photolysis of Hydrogen Peroxide

$$H_2O_2 \xrightarrow{h\nu} 2HO\cdot$$

Radical Attack

$$R + HO\cdot \longrightarrow R\cdot + H_2O$$

Some contaminants do not dissociate to a significant extent upon absorption of UV light, but instead form a relatively long lived reactive intermediate called a "triplet", shown in Table 1 as $^{3}R_1R_2^{*}$. The triplet species thus formed have a sufficient lifetime to encounter and react with any oxidizing species (O_3,O_2,$HO\cdot$) that is present in solution, yielding, as products, more oxygenated compounds, which themselves will be subject to all the oxidizing processes underway in the water stream in question. If sufficient time is allowed, the contaminants will be fully mineralized.

In addition to direct photooxidation of the contaminants, the use of UV light has a powerful complementary benefit, which is the formation of extremely strong oxidizing agents such as the hydroxyl radical ($HO\cdot$). Once formed, the hydroxyl radical will result in the rapid oxidation of the contaminants present. The importance of the $HO\cdot$ radical becomes obvious when one realizes that $HO\cdot$ reacts with a compound like phenol $\sim 10^{6}$ (one million) times as fast as does molecular ozone. These processes are also illustrated in Table 1.

In all the mechanisms described, optimization of the UV and oxidant dosage is essential. While complete detailed breakdown pathways for specific chemicals are generally not elucidated, the process is, nonetheless, reasonably well understood overall. Chlorinated compounds, such as perchloroethylene, dioxin etc., are particularly well suited to these enhanced oxidation processes. As an example, Table 2 has a proposed breakdown of the steps in the mineralization of perchloroethylene, as suggested by Proksch et al (4).

Table 2

REACTION MECHANISM FOR HYDROXYL RADICAL INITIATED

OXIDATION OF PERCHLOROETHYLENE

$$CCl_2 - CCl_2 + HO\cdot \dashrightarrow HOCCl_2 - CCl_2\cdot$$

$$HOCCl_2 - CCl_2\cdot \dashrightarrow COCL - CCl_2\cdot + HCl$$

$$COCl - CCl_2\cdot + O_2 \dashrightarrow COCl - CCl_2OO\cdot$$

$$2COCl - CCl_2OO\cdot \dashrightarrow O_2 + 2COCl - CCl_2O\cdot$$

$$COCl - CCl_2O\cdot \dashrightarrow \cdot COCl + CCl_2O$$

$$CCl_2O + H_2O \dashrightarrow CO_2 + HCl$$

$$\cdot COCl + H_2O \dashrightarrow \cdot CCO^{-} + H^{+} + HCl$$

$$\cdot COO^{-} + O_2 \dashrightarrow \cdot O_2^{-} + CO_2$$

Using enhanced oxidation, a wide range of organic and inorganic compounds can quickly be oxidized. Intermediates generated in these processes are generally less stable than the original compound (s) and are thus easily oxidizable as well. The mechanisms outlined above are particularly attractive in environmental remediation technology since they produce no secondary disposal problems i.e. they represent an on-site destruction technology.

III. THE TEST PROGRAM

Experienced gained to date suggests that the operation and attendant results obtained from second generation enhanced oxidation systems like RAYOX depend on four major considerations:

- the nature of the contaminant - affects the choice of oxidant and catalyst regimen as well as the wavelength of UV light required
- the initial concentration - affects the amount of oxidant and catalyst required as well as the processing time
- the flow rate - affects the number, size and design of the reactors, as well as the lamp power to be used
- the degree of removal required - affects the processing time, the number and nature of the treatment stages, as well as the reactor design.

Normally a treatment regimen and an equipment configuration can be optimized by Solarchem in a laboratory treatability study before on-site work begins. Because an adequate volume of sample was not easily available before this trial began, pilot scale equipment with a general purpose reactor configuration was selected for the run.

A. THE TEST EQUIPMENT

The RAYOX test unit, which was housed in a twenty foot truck for the duration of the trial, was plumbed on site to accept the three different feedstocks being evaluated; leachate, permeate and concentrate. A drain line for treated water was placed into a re-injection well located on the property.

The general purpose equipment configuration selected consisted of two holding/processing tanks of 210L each, three identical RAYOX reactors each equipped with a proprietary Solarchem UV lamp, oxidant injection ports and contactors as well as automatic pH control. The unit could be run in either batch or continuous flow mode at a circulation flow rate of 5GPM. For complete operator safety, a proprietary ozone destruction unit was provided for off-gas treatment from the air/water separation tank. Additional safety features included automatic shutdown of the lamps upon pump failure or ground fault detection. An ozone generator and air preparation unit completed the equipment package shown in schematic in Figure 1.

B. TRIAL PROTOCOL

Twenty-one runs were performed over the six week test period in both batch and continuous flow mode. Table 3 presents a summary of run conditions grouped by feedstock source. Because of the long turnaround time for on-site sample analysis and the limited feedstock availability for any individual run, optimization of the RAYOX system could not realistically be attempted. While several runs were initially designed to demonstrate the effect of varying two of the four process parameters - light dose and oxidant dose - insufficient information was gathered to demonstrate their effect conclusively. Indeed, during the last week of testing, when several key experiments in this regard were attempted, the RO system suffered a membrane rupture which resulted in dramatically increased permeate concentrations inconsistent with the previous data obtained.

While the presence of metals (<100 ppm) is not generally a problem for the RAYOX process, the unanticipated and unusually high iron content (500ppm) of the leachate was reduced by alkaline precipitation prior to all runs, either through the RAYOX unit on a stand alone basis, or through the RO.

IV. DISCUSSION OF RESULTS

A complete listing of the GC analyses for the twenty-four VOC compounds under evaluation is provided in Tables A-1 through A-15 in Appendix A. Tables B-1 through B-6 provide similar analyses for the semi-volatile compounds such as phenols for the clean permeate and concentrate runs. Acetone results have not been included in our calculations for total VOC since results from subsequent analysis by GC/MS were significantly at odds with the on-site GC analysis.

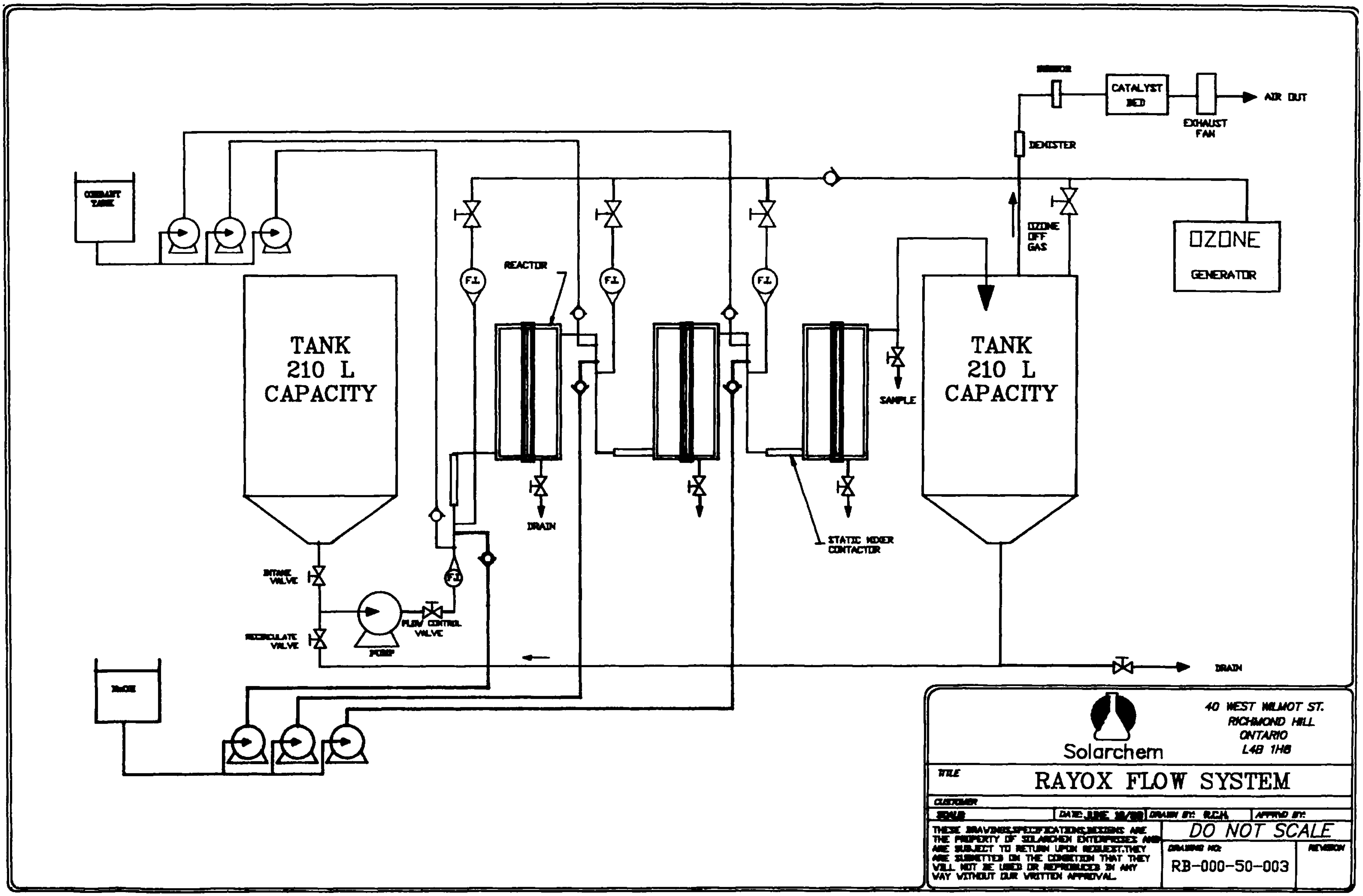

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FIGURE 1. RAYOX TEST UNIT

Removal rates for all compounds are shown by plotting log (C/Co) versus dose where C is the concentration in ppb and Co is the initial concentration in ppb. This representation permits direct reading of orders of magnitude reduction while separating the destruction curves for easier interpretation. Direct and indirect oxidant source dose is shown in cumulative arbitrary dose units in order to permit comparison of one graph with another.

Table 3

SUMMARY OF RUN CONDITIONS

TYPE OF FEED	RUN #	DATE	INITIAL VOC CONC (PPM)	CONDITIONS
SHAKEDOWN	1-4	8/10-13	-	VARIOUS
LEACHATE	6	8/19	19.90	UV/O_3/H_2O_2 pH10
	7	8/19	23.62	UV/O_3 pH10
	8	8/20	19.90	UV/O_3/H_2O_2 pH10
	9	8/22	19.90	UV/O_3/H_2O_2 pH10
	10	8/23	28.42	O_3/H_2O_2 pH10
	11	9/7	85.45	UV/O_3 pH10 FLOW
PERMEATE	5	8/18	1.23	UV/O_3 pH10
	13	9/10	21.94	UV/O_3 pH5
	14	9/12	57.74	O_3 pH8+UV/O_3pH5
	15	9/13	19.18	UV/O_3 pH5 FLOW
	16	9/13	12.58	UV/O_3 pH10 FLOW
CONTAMINATED PERMEATE	17	9/14	80.08	O_3+UV/O_3 pH5 FLOW
	18	9/14	124.73	UV/O_3 pH5 FLOW
	19	9/14	124.73	O_3 pH10+UV/O_3 pH5 FLOW
	20	9/14	124.73	O_3 pH10+UV/O_3 pH10 FLOW
CONCENTRATE	12	9/9	304.69	UV/O_3 pH10
	21	9/15	325.45	UV/O_3 pH4

A. LEACHATE RUNS

During this group of six runs, leachate at 20-30 ppm of VOC's was processed directly by the RAYOX unit. One run with an initial concentration of 85 ppm was also undertaken. As expected, the equipment was switched on and ran without incident as long as feedstock was available.

Figure 2 presents the results for total VOC concentration at various points during runs six through eleven. Results from runs six, eight and nine were averaged as the run conditions were identical ($UV/O_3/H_2O_2$ at pH10).

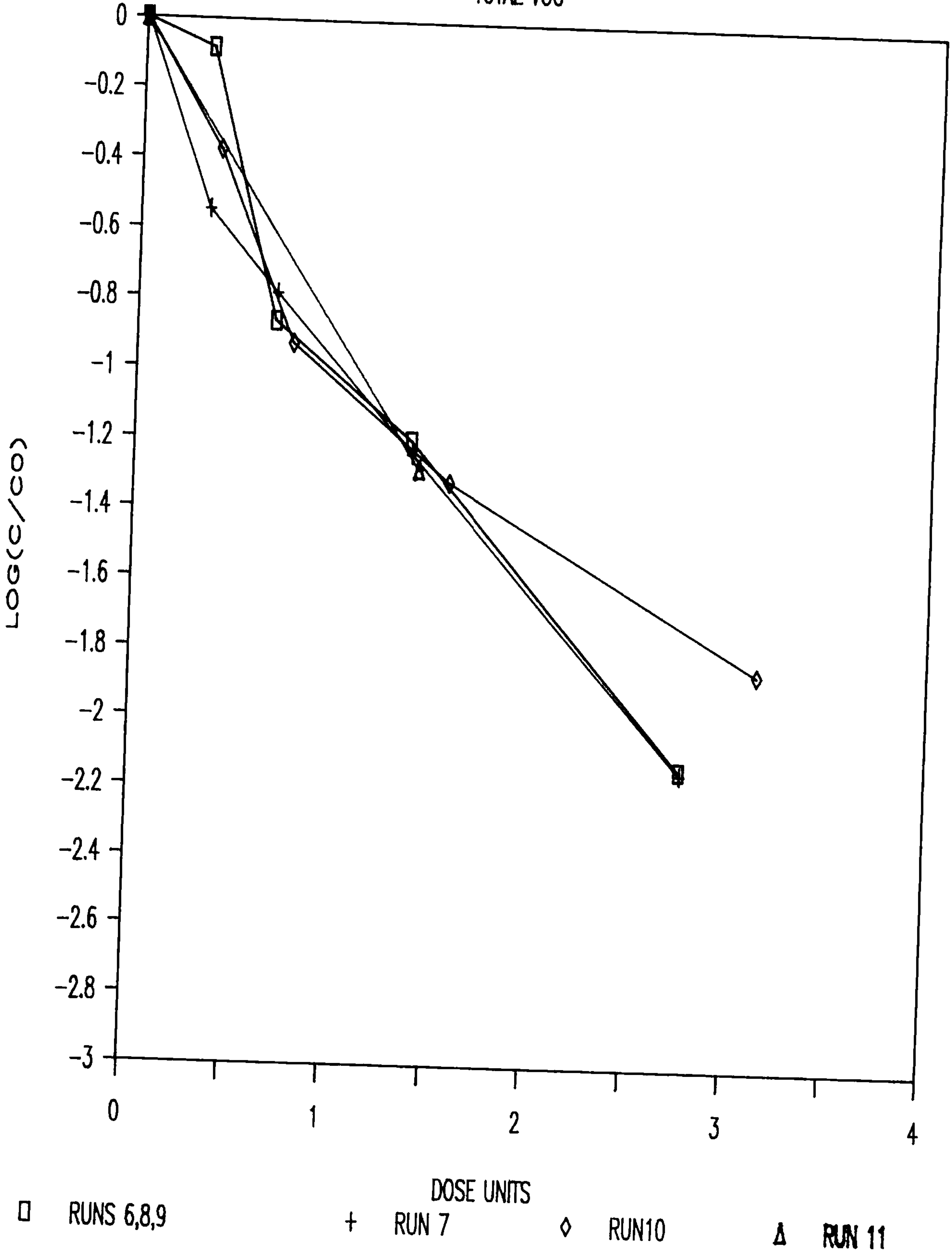
The total VOC removal was greater than 99% for runs six through nine and slightly less than 99% for run ten where no UV light was used. Although the rate of removal was similar for the first part of the reaction (ie: to about 95% removal or log (C/Co) = -1.3), the presence of UV enhances the rate of reaction during the last part of the removal process (ie: to 99^+% removal or log $(C/Co)=-2^+$). This observation is consistent with experience gained elsewhere which indicates a staged processing regimen is often more cost-effective in treating low concentration streams of this nature.

Reference to the GC analyses for runs six through nine in Appendix A shows that the final discharge concentrations would meet the EPA's maximum monthly average indirect discharge standards for all the VOC's present in the treated leachate. Furthermore, if one examines the final concentrations of normally refractory compounds such as the dichloroethanes, it is clear from the GC data for runs seven (with UV) and ten (without UV) in Appendix A, that the presence of UV is necessary in order to achieve these discharge standards. With effluent levels like those obtained in runs six through nine, post-treatment processing by reverse osmosis would not make practical sense.

For the continuous flow run undertaken on leachate (run eleven), reference to Figure 2 indicates that the rate of removal was entirely consistent with the other runs at the same fixed dosage rate of direct and indirect oxidants. This observation confirms that batch and continuous flow operation are equally effective processing modes using the RAYOX enhanced oxidation equipment.

LEACHATE

TOTAL VOC



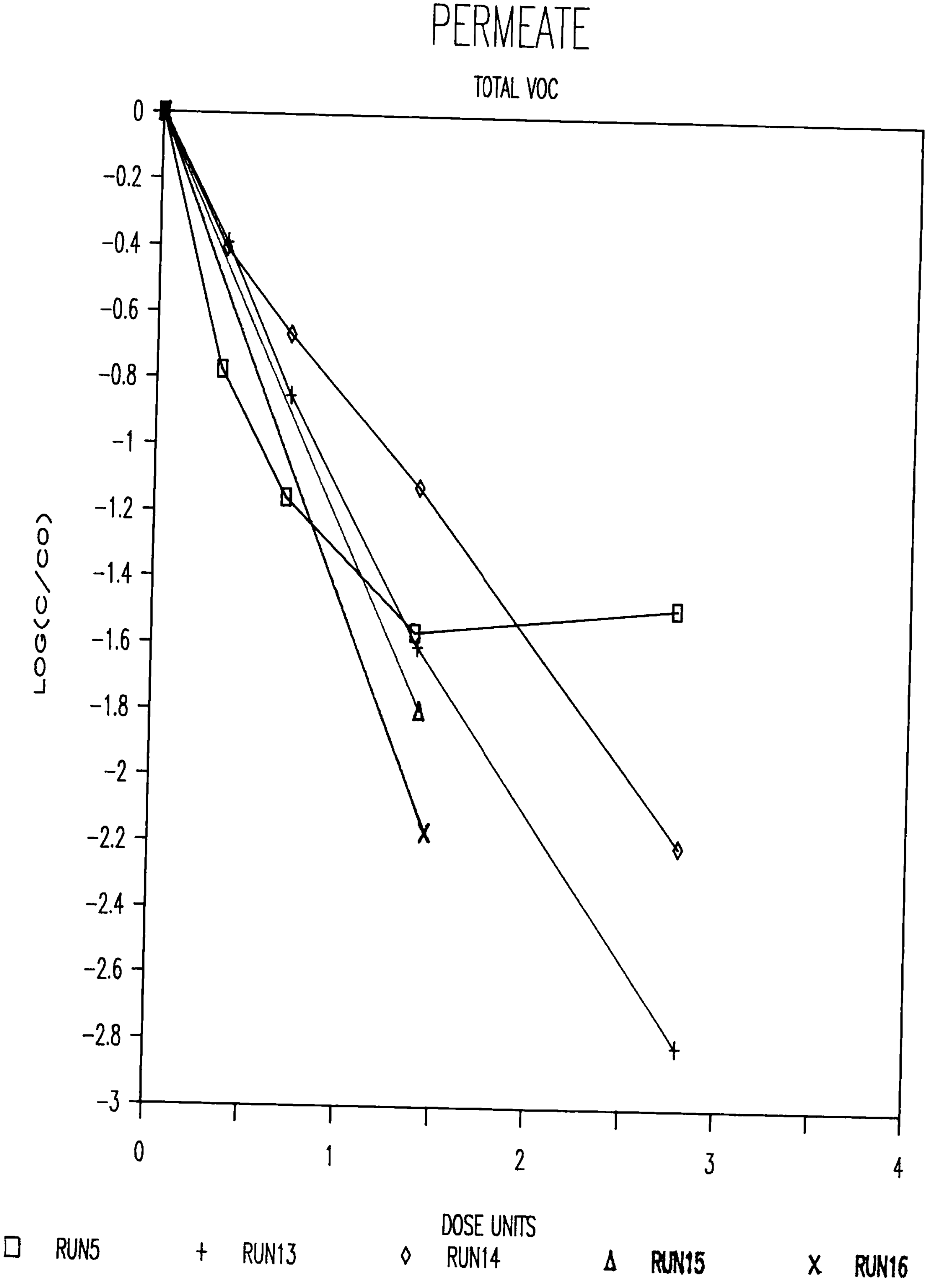
B. PERMEATE RUNS

During this group of five runs, the objective was to evaluate **RAYOX** as a post-treatment, or polishing step, for the reverse osmosis system. Figure 3 presents the results for the total VOC analyses for runs five and thirteen through sixteen.

Runs five and thirteen were processed identically albeit from more than an order of magnitude difference in initial concentration (1.2 ppm versus 21.9 ppm) and at pH 10 and 5 respectively. The rate of VOC removal was identical at mid-point during the run (ie: 97% removal-log(C/Co)=-1.5). However, by the end of the run, the VOC removal from run five remained at 97% or 30 ppb while run thirteen continued on down to 34 ppb or 99.8% removal (log (C/Co)=-2.8). While the anomaly evident with the run five data might be due to the reduced efficiency of radical usage at these low concentrations or, alternatively, a pH related phenomenon, the former would be inconsistent with the "equally inefficient" environment relevant in run thirteen, and the latter would be inconsistent with the findings in comparing runs fifteen and sixteen as well as experience gained elsewhere. The more probable explanation after referring to the run five GC data in Appendix A lies in analytical error at these detection levels for 1,1-dichloroethene and toluene both of which actually "rose" significantly from their previous readings at the mid point of the processing cycle.

While run fourteen achieved 99.4% VOC removal from an initial concentration of 57.7 ppm, the final effluent concentration still met indirect discharge standards even though the inlet concentration of methylene chloride represented 82% of the initial concentration of VOC's present! This run clearly demonstrated the effectiveness of the **RAYOX** system in dealing with methylene chloride which generally cannot be treated cost-effectively with traditional remediation processes.

Flow through runs fifteen and sixteen again confirmed that results from flow through operation are as good as, if not better than, batch processing operation. Starting with initial concentrations in the twelve to twenty ppm range, indirect discharge standards could straightforwardly be met when processing RO permeate with the **RAYOX** enhanced oxidation unit.


PERMEATE
TOTAL VOC
LOG(C/CO)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
-2.8
-3
0
1
2
3
4
DOSE UNITS
□ RUN5
+ RUN13
◇ RUN14
Δ RUN15
X RUN16

In addition, it is interesting to note that the permeate runs would have been virtually metal free as a result of RO processing, while the leachate runs discussed in section A above would likely have contained some metals even after pretreatment by alkaline precipitation. Since the leachate and permeate destruction results were so similar, it becomes apparent that metals or other inorganics present in the leachate after pretreatment do not interfere with **RAYOX** processing.

C. CONTAMINATED PERMEATE RUNS

The intended purpose of this group of runs was to explore the effect of dose variation on the treatment of RO permeate by the **RAYOX** system in the continuous flow mode. Unfortunately, these runs were performed after the rupture of an RO membrane, and it was only later discovered that the permeate had been heavily contaminated with concentrate. The starting VOC concentration was therefore relatively high at about 124 ppm, and the material had a darker colour than the earlier permeate, along with a strong leachate odour.

Figure 4 presents the results from the total VOC analyses for runs seventeen, eighteen, nineteen and twenty. These runs were all performed in the continuous mode at one third the UV dose and variations in the pH of the reaction.

VOC removal was virtually identical for the three runs that varied the pH (runs seventeen, nineteen and twenty). About 90% removal was achieved at a dose equal to about half the dose used for 99% removal in a batch run at full UV dose. This was less removal than was noted for either the permeate or leachate runs, which was undoubtedly due to the much higher starting concentration of VOC and the much reduced UV dose. It is unfortunate that clean permeate was not available for these runs, since these reduced dose runs cannot be directly compared to the previous runs at a normal UV dosage. No further discussion of these results is therefore warranted.

D. CONCENTRATE RUNS

The purpose of these two runs was to evaluate the effectiveness of **RAYOX** as a post-treatment adjunct to the RO system.

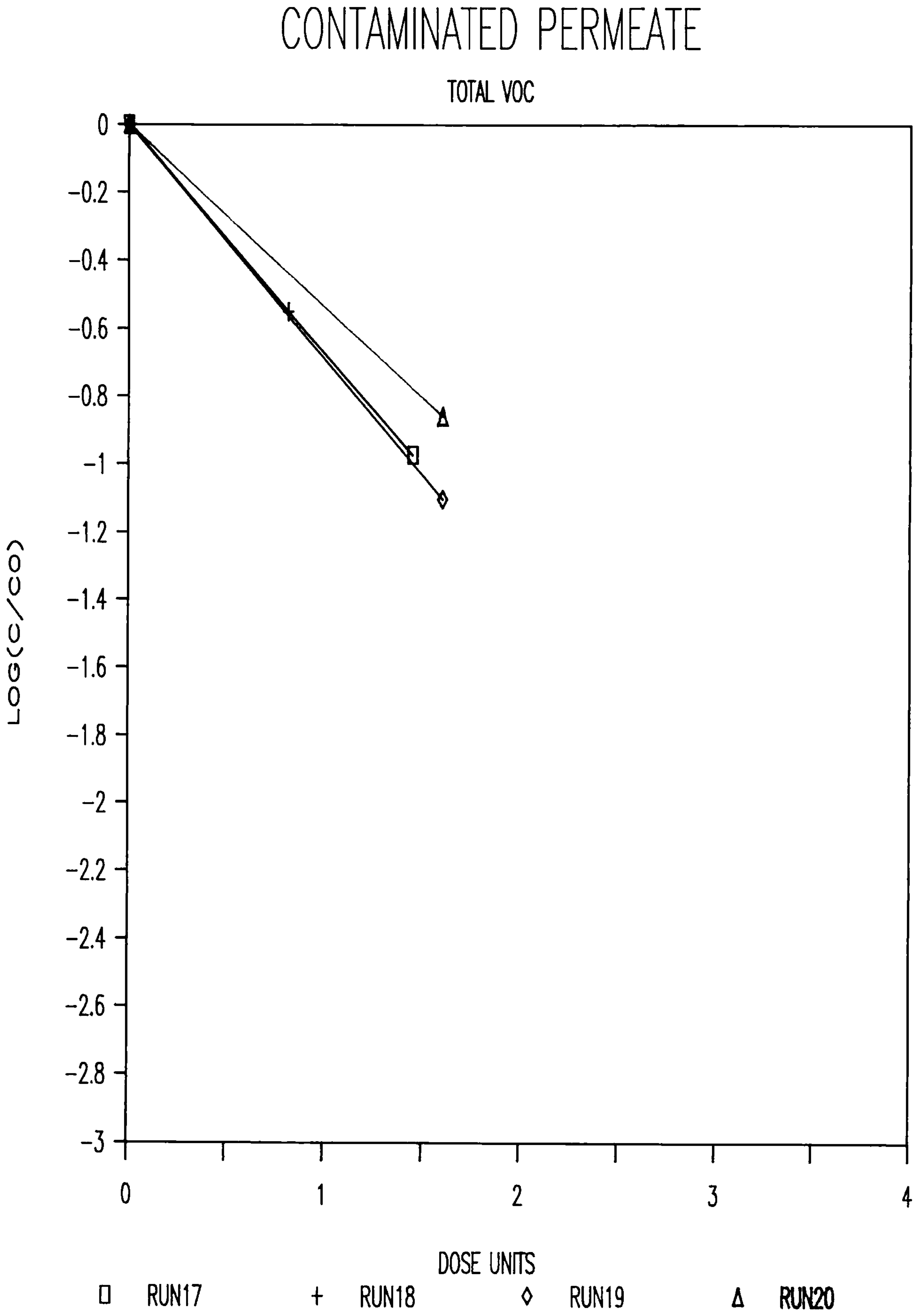

CONTAMINATED PERMEATE
TOTAL VOC
LOG(C/CO)
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
-2.8
-3
0
1
2
3
4
DOSE UNITS
□ RUN17
+ RUN18
◇ RUN19
△ RUN20

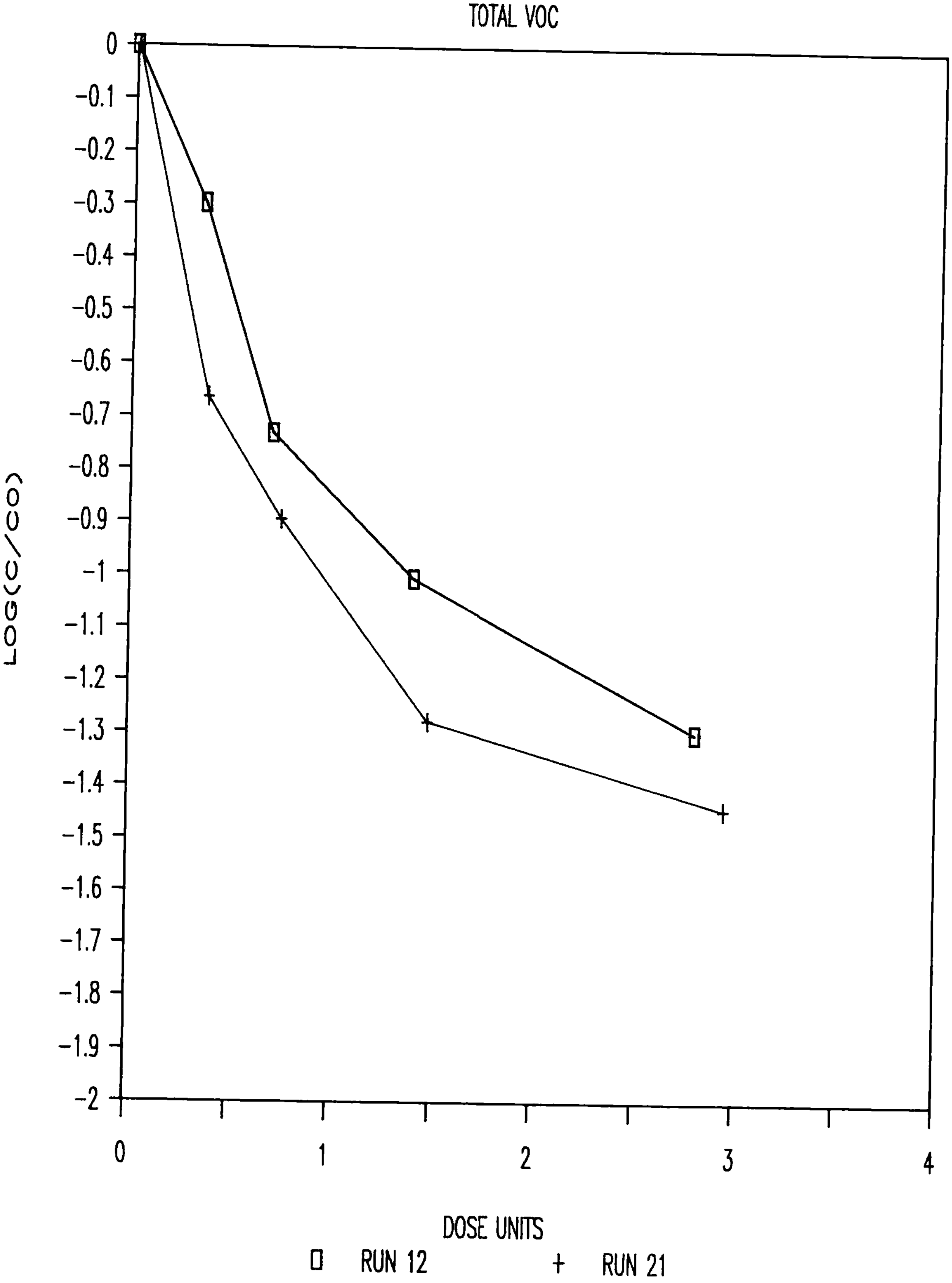
FIGURE 4.

Starting with similar initial concentrations of VOC's and processing in an identical manner save for pH conditions, Figure 5 shows that runs twelve and twenty-one achieved 95-96% removals at the same level of direct and indirect oxidant inputs as were used to achieve $99^{+}\%$ removals in the RAYOX leachate runs. With residual concentrations at that point in the 10-15 ppm range ie: similar to the initial concentration values for the leachate and permeate runs at 12 to 28 ppm, it is likely that 1.5-2.0 times as much additional processing would have yielded removal rates on the concentrate suitable for indirect discharge. This logic would therefore indicate that this particular treatment regimen and equipment configuration of RAYOX is most efficient when processing higher initial concentration streams ie: less than a factor of two increase in dosage can treat ten times the concentration of VOC's to a similar end point. It should be noted at this point however, that experience gained elsewhere has shown that a change in treatment regimen can significantly alter the conclusions peculiar to these runs, ie: can treat low concentration streams with similar efficiency. These runs further confirm that any metals present, even after concentration by reverse osmosis, did not interfere with RAYOX processing.

E. REFRACTORY COMPOUNDS

Most compounds in the leachate and permeate runs undertaken were easily removed to indirect discharge standards, or to non-detectable levels, using the RAYOX enhanced oxidation process. Nonetheless the key to achieving a given total toxic organics discharge level from a leachate "soup", will depend on the rate of removal for the more refractory compounds therein. This phenomenon becomes more obvious as initial concentrations rise. With concentrate run twenty-one as an example, it can be seen that compounds with higher hydroxyl radical rate constants (xylene, toluene, dichloroethenes) will disappear before those with rate constants one to two orders of magnitude lower (methylene chloride, dichloroethanes). While we were unable to compensate for this fact during these runs, Solarchem's experience to date has shown that an alternative treatment regimen would likely be necessary in order to arrive at the most cost-effective treatment process for "soups" containing high concentrations of these latter compounds.

CONCENTRATE



F. SEMI-VOLATILE COMPOUNDS (BNA's)

Tables B-1 through B-6 in Appendix B present the GC analyses for semi-volatile compounds, or BNA's, such as phenols, nitrobenzene and benzoic acid. The data is also presented graphically in Figures 6 and 7. In the permeate runs, thirteen through sixteen, initial total concentrations in the 0.5ppm to 1.6ppm range were destroyed to non-detectable levels. A similar pattern was evident for concentrate run twenty-one even though the total initial concentration was 42ppm ! Unfortunately, conclusions cannot realistically be drawn on the run twelve concentrate because of incomplete data ie: no initial concentration figures were available.

Clearly, this class of compounds can be easily removed with the Rayox enhanced oxidation process.

V. CONCLUSIONS

Several important conclusions can be drawn from an analysis of the data arising from the demonstration work undertaken at the Oswego Superfund site. The most significant among these are:

- the RAYOX second generation enhanced oxidation system performed reliably as a stand alone process for treating the subject leachate to EPA indirect discharge standards (>99% removal of VOC's)

- as a post-treatment process for RO permeate, the RAYOX system again comfortably met indirect discharge standards as above

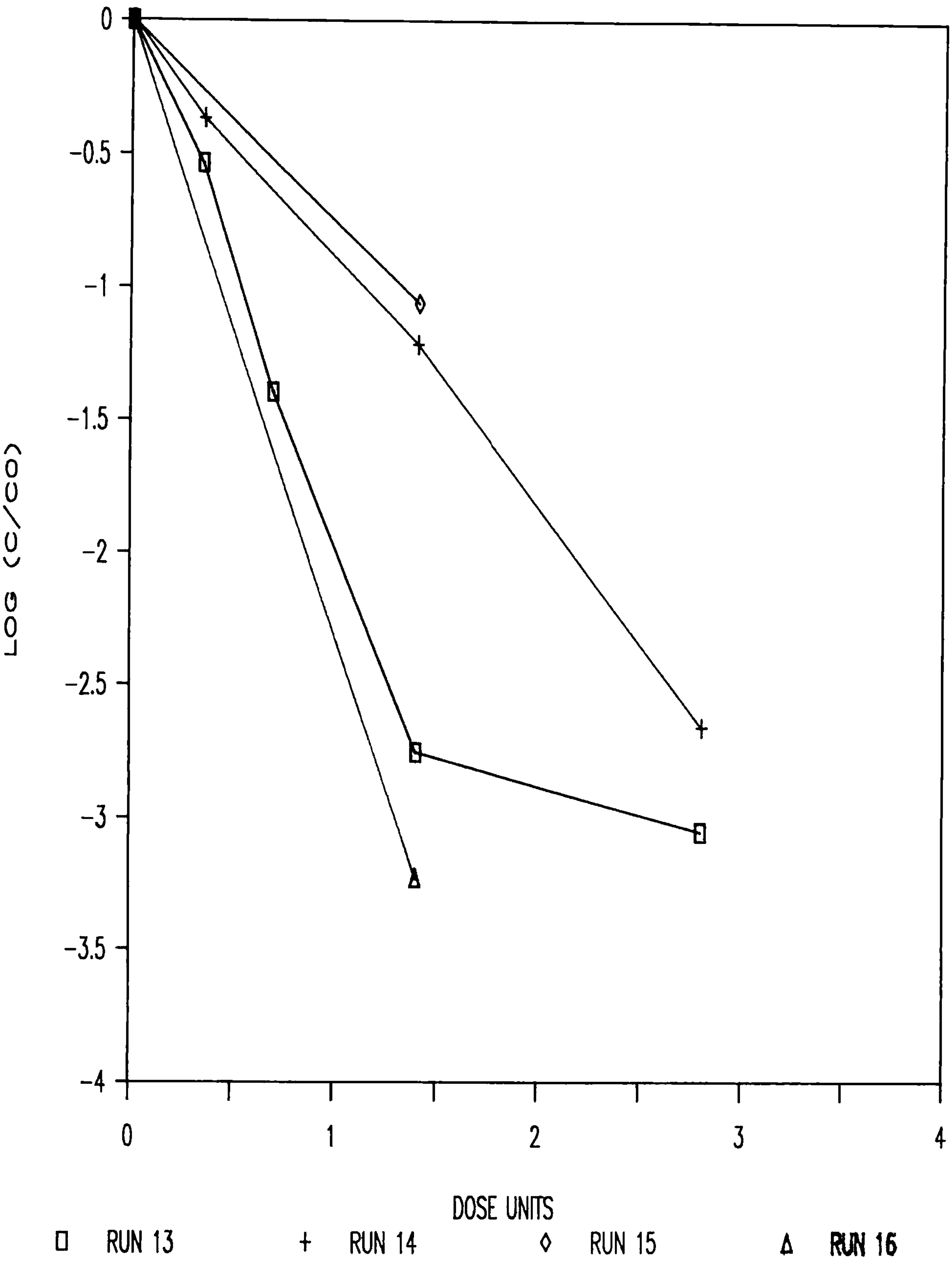
- as a post-treatment for RO concentrate, and when compared to treating permeate or leachate, the particular RAYOX equipment configuration and treatment regimen used were most efficient (moles of contaminant removed per unit of input) at removing the higher concentrations typical of RO concentrates

- given the same dosage rates, batch and continuous modes of operation for RAYOX are equally effective

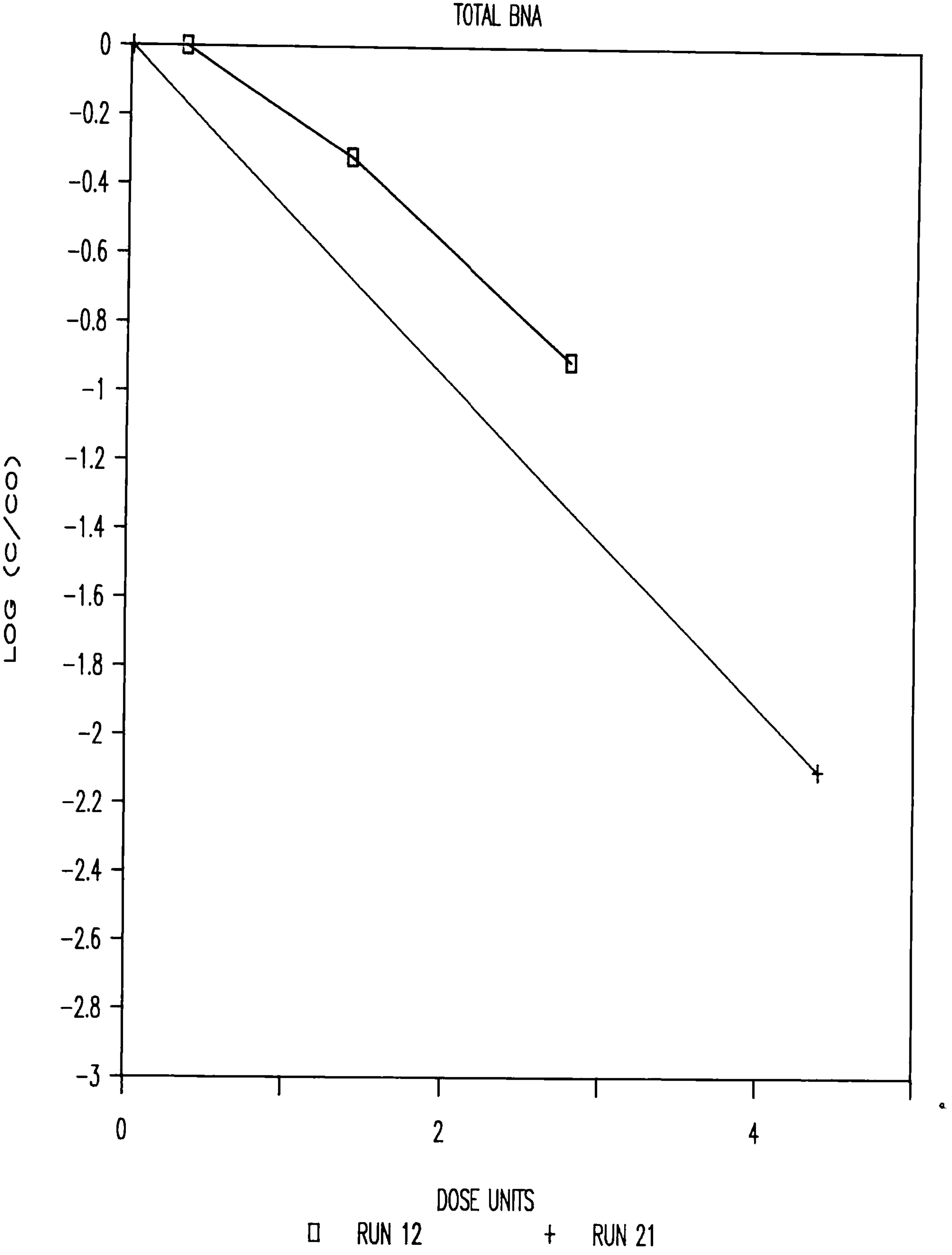
- the presence of modest levels of metals or other inorganics, even after concentration by reverse osmosis do not interfere with the RAYOX process, and

PERMEATE

TOTAL BNA

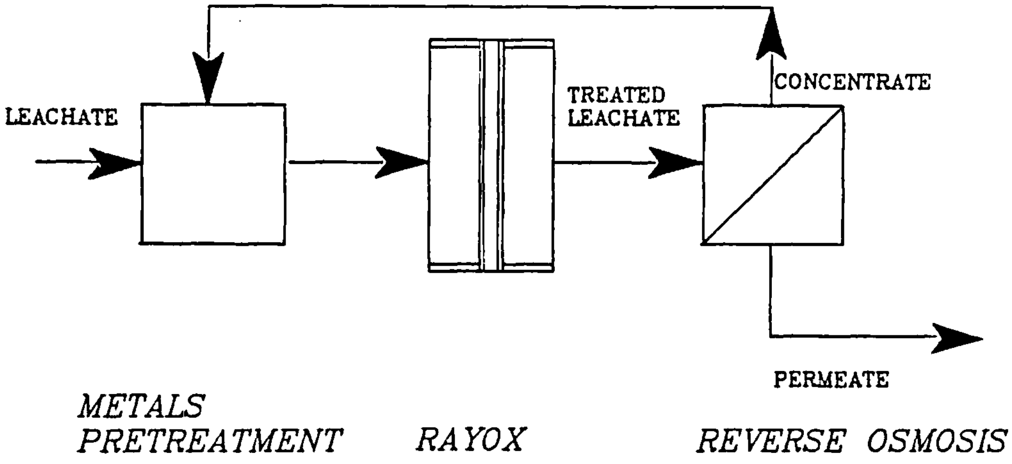


CONCENTRATE



- if enhanced oxidation were to be used in conjunction with an RO system, it appears as if the RAYOX system should be used (Figure 8 below), to first treat the subject stream ie: use RAYOX in its most efficient mode, followed, as necessary, by RO with concentrate recycle. However, more detailed testing would have to be performed in order to confirm this hypothesis and to determine the most cost effective combination for given initial leachate concentrations.

FIGURE 8



While it was not practical to calculate processing costs on a treatment regimen which could not be optimized on site for the reasons discussed in Sections I and III above, Solarchem's experience to date indicates streams contaminated with less than 100 ppm of total organics can typically be treated to appropriate discharge levels for less than $3/1000 gallons including lamp replacement costs. For concentrations below 500 ppm, the corresponding figure would typically be approximately double this amount.

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APPENDIX A

TABLE A-1 VOLATILE RESULTS

#	RUN #5						
	UV/03 pH10	DOSE UNITS	0.00	0.34	0.69	1.38	2.76
	PERMEATE						
#	COMPOUND	TIME(MIN)	0	15	30	60	120
1	STANDARD		102.30	101.00	100.40	95.20	96.7
2	METHYLENE CHLORIDE		124.60	1.00	1.00	1.00	1
3	ACETONE						
4	1,1-DICHLOROETHENE		2.40	ND	ND	ND	ND
5	1,1-DICHLOROETHANE		50.80	18.20	12.20	10.50	15.8
6	t-1,2-DICHLOROETHENE		617.50	71.10	13.40	1.10	2
7	CHLOROFORM		NA	NA	NA	NA	NA
8	1,2-DICHLOROETHANE		164.40	80.50	41.30	9.60	5.7
9	1,1,1-TRICHLOROETHANE		6.90	3.20	3.20	1.50	2.1
10	CARBON TETRACHLORIDE		NA	NA	NA	NA	NA
11	BROMODICHLOROMETHANE		NA	NA	NA	NA	NA
12	1,2 DICHLOROPROPANE		NA	NA	NA	NA	NA
13	c-1,3-DICHLOROPROPENE		NA	NA	NA	NA	NA
14	TRICHLOROETHENE		5.90	?	?	0.00	0
15	BENZENE		26.10	3.80	1.60	1.10	1.6
16	TETRACHLOROETHENE		ND	ND	ND	ND	ND
17	METHYL ISOBUTYL KETONE		1.50	0.80	0.90	0.00	1.1
18	BROMOFORM		NA	NA	NA	NA	NA
19	1,1,2,2-TETRACHLOROETHANE		14.50	3.80	1.80	6.60	1.6
20	TOLUENE		91.20	10.00	6.30	2.60	8.1
21	CHLOROBENZENE		20.20	2.20	0.50	ND	0.2
22	ETHYLBENZENE		ND	ND	ND	ND	ND
23	M-,P- XYLENE		30.70	3.80	1.20	0.50	0.3
24	O-XYLENE		68.30	8.00	2.70	0.00	1.7

ALL CONCENTRATIONS IN PPB

TOTAL VOC	1225	206.4	86.1	34.5	41.2
LOG(C/CO)	0.00	-0.77	-1.15	-1.55	-1.47

TABLE A-2 VOLATILE RESULTS

AVERAGE RUNS 6,8,9
UV/03/H202 pH10
LEACHATE

	DOSE UNITS	0.00	0.34	0.69	1.38	2.76
	COMPOUND TIME(MIN)	0	15	30	60	120
1	STANDARD	106.31	109.31	179.64	197.53	123.87
2	METHYLENE CHLORIDE	471.00	637.54	832.12	331.26	1.00
3	ACETONE					
4	1,1-DICHLOROETHENE	158.31	153.16	102.16	61.92	23.47
5	1,1-DICHLOROETHANE	436.76	1772.79	199.66	66.01	12.17
6	t-1,2-DICHLOROETHENE	2711.32	1854.18	194.90	56.68	16.77
7	CHLOROFORM	0.00	0.00	0.00	0.00	0.00
8	1,2-DICHLOROETHANE	856.36	802.62	634.01	446.97	71.61
9	1,1,1-TRICHLOROETHANE	227.00	195.62	66.71	30.69	4.16
10	CARBON TETRACHLORIDE	0.00	0.00	0.00	0.00	0.00
11	BROMODICHLOROMETHANE	0.00	0.00	0.00	0.00	0.00
12	1,2 DICHLOROPROPANE	0.00	0.00	0.00	0.00	0.00
13	c-1,3-DICHLOROPROPENE	0.00	0.00	0.00	0.00	0.00
14	TRICHLOROETHENE	53.16	77.50	57.17	45.66	3.85
15	BENZENE	353.22	256.39	33.08	12.92	1.43
16	TETRACHLOROETHENE	0.00	0.00	17.43	16.29	0.00
17	METHYL ISOBUTYL KETONE	34.47	67.91	26.87	24.68	1.15
18	BROMOFORM	0.00	0.00	0.00	0.00	0.00
19	1,1,2,2-TETRACHLOROETHANE	229.39	197.12	114.30	98.84	1.78
20	TOLUENE	2739.74	1911.22	94.74	20.92	3.66
21	CHLOROBENZENE	418.64	504.87	36.97	10.88	0.34
22	ETHYLBENZENE	1992.16	1428.78	69.50	13.17	1.04
23	M-,P- XYLENE	3848.84	2745.11	78.70	6.78	0.89
24	O-XYLENE	5364.50	3802.42	155.19	11.07	2.33
	TOTAL VOC (PPB)	19894.87	16407.22	2713.49	1254.74	145.66
	LOG(C/CO)	0.00	-0.08	-0.87	-1.20	-2.14

TABLE A-3 VOLATILE RESULTS

RUN#7
UV/03 pH10

	LEACHATE	DOSE UNITS	0.00	0.34	0.69	1.38	2.76
*	COMPOUND	TIME(MIN)	0	15	30	60	120
1	STANDARD		105.69	100.77	139.85	202.62	126.78
2	METHYLENE CHLORIDE		204.01	620.73	1240.02	424.12	1.00
3	ACETONE						
4	1,1-DICHLOROETHENE		118.31	118.93	195.22	59.64	0.00
5	1,1-DICHLOROETHANE		401.27	410.06	394.54	76.83	15.76
6	t-1,2-DICHLOROETHENE		3690.09	993.68	376.68	61.71	14.90
7	CHLOROFORM						0.00
8	1,2-DICHLOROETHANE		701.32	804.12	846.97	473.76	109.58
9	1,1,1-TRICHLOROETHANE		261.93	124.76	159.33	54.47	3.13
10	CARBON TETRACHLORIDE					0.00	0.00
11	BROMODICHLOROMETHANE					0.00	0.00
12	1,2 DICHLOROPROPANE					0.00	0.00
13	c-1,3-DICHLOROPROPENE					0.00	0.00
14	TRICHLOROETHENE		0.00	22.93	57.97	49.81	7.40
15	BENZENE		469.04	125.05	43.72	13.21	1.88
16	TETRACHLOROETHENE		0.00	0.00	10.34	14.74	0.00
17	METHYL ISOBUTYL KETONE		47.95	13.07	26.14	24.51	2.26
18	BROMOFORM						
19	1,1,2,2-TETRACHLOROETHANE		344.43	108.34	68.91	63.67	4.20
20	TOLUENE		3620.40	762.99	122.46	18.71	3.91
21	CHLOROBENZENE		704.00	187.69	34.38	12.26	0.00
22	ETHYLBENZENE		2263.51	439.21	55.99	6.13	1.10
23	M-,P- XYLENE		4635.69	697.32	78.33	4.80	1.32
24	O-XYLENE		6158.46	1293.61	169.64	9.35	2.43

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	23620.41	6722.487	3880.64	1367.732	168.848
LOG(C/CO)	0.00	-0.55	-0.78	-1.24	-2.15

TABLE A-4 VOLATILE RESULTS

RUN#10
03/H202 pH10

	LEACHATE	DOSE UNITS	0.00	0.39	0.78	1.57	3.14
#	COMPOUND	TIME(MIN)	0	15	30	60	120
1	STANDARD		82.22	70.13	121.48	125.89	172.63
2	METHYLENE CHLORIDE		0.00	339.44	497.38	360.38	1.00
3	ACETONE						
4	1,1-DICHLOROETHENE		120.87	81.32	83.28	64.89	67.47
5	1,1-DICHLOROETHANE		366.03	239.42	224.12	104.94	37.05
6	t-1,2-DICHLOROETHENE		2765.57	927.66	332.23	73.83	37.31
7	CHLOROFORM						0.00
8	1,2-DICHLOROETHANE		707.15	630.63	595.14	464.24	203.48
9	1,1,1-TRICHLOROETHANE		174.61	97.72	60.36	25.10	18.15
10	CARBON TETRACHLORIDE					0.00	0.00
11	BROMODICHLOROMETHANE					0.00	0.00
12	1,2 DICHLOROPROPANE					0.00	0.00
13	c-1,3-DICHLOROPROPENE				0.00	0.00	0.00
14	TRICHLOROETHENE		0.00	0.00	39.66	37.04	14.33
15	BENZENE		454.22	165.48	51.59	17.35	3.22
16	TETRACHLOROETHENE		0.00	0.00	19.51	16.37	0.00
17	METHYL ISOBUTYL KETONE		22.82	62.46	20.57	14.33	0.85
18	BROMOFORM					0.00	0.00
19	1,1,2,2-TETRACHLOROETHANE		206.74	3288.87	77.66	59.93	3.95
20	TOLUENE		4116.37	1379.28	248.29	35.89	1.96
21	CHLOROBENZENE		747.45	294.20	72.89	13.32	0.00
22	ETHYLBENZENE		3402.57	872.02	204.15	16.24	1.10
23	M-,P- XYLENE		6714.07	1397.52	307.80	20.33	1.73
24	O-XYLENE		8619.33	2090.89	504.47	34.67	2.58

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	28417.8	11866.91	3339.094	1358.848	394.176
LOG(C/CO)	0.00	-0.38	-0.93	-1.32	-1.86

TABLE A-5 VOLATILE RESULTS

RUN#11
UV/O3 pH10
LEACHATE

#	COMPOUND	DOSE UNITS 0 initial	1.42 final
1	STANDARD	129.41	155.17
2	METHYLENE CHLORIDE	16765.60	1670.80
3	ACETONE		
4	1,1-DICHLOROETHENE	746.51	124.85
5	1,1-DICHLOROETHANE	806.10	178.16
6	t-1,2-DICHLOROETHENE	10514.80	318.77
7	CHLOROFORM	ND	ND
8	1,2-DICHLOROETHANE	2289.76	1018.51
9	1,1,1-TRICHLOROETHANE	552.75	122.87
10	CARBON TETRACHLORIDE	ND	434.91
11	BROMODICHLOROMETHANE	623.20	56.51
12	1,2 DICHLOROPROPANE	74.27	ND
13	c-1,3-DICHLOROPROPENE	ND	28.27
14	TRICHLOROETHENE	401.60	60.88
15	BENZENE	914.59	60.00
16	TETRACHLOROETHENE	ND	ND
17	METHYL ISOBUTYL KETONE	113.60	13.67
18	BROMOFORM	32016.10	226.12
19	1,1,2,2-TETRACHLOROETHANE	475.55	45.23
20	TOLUENE	3508.27	75.53
21	CHLOROBENZENE	768.18	41.13
22	ETHYLBENZENE	2832.01	1.00
23	M-,P- XYLENE	4566.52	ND
24	O-XYLENE	7479.17	1.00

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	85448.58	4478.21
LOG (C/CO)	0.00	-1.28

TABLE A-6 VOLATILE RESULTS

RUN*12
UV/O3 pH10

	CONCENTRATE	DOSE UNITS	0.00	0.35	0.70	1.40	2.80
*	COMPOUND	TIME(MIN)	0	15	30	60	120
1	STANDARD		141.67	147.08	210.32	220.38	193.33
2	METHYLENE CHLORIDE		100270.20	50178.58	36117.30	11221.50	0.00
3	ACETONE						
4	1,1-DICHLOROETHENE		7052.92	5107.67	5722.63	1248.53	773.16
5	1,1-DICHLOROETHANE		4180.33	1922.51	2071.54	1931.79	1131.28
6	t-1,2-DICHLOROETHENE		20228.75	6369.29	2526.15	945.26	757.53
7	CHLOROFORM		248.27	670.03	0.00	0	0.00
8	1,2-DICHLOROETHANE		5997.85	1460.36	4402.19	4555.43	2954.42
9	1,1,1-TRICHLOROETHANE		1907.46	1225.70	1377.50	0.00	0.00
10	CARBON TETRACHLORIDE		0.00	0.00	0.00	4419.02	3156.52
11	BROMODICHLOROMETHANE		1251.93	833.12	536.41	436.08	789.56
12	1,2 DICHLOROPROPANE		0.00	148.80	261.17	186.07	224.39
13	c-1,3-DICHLOROPROPENE		423.68	0.00	0.00	56.01	0.00
14	TRICHLOROETHENE		0.00	0.00	0.00	0.00	350.18
15	BENZENE		3295.24	773.63	435.46	175.22	115.08
16	TETRACHLOROETHENE		0.00	0.00	0.00	1098.45	497.86
17	METHYL ISOBUTYL KETONE		177.95	124.84	216.01	197.80	197.39
18	BROMOFORM		113709.60	75976.20	1188.03	717.19	1961.17
19	1,1,2,2-TETRACHLOROETHANE		606.45	0.00	504.54	405.36	481.47
20	TOLUENE		9474.54	1758.49	581.27	2151.47	1713.05
21	CHLOROBENZENE		1409.09	670.59	387.59	134.11	118.24
22	ETHYLBENZENE		6039.06	1074.43	233.31	48.09	37.27
23	M-,P- XYLENE		10122.06	1734.63	0.00	0.00	0.00
24	O-XYLENE		18293.83	3666.67	0.00	3.97	0.00
	TOTAL VOC (PPB)		304689.21	153695.5	56561.1	29931.34	15258.57
	LOG (C/CO)		0.00	-0.30	-0.73	-1.01	-1.30

TABLE A-7 VOLATILE RESULTS

RUN#13
UV/03 pH5

	PERMEATE	DOSE UNITS	0.00	0.35	0.70	1.40	2.80
	COMPOUND	TIME(MIN)	0	15	30	60	120
1	STANDARD		160.21	161.20	161.95	106.83	100.41
2	METHYLENE CHLORIDE		9245.68	4795.85	2019.03	388.24	1.00
3	ACETONE						
4	1,1-DICHLOROETHENE		92.57	72.84	53.10	18.32	24.22
5	1,1-DICHLOROETHANE		142.61	71.79	36.57	4.00	
6	t-1,2-DICHLOROETHENE		3200.27	986.09	257.53	22.87	1.10
7	CHLOROFORM		0.00	0.00	0.00	0	
8	1,2-DICHLOROETHANE		509.94	305.10	123.34	30.09	2.72
9	1,1,1-TRICHLOROETHANE		34.78	28.20	14.62	2.08	
10	CARBON TETRACHLORIDE		145.24	126.89	45.64	5.62	0.00
11	BROMODICHLOROMETHANE		66.90	39.78	17.53	0.00	
12	1,2 DICHLOROPROPANE		0.00	0.00	0.00	0.00	
13	c-1,3-DICHLOROPROPENE		10.94	0.00	0.00	0.00	
14	TRICHLOROETHENE		78.99	44.05	3.88	0.00	
15	BENZENE		153.67	49.69	9.76	1.71	0.79
16	TETRACHLOROETHENE		0.00	0.00	0.00	0.00	
17	METHYL ISOBUTYL KETONE		13.16	13.09	0.00	0.00	
18	BROMOFORM		49.72	44.55	0.00	0.00	
19	1,1,2,2-TETRACHLOROETHANE		26.54	24.66	4.10	1.00	1.00
20	TOLUENE		6571.15	1886.62	423.61	60.99	2.17
21	CHLOROBENZENE		155.91	61.11	11.22	2.44	
22	ETHYLBENZENE		310.05	87.04	17.50	1.64	1.00
23	M-,P- XYLENE		434.19	113.57	25.26	2.56	
24	O-XYLENE		701.10	190.222	42.87	4.03	1.00
	TOTAL VOC (PPB)		21943.39	8941.13	3105.55	545.59	35.00
	LOG(C/CO)		0.00	-0.39	-0.85	-1.60	-2.80

TABLE A-8 VOLATILE RESULTS

RUN#14

03 pH 8->UV/03 pH5

	PERMEATE	0.00	0.35	0.69	1.39	2.78
#	COMPOUND	0	15	30	60	120
1	STANDARD	94.62	95.38	153.49	157.59	101.51
2	METHYLENE CHLORIDE	47492.60	19871.20	10943.90	3818.71	280.37
3	ACETONE					
4	1,1-DICHLOROETHENE	248.94	114.29	234.36	195.99	46.29
5	1,1-DICHLOROETHANE	170.87	42.93	45.93	22.00	0.00
6	t-1,2-DICHLOROETHENE	5421.68	1342.67	522.50	59.42	6.27
7	CHLOROFORM	0.00	0.00	0.00	0	0.00
8	1,2-DICHLOROETHANE	587.38	313.60	205.60	74.60	8.37
9	1,1,1-TRICHLOROETHANE	26.04	20.82	0.00	0.00	1.23
10	CARBON TETRACHLORIDE	0.00	81.58	148.95	40.03	6.79
11	BROMODICHLOROMETHANE	0.00	25.62	0.00	0.00	0.00
12	1,2 DICHLOROPROPANE	0.00	0.00	0.00	0.00	0.00
13	c-1,3-DICHLOROPROPENE	0.00	0.00	0.00	0.00	0.00
14	TRICHLOROETHENE	81.00	18.91	22.21	1.68	0.00
15	BENZENE	211.62	39.70	17.35	2.19	0.83
16	TETRACHLOROETHENE	0.00	0.00	0.00	0.00	0.00
17	METHYL ISOBUTYL KETONE	8.62	0.00	0.00	0.00	0.00
18	BROMOFORM	103.11	0.00	54.84	93.23	4.08
19	1,1,2,2-TETRACHLOROETHANE	62.81	53.22	11.34	3.78	2.67
20	TOLUENE	966.52	211.66	65.25	7.51	2.54
21	CHLOROBENZENE	204.07	48.81	17.62	1.68	0.00
22	ETHYLBENZENE	458.58	85.12	30.44	2.95	0.23
23	M-,P- XYLENE	662.74	123.17	42.47	4.01	0.31
24	O-XYLENE	1032.11	198.34	68.49	6.28	1.00
TOTAL VOC (PPB)		57738.69	22591.64	12431.241	4334.057	360.972
LOG(C/CO)		0.00	-0.41	-0.67	-1.12	-2.20

TABLE A-9 VOLATILE RESULTS

RUN#15
UV/O3 pH5

	PERMEATE	DOSE UNITS	0	1.41	
#	COMPOUND	TIME (MIN)	initial	final	%removal
1	STANDARD		74.64	73.98	0.88
2	METHYLENE CHLORIDE		765.70	79.86	89.57
3	ACETONE				
4	1,1-DICHLOROETHENE		87.48	ND	100.00
5	1,1-DICHLOROETHANE		346.40	8.48	97.55
6	t-1,2-DICHLOROETHENE		5657.63	19.97	99.65
7	CHLOROFORM		ND	ND	-
8	1,2-DICHLOROETHANE		918.72	107.34	88.32
9	1,1,1-TRICHLOROETHANE		83.06	13.47	83.78
10	CARBON TETRACHLORIDE		260.84	40.26	84.57
11	BROMODICHLOROMETHANE		26.66	ND	100.00
12	1,2 DICHLOROPROPANE		ND	ND	-
13	c-1,3-DICHLOROPROPENE		ND	ND	-
14	TRICHLOROETHENE		36.99	ND	100.00
15	BENZENE		2773.89	9.43	99.66
16	TETRACHLOROETHENE		ND	ND	-
17	METHYL ISOBUTYL KETONE		8.60	ND	100.00
18	BROMOFORM		39.27	ND	100.00
19	1,1,2.2-TETRACHLOROETHANE		164.59	1.00	99.39
20	TOLUENE		2560.96	24.06	99.06
21	CHLOROBENZENE		500.99	ND	100.00
22	ETHYLBENZENE		1072.18	1.00	99.91
23	M-,P- XYLENE		1421.94	ND	100.00
24	O-XYLENE		2451.33	1.00	99.96

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	19177.23	305.87
LOG(C/CO)	0	-1.80

TABLE A-10 VOLATILE RESULTS

RUN#16
UV/O3 pH10

	PERMEATE	DOSE UNITS	0	1.45	
#	COMPOUND	TIME(MIN)	initial	final	%removal
1	STANDARD		68.89	78.19	-13.51
2	METHYLENE CHLORIDE		243.80	1.00	99.59
3	ACETONE				
4	1,1-DICHLOROETHENE		32.79	8.621	73.71
5	1,1-DICHLOROETHANE		168.99	3.13	98.15
6	t-1,2-DICHLOROETHENE		5195.66	4.45	99.91
7	CHLOROFORM		ND	ND	-
8	1,2-DICHLOROETHANE		490.52	41.69	91.50
9	1.1,1-TRICHLOROETHANE		42.04	2.23	94.70
10	CARBON TETRACHLORIDE		134.82	8.87	93.42
11	BROMODICHLOROMETHANE		17.35	ND	100.00
12	1,2 DICHLOROPROPANE		ND	ND	-
13	c-1,3-DICHLOROPROPENE		ND	ND	-
14	TRICHLOROETHENE		23.87	0.75	96.86
15	BENZENE		208.92	9.39	95.51
16	TETRACHLOROETHENE		ND	ND	-
17	METHYL ISOBUTYL KETONE		9.27	ND	100.00
18	BROMOFORM		ND	ND	-
19	1,1,2.2-TETRACHLOROETHANE		39.40	1.72	95.65
20	TOLUENE		1767.27	1.51	99.91
21	CHLOROBENZENE		368.51	0.65	99.82
22	ETHYLBENZENE		836.06	0.21	99.97
23	M-,P- XYLENE		1104.88	0.24	99.98
24	O-XYLENE		1890.98	1.00	99.95

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	12575.13	85.442
LOG(C/CO)	0.00	-2.17

TABLE A-11 VOLATILE RESULTS

RUN#17
03 pH5 in first two reactors, UV/03 pH5 in third reactor
CONTAMINATED PERMEATE 0 1.45

#	COMPOUND	initial	final	%removal
1	STANDARD	163.51	121.88	25.46
2	METHYLENE CHLORIDE	5440.41	1279.42	76.48
3	ACETONE			
4	1,1-DICHLOROETHENE	907.83	ND	100.00
5	1,1-DICHLOROETHANE	1091.45	ND	100.00
6	t-1,2-DICHLOROETHENE	33366.60	1669.99	95.00
7	CHLOROFORM	ND	ND	-
8	1,2-DICHLOROETHANE	2162.14	1301.43	39.81
9	1,1,1-TRICHLOROETHANE	831.49	208.11	74.97
10	CARBON TETRACHLORIDE	ND	1043.76	ERR
11	BROMODICHLOROMETHANE	796.44	474.20	40.46
12	1,2 DICHLOROPROPANE	ND	ND	-
13	c-1,3-DICHLOROPROPENE	25.66	ND	100.00
14	TRICHLOROETHENE	206.24	103.08	50.02
15	BENZENE	847.50	94.25	88.88
16	TETRACHLOROETHENE	ND	ND	-
17	METHYL ISOBUTYL KETONE	77.45	37.06	52.15
18	BROMOFORM	850.63	719.95	15.36
19	1,1,2,2-TETRACHLOROETHANE	319.64	268.69	15.94
20	TOLUENE	8866.62	315.49	96.44
21	CHLOROBENZENE	376.44	168.96	55.12
22	ETHYLBENZENE	6195.38	203.92	96.71
23	M-,P- XYLENE	3080.07	119.64	96.12
24	O-XYLENE	14642.40	525.58	96.41

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB) 80084.39 8533.53
LOG(C/CO) 0 -0.97241

TABLE A-12 VOLATILE RESULTS

RUN#18
first two reactors OFF pH5, high O3/UV pH5 in last reactor

#	COMPOUND	initial	final	%removal
	CONTAMINATED PERMEATE	0	0.81	
1	STANDARD	?	156.37	-
2	METHYLENE CHLORIDE	8497.40	1321.61	84.45
3	ACETONE			
4	1,1-DICHLOROETHENE	ND	ND	-
5	1,1-DICHLOROETHANE	5202.00	533.81	89.74
6	t-1,2-DICHLOROETHENE	25349.30	2356.95	90.70
7	CHLOROFORM	ND	ND	-
8	1,2-DICHLOROETHANE	1539.30	1392.98	9.51
9	1,1,1-TRICHLOROETHANE	766.00	375.48	50.98
10	CARBON TETRACHLORIDE	ND	ND	-
11	BROMODICHLOROMETHANE	ND	706.38	?
12	1,2 DICHLOROPROPANE	ND	ND	-
13	c-1,3-DICHLOROPROPENE	ND	ND	-
14	TRICHLOROETHENE	92.80	108.29	-16.69
15	BENZENE	591.70	117.53	80.14
16	TETRACHLOROETHENE	ND	ND	-
17	METHYL ISOBUTYL KETONE	98.30	93.63	4.75
18	BROMOFORM	55992.30	26345.20	52.95
19	1,1,2,2-TETRACHLOROETHANE	584.30	386.28	33.89
20	TOLUENE	6232.10	465.61	92.53
21	CHLOROBENZENE	944.20	193.53	79.50
22	ETHYLBENZENE	4113.10	198.72	95.17
23	M-,P- XYLENE	5400.40	162.15	97.00
24	O-XYLENE	9330.90	434.18	95.35

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	124734.1	35192.33
LOG(C/CO)	0	-0.54953

TABLE A-13 VOLATILE RESULTS

RUN#19

first two reactors O3 pH10, O3/UV pH5 in last reactor

	CONTAMINATED PERMEATE	0	1.60	
#	COMPOUND	initial	final	%removal
1	STANDARD	?	142.74	-
2	METHYLENE CHLORIDE	8497.40	1329.38	84.36
3	ACETONE			
4	1,1-DICHLOROETHENE	ND	ND	-
5	1,1-DICHLOROETHANE	5202.00	409.58	92.13
6	t-1,2-DICHLOROETHENE	25349.30	1138.39	95.51
7	CHLOROFORM	ND	ND	-
8	1,2-DICHLOROETHANE	1539.30	1409.02	8.46
9	1,1,1-TRICHLOROETHANE	766.00	318.17	58.46
10	CARBON TETRACHLORIDE	ND	1595.21	?
11	BROMODICHLOROMETHANE	ND	598.50	?
12	1,2 DICHLOROPROPANE	ND	ND	-
13	c-1,3-DICHLOROPROPENE	ND	ND	-
14	TRICHLOROETHENE	92.80	50.07	46.05
15	BENZENE	591.70	722.33	-22.08
16	TETRACHLOROETHENE	ND	ND	-
17	METHYL ISOBUTYL KETONE	98.30	42.97	56.29
18	BROMOFORM	55992.30	1153.03	97.94
19	1,1,2,2-TETRACHLOROETHANE	584.30	379.50	35.05
20	TOLUENE	6232.10	265.28	95.74
21	CHLOROBENZENE	944.20	58.02	93.86
22	ETHYLBENZENE	4113.10	81.94	98.01
23	M-,P- XYLENE	5400.40	120.68	97.77
24	O-XYLENE	9330.90	146.06	98.43

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	124734.1	9818.125
LOG(C/CO)	0	-1.10395

TABLE A-14 VOLATILE RESULTS

RUN#20
first two reactors O3 pH10, O3/UV pH10 in last reactor

	CONTAMINATED PERMEATE	0	1.60	
#	COMPOUND	initial	final	%removal
1	STANDARD	?	158.16	-
2	METHYLENE CHLORIDE	8497.40	922.65	89.14
3	ACETONE			
4	1,1-DICHLOROETHENE	ND	ND	-
5	1,1-DICHLOROETHANE	5202.00	328.79	93.68
6	t-1,2-DICHLOROETHENE	25349.30	1391.55	94.51
7	CHLOROFORM	ND	ND	-
8	1,2-DICHLOROETHANE	1539.30	1191.02	22.63
9	1,1,1-TRICHLOROETHANE	766.00	180.12	76.49
10	CARBON TETRACHLORIDE	ND	795.39	?
11	BROMODICHLOROMETHANE	ND	171.62	?
12	1,2 DICHLOROPROPANE	ND	ND	-
13	c-1,3-DICHLOROPROPENE	ND	ND	-
14	TRICHLOROETHENE	92.80	69.32	25.30
15	BENZENE	591.70	52.39	91.15
16	TETRACHLOROETHENE	ND	ND	-
17	METHYL ISOBUTYL KETONE	98.30	38.04	61.30
18	BROMOFORM	55992.30	11443.00	79.56
19	1,1,2,2-TETRACHLOROETHANE	584.30	125.42	78.53
20	TOLUENE	6232.10	222.25	96.43
21	CHLOROBENZENE	944.20	58.86	93.77
22	ETHYLBENZENE	4113.10	94.79	97.70
23	M-,P- XYLENE	5400.40	54.76	98.99
24	O-XYLENE	9330.90	153.33	98.36

ALL CONCENTRATIONS IN PPB

TOTAL VOC (PPB)	124734.1	17293.3
LOG(C/CO)	0	-0.85810

TABLE A-15 VOLATILE RESULTS

RUN#21
UV/O3 pH5

	CONCENTRATE	0.00	0.37	0.74	1.47	2.94
#	COMPOUND	0	15	30	60	120
1	STANDARD	82.04	75.27	103.88	138.22	134.53
2	METHYLENE CHLORIDE	5200.30	3386.00	6890.10	4922.89	3466.22
3	ACETONE					
4	1,1-DICHLOROETHENE	154.90	171.70	0.00	0.00	0.00
5	1,1-DICHLOROETHANE	1759.70	1552.30	1519.70	1007.10	495.08
6	t-1,2-DICHLOROETHENE	29494.90	16671.00	7621.40	533.40	348.18
7	CHLOROFORM	0.00	0.00	0.00	0	0.00
8	1,2-DICHLOROETHANE	3974.00	4023.10	4184.70	3509.88	2594.19
9	1,1,1-TRICHLOROETHANE	1323.80	855.50	618.30	556.66	336.55
10	CARBON TETRACHLORIDE	0.00	2878.70	0.00	2592.85	2207.12
11	BROMODICHLOROMETHANE	498.00	327.30	402.00	558.47	265.19
12	1,2 DICHLOROPROPANE	0.00	0.00	0.00	691.00	0.00
13	c-1,3-DICHLOROPROPENE	0.00	0.00	0.00	0.00	0.00
14	TRICHLOROETHENE	144.20	0.00	0.00	154.20	162.24
15	BENZENE	1789.60	1153.90	433.80	167.79	119.95
16	TETRACHLOROETHENE	0.00	0.00	0.00	0.00	0.00
17	METHYL ISOBUTYL KETONE	124.40	217.20	249.30	88.35	72.13
18	BROMOFORM	220231.70	1699.13	1959.70	1435.54	1564.09
19	1,1,2,2-TETRACHLOROETHANE	0.00	596.40	1150.60	365.37	1.00
20	TOLUENE	15985.10	9405.10	2268.80	120.50	78.84
21	CHLOROBENZENE	1956.60	1260.90	513.50	101.69	0.00
22	ETHYLBENZENE	8922.10	5333.80	998.70	51.35	6.83
23	M-,P- XYLENE	12263.20	7352.70	1287.80	32.27	4.06
24	O-XYLENE	21627.80	13693.30	11331.10	259.04	0.00
TOTAL VOC (PPB)		325450.3	70578.03	41429.5	17148.35	11721.67
LOG (C/CO)		0.00	-0.66	-0.90	-1.28	-1.44

APPENDIX B

TABLE B-1 SEMIVOLATILE RESULTS

RUN #12
UV/03 pH10

	CONCENTRATE	DOSE UNITS	RO	0.00	0.35	0.70	1.40	2.80
#	COMPOUND	TIME (MIN)	IN	0	15	30	60	120
1	PHENOL		475		24864	13895	4740	ND
2	2-METHYLPHENOL		813		549	1436	360	50
3	4-METHYLPHENOL		1008		538	11044	322	64
4	NITROBENZENE		ND		ND	ND	269	142
5	ISOPHORONE		26		125	108	129	50
6	2,4-DIMETHYLPHENOL		706		2693	998	146	ND
7	BENZOIC ACID		5436		67585	128330	40076	11513
8	NAPHTHALENE							
	TOTAL BNA (PPB)		8464		96354	155811	46042	11819
	LOG(C/CO)				0	0.21	-0.32	-0.91

TABLE B-2 SEMIVOLATILE RESULTS

RUN #13
UV/03 pH5

	PERMEATE	DOSE UNITS	RO	0.00	0.35	0.70	1.40	2.80
#	COMPOUND	TIME (MIN)	IN	0	15	30	60	120
1	PHENOL		485	322	107	7	ND	ND
2	2-METHYLPHENOL		ND	5	27	2	ND	ND
3	4-METHYLPHENOL		825	137	76	6	ND	ND
4	NITROBENZENE		ND	ND	31	11	2	ND
5	ISOPHORONE							
6	2,4-DIMETHYLPHENOL		895	76	9	ND	ND	ND
7	BENZOIC ACID		ND	599	83	20	ND	ND
8	NAPHTHALENE		14	2	ND	ND	ND	ND
	TOTAL BNA (PPB)		2219	1141	333	46	2	0
	LOG(C/CO)			0	-0.53	-1.39	-2.76	ERR

TABLE B-3 SEMIVOLATILE RESULTS

RUN #14
03 pH 8->UV/03 pH5

	PERMEATE	DOSE UNITS	RO	0.00	0.35	0.69	1.39	2.78
#	COMPOUND	TIME (MIN)	IN	0	15	30	60	120
1	PHENOL		183	221	82	ND	1	1
2	2-METHYLPHENOL		ND	ND	21	ND	ND	ND
3	4-METHYLPHENOL		2320	179	55	ND	ND	ND
4	NITROBENZENE		ND	ND	32	11	4	ND
5	ISOPHORONE							
6	2,4-DIMETHYLPHENOL		1054	44	4	ND	ND	ND
7	BENZOIC ACID		60	15	2	ND	23	ND
8	NAPHTHALENE							
	TOTAL BNA (PPB)		1297	459	196	11	28	1
	LOG(C/CO)			0	-0.37	-1.62	-1.21	-2.66

TABLE B-4 SEMIVOLATILE RESULTS

RUN #15
UV/03 pH5

	PERMEATE	DOSE UNITS	RO	0	1.41
#	COMPOUND	SAMPLE	IN	INITIAL	FINAL
1	PHENOL		146	150	6
2	2-METHYLPHENOL				
3	4-METHYLPHENOL		2017	ND	ND
4	NITROBENZENE		ND	ND	28
5	ISOPHORONE				
6	2,4-DIMETHYLPHENOL		1000	418	ND
7	BENZOIC ACID		ND	ND	15
8	NAPHTHALENE				
	TOTAL BNA (PPB)		3163	568	49
	LOG(C/CO)			0	-1.06

TABLE B-5 SEMIVOLATILE RESULTS

RUN #16
UV/03 pH10

	PERMEATE	DOSE UNITS	RO	0	1.45
#	COMPOUND	SAMPLE	IN	INITIAL	FINAL
1	PHENOL		2474	571	ND
2	2-METHYLPHENOL				
3	4-METHYLPHENOL		4797	915	ND
4	NITROBENZENE				
5	ISOPHORONE				
6	2,4-DIMETHYLPHENOL		1090	210	ND
7	BENZOIC ACID				
8	NAPHTHALENE				
	TOTAL BNA (PPB)		8661	1696	1
	LOG(C/CO)			0	-3.94

TABLE B-6 SEMIVOLATILE RESULTS

RUN #21
UV/03 pH14

	CONCENTRATE	DOSE UNITS	RO	0.00	4.38
#	COMPOUND	SAMPLE	IN	0	180
1	PHENOL		1104	7926	ND
2	2-METHYLPHENOL		ND	4115	ND
3	4-METHYLPHENOL		ND	12417	ND
4	NITROBENZENE		ND	ND	335
5	ISOPHORONE				
6	2,4-DIMETHYLPHENOL		ND	3184	ND
7	BENZOIC ACID		ND	15042	ND
8	NAPHTHALENE				
	TOTAL BNA (PPB)		1104	42684	335
	LOG(C/CO)			0	-2.11