

REVERSE OSMOSIS AND ULTRAVIOLET PHOTOLYSIS/OZONATION TESTING AT THE PAS SITE - OSWEGO N.Y.

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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 were 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 efficacy 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 (O₃) or hydrogen peroxide (H₂O₂).

In the RAYOX process, O₃, and sometimes H₂O₂, 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 HCOO₂ 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 \cdot). Once formed, the HO \cdot 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 \cdot radical is one million times as fast as with molecular O₃.

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 alkylation 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 CaCO₃ as CaCl₂ 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/ozonation unit. The same procedures as for UV photolysis/ozonation alone were then followed.

Ultraviolet Photolysis/Ozonation Alone

The leachate, normally basified and filtered but not acidified was fed to the UV Photolysis/ozonation unit. It was then subjected to O₃ treatment alone or some combination of O₃, UV, H₂O₂ 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/O₃ 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

UV Photolysis/Ozonation Alone

The mean destructions of compounds in the leachate is tabulated in Table IV and Figure III.

RO Followed BY UV Photolysis/Ozonation

The mean results of this combination are recorded as follows:

- (a) UV Photolysis/Ozonation of concentrate - Tables V and VI and Figure IV;
- (b) UV Photolysis/Ozonation of permeate - Batch - Tables VII and VIII;
- (c) UV Photolysis/Ozonation of permeate - Flow through - Tables IX and X;

UV Photolysis/Ozonation Followed by RO

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

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 cross-flow microfiltration was the preferred 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 XIII.

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 rejections achieved for the membranes are categorized as follows:

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

Organics

Table II shows that there was a wide variation among the membranes in rejection of any given compound and within an individual membrane type in the rejection of various compounds.

With a few exceptions, the rejection of the lower molecular weight chlorinated alkanes and alkenes ranged from poor to fair. The same can be said for acetone. This is not surprising given the size and characteristics of these molecules. The results, in fact, are similar to those achieved, at lower concentrations, in earlier studies at the Gloucester Landfill. (1, 2)

Below benzene in Table II there is a rapid increase in rejection, especially with the Filmtec membrane. These larger molecules are much easier to deal with by reverse osmosis. The Filmtec was obviously the superior membrane and would be recommended for any spill clean up of these compounds by reverse osmosis.

At first glance, it appears that the Toray membrane was the worst of those tested. This is not consistent with earlier work (1, 2). In fact, the Toray performed very well, almost as well in fact as the Filmtec, for the first half of the testing. At that time, an accidental system overpressurization occurred which seriously damaged the Torays. After that time, their performance deteriorated rapidly. The other membranes do not seem to have been affected.

The UOP and DSI membranes performance was not as good as the Filmtecs or as the Torays before the overpressurization. They are not considered to be appropriate for a clean up involving the organics encountered here.

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	2378.9	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	12890.9
o-XYLENE	13352.7	2391.4	1702.5	5339.5	299.7	57672.1
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 II

OSWEGO RO RESULTS - ORGANIC COMPOUND % REJECTIONS

COMPOUND	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

Metals

As previously mentioned, the low rejections achieved for lead are considered suspect. For the other metals, the results parallel those for the higher molecular weight organics. The Filmtec is definitely the best membrane while the UOP and DSI, which are generally fair to excellent, are not as good as the former. Once again, the Toray results are skewed as a result of the overpressurization damage.

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

UV Photolysis/Ozonation Alone

Using the same designations as for RO, the destructions achieved in the leachate were all either good or excellent except for 1,1-dichloroethene. The weighted mean destruction for all of the organic compounds was 97%. Acetone is not included in these calculations, or the table because an intermediate from the photolysis co-eluted with acetone on the GC making reliable estimation impossible.

The destruction of the aromatics was higher than that for the halogenated or oxygenated alkanes or alkenes of similar molecular weight. Ethylbenzene and the xylenes gave very impressive results. No GC analysis of the semivolatiles was carried out due to time constraints. It is expected, however, based on the results for the combined RO - UV/ozone runs that these compounds were essentially all destroyed.

RO followed by UV Photolysis/Ozonation

RO - UV/O3 - Concentrate (Tables V and VI)

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. In spite 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 higher destructions. This can be seen in Figure IV 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.

RO - UV/O3 - Permeate (Batch) (Tables VII and VIII)

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 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) (Tables IX and X)

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 XI 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.

UV/O3 (Flow through) - RO (Table XII)

Only one run was attempted using this sequence of technologies. Excellent total removals were obtained for 13 of 24 compounds but the results were not as good as had been desired. 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

TABLE IV

UV PHOTOLYSIS / OZONATION OF LEACHATE - MEAN RESULTS

COMPOUND	FEED (PPB)	UV EFFLUENT (PPB)	% 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 V

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

COMPOUND	RO FEED	RO CONC	UV 15 MIN	UV 30 MIN	UV 60 MIN	UV 120 MIN	UV 180 MIN
DICHLOROMETHANE	74893.3	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	16697.1	38837.7	1573.9	1076.4	1762.6	2484.1
TETRACHLOROETHANE/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 VI

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

COMPOUND	% 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
TETRACHLOROETHANE/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	--

TABLE VII

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
TETRACHLOROETHANE/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 VIII

OSWEGO RESULTS - RO (PERM) - UV (BATCH) - % REMOVAL

COMPOUND	% 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
TETRACHLOROETHANE/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 IX

OSWEGO RESULTS - RO - UV / 03 (FLOW THROUGH)

COMPOUND	RO FEED	UV FEED	RO 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
t-1,2-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
TRICHLOROETHENE	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 ISOBUTYL 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/ENE	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,p-XYLENE	14345.8	4001.8	76.2	72.1	98.1	99.5
o-XYLENE	24788.5	7078.9	209.9	71.4	97.1	99.2
PHENOL	1987.3	772.8	42.8	61.1	94.5	97.8
4-METHYLPHENOL	4083.9	1378.8	44.3	66.2	96.8	98.9
2,4-DIMETHYLPHENOL	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 X

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

COMPOUND	% 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
TETRACHLOROETHANE/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 XI

OSWEGO RESULTS - RO - UV / 03 (FLOW THROUGH) - FIRST TWO RUNS

COMPOUND	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
t-1,2-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
TRICHLOROETHENE	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 ISOBUTYL 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/ENE	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,p-XYLENE	19546.0	1263.4	0.0	93.5	100.0	100.0
o-XYLENE	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-METHYLPHENOL	3407.0	457.5	0.0	86.6	100.0	100.0
2,4-DIMETHYLPHENOL	1195.0	314.0	0.0	73.7	100.0	100.0
BENZOIC ACID	0.0	0.0	7.5			

TABLE XII

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

COMPOUND	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
TETRACHLOROETHANE/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

A comparison of these results with those in Table XIII 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 CaCO₃. The variance of CaCO₃ 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/O₃ units. Table XIII data show that pH 10 was the optimum pH for that purpose.

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/O₃ 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 concentrate to a similar level;
- (b) 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;
- (c) the combination of RO followed by UV/O₃ of the permeate resulted in a good quality effluent. The RO concentrate must still be treated at a proper facility;
- (d) the combination of RO followed by UV/O₃ treatment of the concentrate resulted in a relatively clean permeate 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;
- (e) the combination of UV/O₃ treatment of the leachate followed by RO treatment of the effluent is not as effective as the converse; and
- (f) hydroxide precipitation of metals followed by cross-flow microfiltration should be the first step in any treatment system.

TABLE XIII

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

References

1. H. Whittaker et al; Reverse Osmosis at the Gloucester Landfill; Proceedings of the Technical Seminar on Chemical Spills; Toronto, Ontario; February 5-7, 1985; pages 190-207.
2. H. Donison et al; Development and Demonstration of a Mobile Reverse Osmosis and Adsorption System for Environmental Cleanups; Proceedings of the 4th Technical Seminar on Chemical Spills; Toronto, Ontario; February 10-12, 1987; pages 201-222.

FIGURE I

ORIGINAL SET-UP

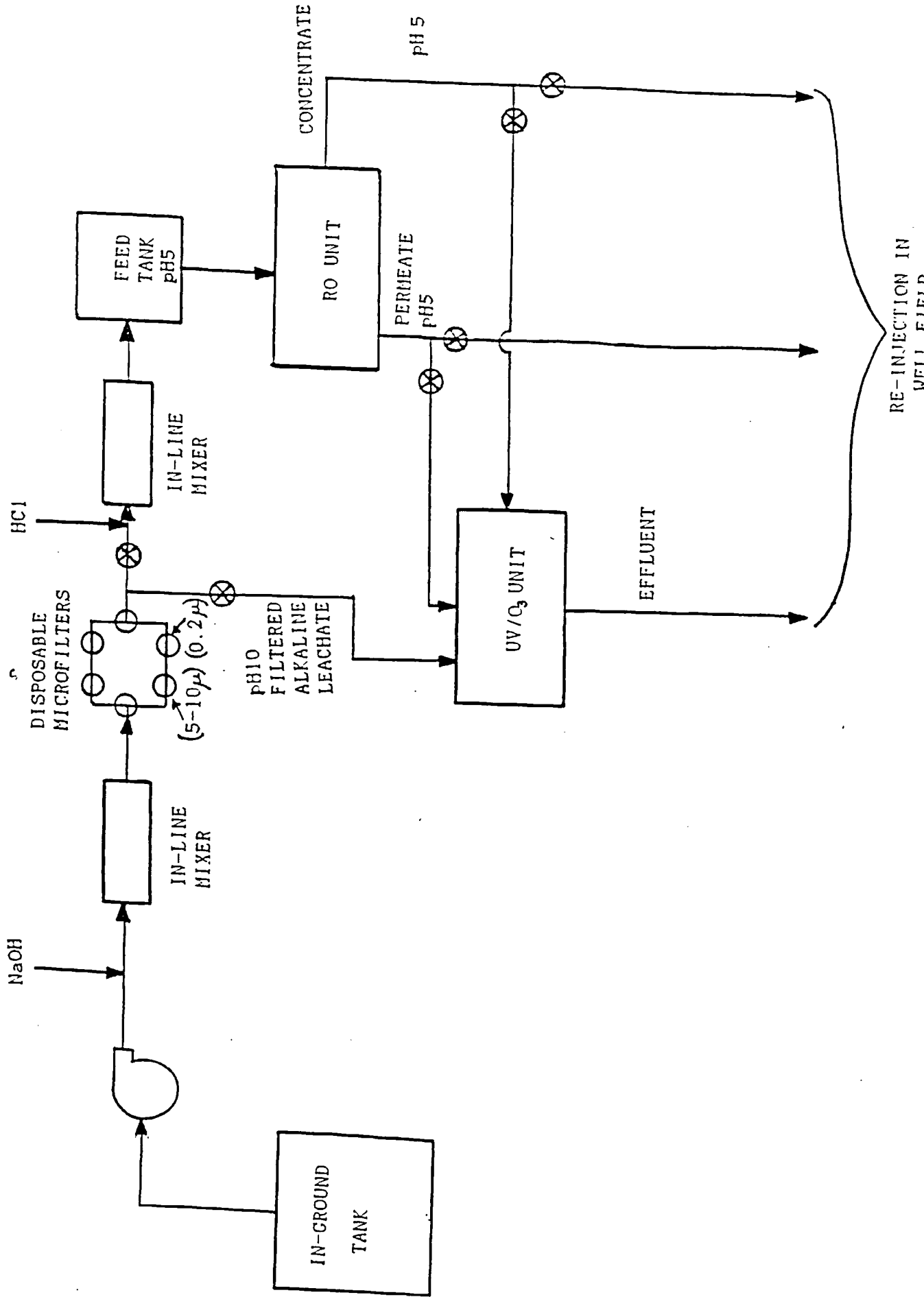


FIGURE 11

MODIFIED SET-UP

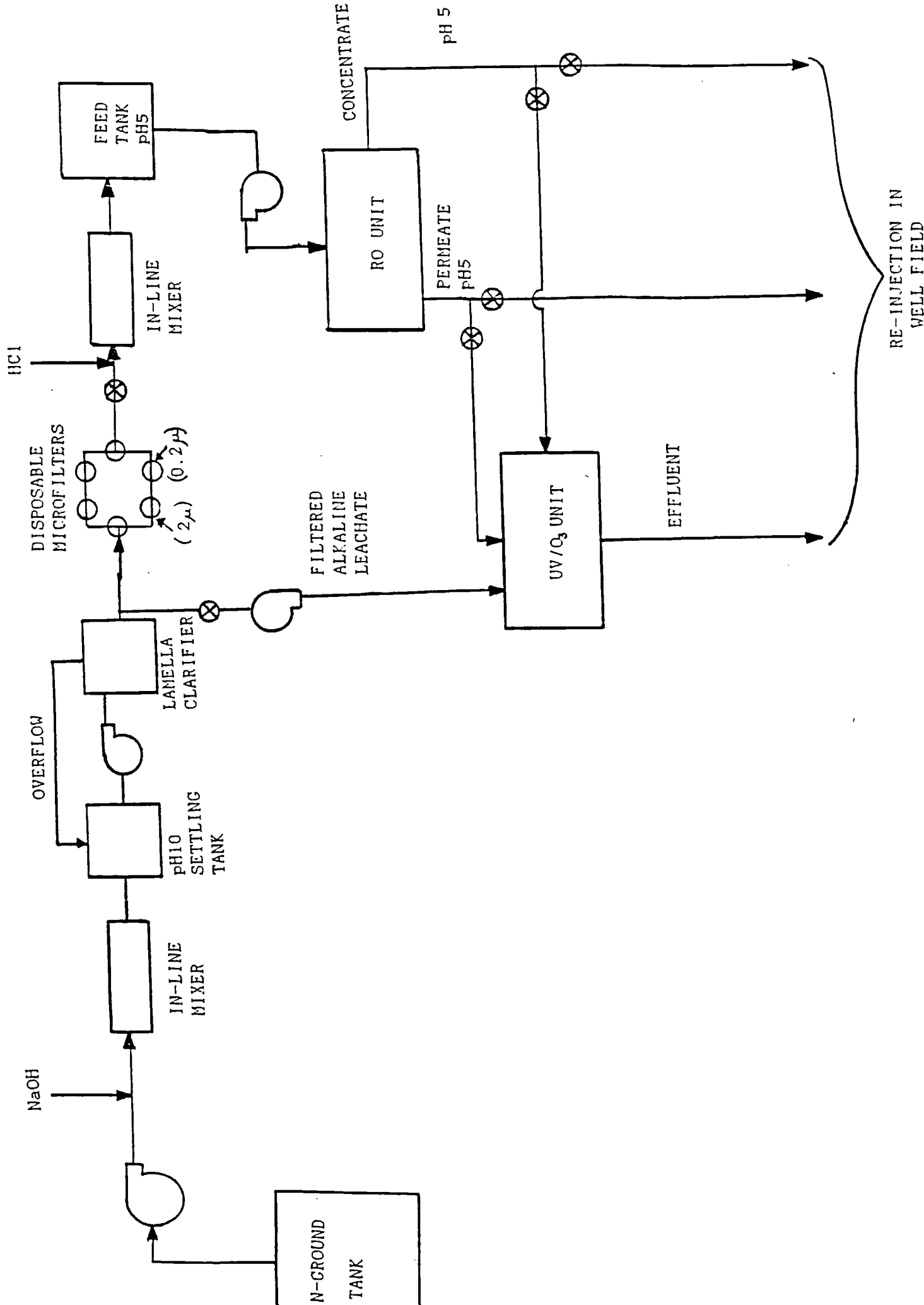


FIGURE III UV/O₃ TREATMENT OF LEACHATE

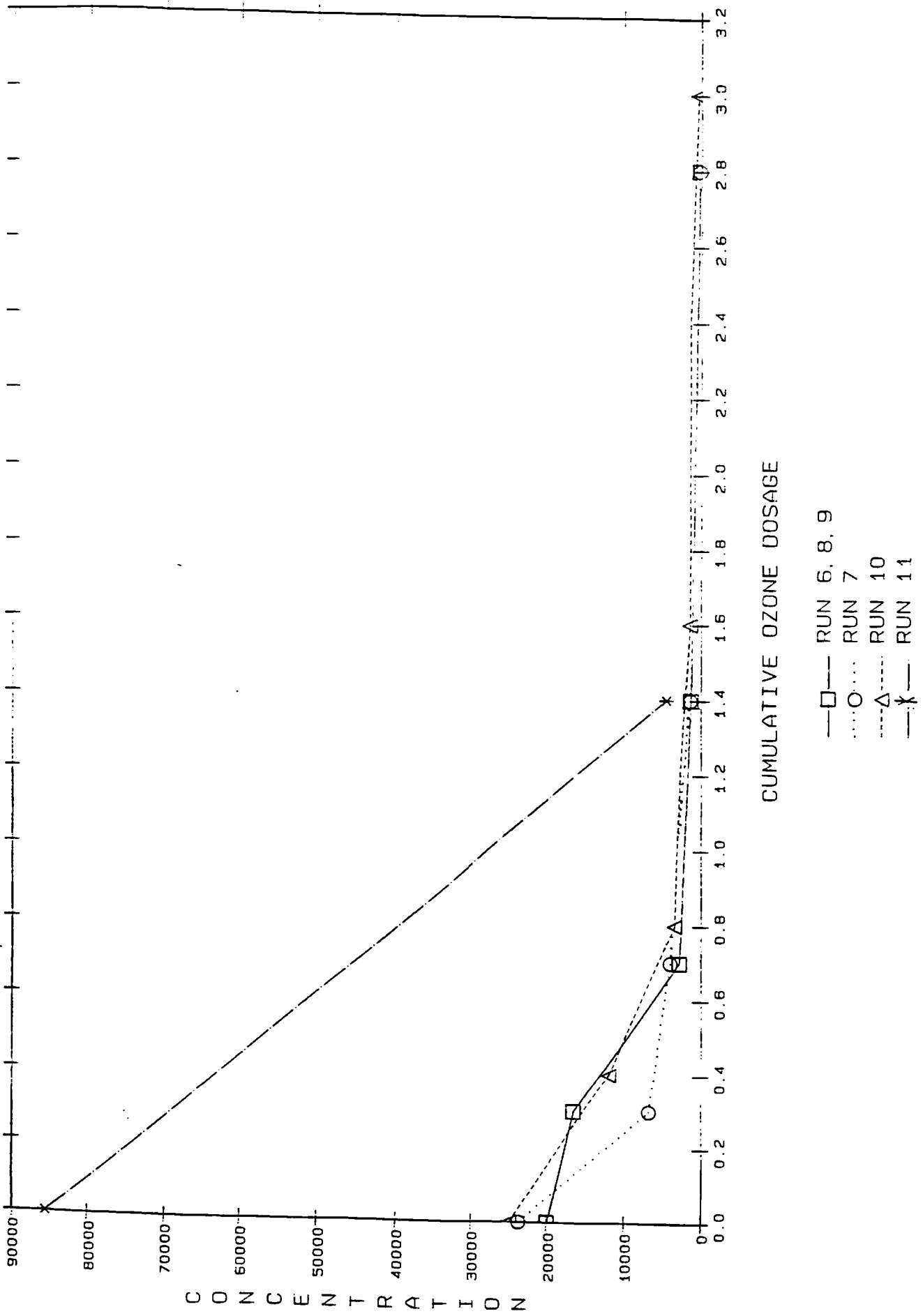


FIGURE IV UV/O₃ TREATMENT OF CONCENTRATE

