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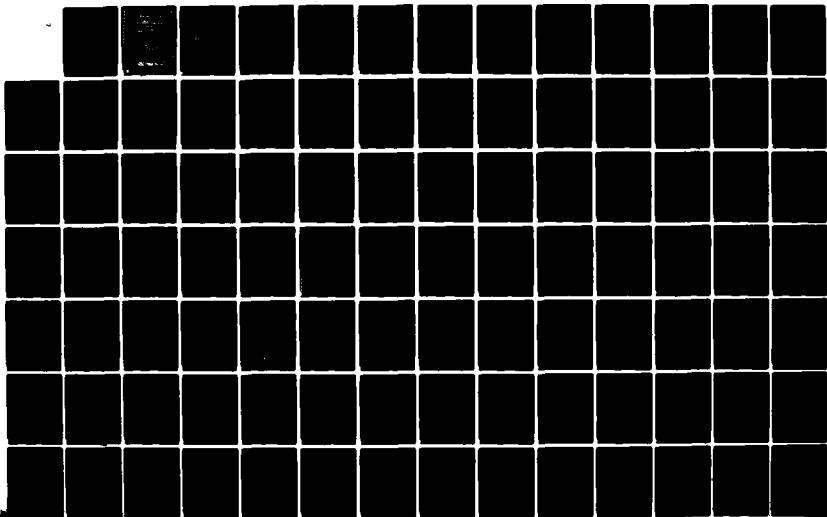
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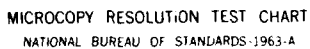
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REPORT DRXTH-TE-CR-94273

**AIR STRIPPING PILOT STUDY OF
VOC-CONTAMINATED GROUND WATER**

FINAL REPORT

**VOLUME I
GENERAL ENGINEERING ASPECTS**

**CONTRACT DAAK11-81-C-0076
TASK 4**

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BETHESDA PROVEDS GROUND, MARYLAND**

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LIST OF ACRONYMS AND ABBREVIATIONS

acfm	actual cubic feet per minute
A/W	air-to-water ratio
CrVI	hexavalent chromium
°C	degrees Celsius
DCE	dichloroethylene
EBCT	empty bed contact time
ESE	Environmental Science and Engineering, Inc.
ft	foot
gal	gallon
gpm	gallons per minute
hp	horsepower
in.	inch
ID	inside diameter
lb/ft ² -hr	pounds per square foot per hour
MeCl	methylene chloride
min	minute
ml	milliliter
mg/l	milligrams per liter
PVC	polyvinyl chloride
TCE	trichloroethylene
ug/l	micrograms per liter
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
VOA	volatile organics analysis
VOC	(volatile organic compounds)

1.0 INTRODUCTION

In previous tasks, Environmental Science and Engineering, Inc. (ESE) has designed and fabricated a prototype air stripping system for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) to demonstrate performance and develop design criteria for a full-scale operational system. ESE completed the construction of this system in October 1982 and submitted an operations manual for its use in February 1983.

ESE has also performed laboratory ion exchange tests (Report DRXTH-TE-CR-83218) to select resin and operating conditions to remove chromium from waste streams.

The purposes of this study include the following:

1. To evaluate the effectiveness of air stripping to remove organic contaminants at concentration ranges identified in actual waste streams.
2. To modify operating procedures and manual as needed.
3. To develop preliminary design criteria for a full-scale system over a range of potential operating conditions.
4. To evaluate chromium removal by an ion exchange column following air stripping.
5. To provide USATHAMA with detailed information on the air stripping technology as it relates to subsequent use or evaluation at other locations.

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2.0 THEORY

Aeration (or air stripping), a method for removing volatile solutes from water, relies on a gas-liquid equilibrium relation which favors the gas phase. When water containing a solute is mixed with air free of the solute, the solute molecules tend to leave the water for the air. This separation method is made more efficient by increasing the surface area of the water so that more contact of water with air is made.

In a countercurrent packed tower, water is pumped to the top of the tower and spread over packing material. The packing is designed to spread the water as thinly as possible as it falls through the tower. Air is blown through the bottom of the tower and passes across the water and through the packing. The rate of mass transfer (of the solute from the water to the air) is greatest when the concentration of solute in the water is much higher than in the air. Therefore, the countercurrent method is the most efficient because the concentration difference remains high at both ends of the column. Because air and water are introduced at opposite ends of the tower, water that has already had solute removed is contacted by air with no or very little solute; thus, the lowest effluent concentrations are reached.

Treybal (1980) and Kavanaugh and Trussell (1980) discuss the general theory of air stripping and its application to the removal of dilute volatile organic compounds (VOC) from water. The most important equations are presented in this section, with discussions of their relevance to experiment, design, and operation.

2.1 EQUILIBRIUM

For slightly soluble gases that do not combine chemically with water, the amount of gas dissolved in a quantity of water is proportional to the partial pressure of the gas above the water. This relationship, known as Henry's Law, also describes the behavior of soluble liquids in water at low concentrations. At constant total pressure, this relationship can be written as follows:

$$V_a = \beta C_a^* \quad (\text{Eq. 1})$$

where: V_a = concentration of solute a in air (mass/volume),
 C_a^* = concentration of solute a in liquid that is in
equilibrium with V_a (mass/volume), and
 β = partition coefficient,

or

$$y_a = \frac{H}{P_t} x_a \quad (\text{Eq. 2})$$

where: y_a = mole fraction of solute a in air,
 P_t = total pressure (force/area),
 x_a = mole fraction of solute a in water, and
 H = Henry's Constant in atmospheres (force/area).

The partition coefficient (β), which is characteristic of the solute, is directly proportional to the dimensional Henry's Constant (H) at a given total pressure (see Appendix D). Henry's Constant (H) is influenced by temperature and generally follows a Van't Hoff relationship of the form:

$$\log H = \frac{-\Delta H_a^*}{RT} + K \quad (\text{Eq. 3})$$

where: H = Henry's Constant (the relationship may alternately be expressed in terms of the partition coefficient),
 ΔH_a^* = change in enthalpy due to dissolution of solute a in water (energy/mass),
 R = universal gas constant,
 T = absolute temperature, and
 K = empirical constant.

For volatile hydrocarbons, the partition coefficient typically increases two- or threefold with a 10 degrees Celsius ($^{\circ}\text{C}$) rise in temperature (Kavanaugh and Trussell, 1980).

The equilibrium concentration of solute in air defines the maximum amount of solute that may be removed from a given quantity of water by a given volume of air. The extent to which this maximum performance is achieved depends on the rate at which the solute leaves the liquid phase in favor of the gas phase. This rate is described by the mass transfer coefficient.

2.2 MASS TRANSFER

Within a countercurrent-flow air stripper column, solute molecules pass between the liquid phase and the solid phase across an interphase boundary. Because the rate of diffusion of solute molecules in air is much greater than the rate in water, the mass transfer rate is usually controlled by the rate of diffusion of solute from the bulk liquid phase to the boundary layer. Since the liquid resistance is controlling, the mass flux across the interphase boundary can be expressed as product of a single resistance term, K_L , and a driving force as:

$$N_a = K_L (C_a^* - C_a) \quad \text{Eq. 4)}$$

where: N_a = mass flux [mass/(area)(time)],
 K_L = intrinsic mass transfer coefficient (length/time),
 C_a = bulk liquid phase concentration of a (mass/volume), and
 C_a^* = concentration of solute a in liquid that is in equilibrium with concentration in air (mass/volume).

In a packed column, the amount of interphase boundary area available in a given volume of packing is expressed as a specific area (α), with units of area per volume. Each type and size of packing material has a characteristic specific area. The mass transfer taking place within a given volume of the column can be expressed by:

$$J_a = N_a \alpha = K_L \alpha (C_a^* - C_a) \quad \text{(Eq. 5)}$$

where: J_a = rate of mass transfer [mass of a stripped/(time) (volume)],
 and
 α = specific packing area (area/volume).

It is convenient to use the combined variable $K_L a$ (the overall mass transfer coefficient), with dimension time^{-1} , to describe the performance of a specific combination of packing and solute.

$K_L a$ is a measure of the rate at which solute molecules leaving the liquid phase at the phase boundary are replaced by molecules from deeper within the water layer. Increased turbulence would be expected to increase this rate and to increase $K_L a$ for a given solute and packing. $K_L a$ has been found to vary with approximately the 0.72 power of the liquid loading rate (Sherwood and Holloway, 1940).

2.3 PERFORMANCE

When Equations 1, 2, and 5 are combined with a material balance, column performance is described by:

$$Z = \frac{L}{K_L a} \left(\frac{R}{R-1} \right) \ln \frac{C_{in}/C_{out}^{(R-1)} + 1}{R} \quad (\text{Eq. 6})$$

where: $R = \beta G/L$ (referred to as the stripping factor),
 G = air rate [volume/(time)(area)],
 L = water rate [volume/(time)(area)],
 Z = column length, and
 β = partition coefficient.

Equation 6 implies the following assumptions:

1. Evaporative loss of water is negligible;
2. Temperature is constant and, therefore, partition coefficient is constant throughout the column;
3. Mass transfer is controlled by liquid phase;
4. Feed air is solute free; and
5. Column is well mixed (i.e., performance is uniform in cross section).

The form of Equation 6 suggests that the ratio of inlet to outlet concentrations is exponentially related to column length and mass

transfer coefficient and strongly influenced by the partition coefficient and air-to-water ratio.

Improved performance would be expected with:

1. An increase in temperature, since the partition coefficient will increase;
2. An increase in water rate up to the hydraulic limitations of the packing since the liquid loading and thus the value of $K_L a$ will increase; and
3. A higher air-to-water ratio.

Table 2-1 contains a summary of the equations describing packed column air stripping performance, and Table 2-2 contains a list of the nomenclature used in the equations.

2.4 DESIGN

The air stripping tower design is influenced by hydraulic and mass transfer considerations. There must be at least enough air to maintain the concentration gradient across the gas-liquid interface at a value favoring the transfer of solute from liquid to gas. The minimum air flow equals the liquid rate divided by the partition coefficient, corresponding to a stripping factor of 1 in Equation 6. Thus, the stripping factor is the ratio of the actual air rate to the minimum air rate for a fixed water rate.

Above the theoretical minimum, as more air is supplied, the removal can be achieved in a shorter column. If too much air is forced through a volume of packing, it can prevent the downward flow of water, a condition known as column flooding. The packing will eventually fill with water at points in the column where the water head is insufficient to overcome the pressure drop. If a larger-diameter column is chosen, the liquid and air loading rate per square foot is lowered and flooding can be prevented. The conditions at which flooding occurs depend on the particular packing media. Packing manufacturers are the best source of

Table 2-1. Equations Describing Air Stripping Performance

1. Henry's Law:

$$V_a = \beta C_a^*$$

2. Henry's Law:

$$y_a = \frac{H}{P_t} x_a$$

3. Van't Hoff's Relationship:

$$\log H = -\frac{\Delta H_a^{\circ}}{RT} + K$$

4.

$$N_a = K_L (C_a^* - C_a)$$

5.

$$J_a = N_a \alpha = K_L \alpha (C_a^* - C_a)$$

6.

$$Z = \frac{L}{K_L \alpha} \left(\frac{R}{R-1} \right) \ln \frac{C_{in}/C_{out}^{(R-1)} + 1}{R}$$

Source: ESE, 1984.

Table 2-2. Nomenclature Used in Equations

V_a	= concentration of solute a in air (mass/volume)
y_a	= mole fraction of solute a in air
C_a^*	= concentration of solute a in liquid that is in equilibrium with concentration in air (mass/volume)
β	= partition coefficient
P_t	= total pressure (force/area)
x_a	= mole fraction of solute a in water
H	= Henry's Constant in atmospheres (force/area)
H_a^*	= change in enthalpy due to dissolution of solute a in water (energy/mass)
R	= universal gas constant
T	= absolute temperature
K	= empirical constant
N_a	= mass flux [mass/(area)(time)]
K_L	= intrinsic mass transfer coefficient (length/time)
C_a	= bulk liquid phase concentration of a (mass/volume)
J_a	= rate of mass transfer [mass of a stripped/(time) (volume)]
a	= specific packing area (area/volume)
$K_L a$	= combined mass and transfer coefficient (time ⁻¹)
R	= $\beta G/L$ (referred to as the stripping factor)
G	= air rate [volume/(time)(area)]
L	= water rate [volume/(time)(area)]
Z	= column length

Source: ESE, 1984.

this information. Their literature should be consulted in determining the optimum column diameter (i.e., a diameter which will allow a high air-to-water ratio without approaching flooding conditions).

When an air-to-water ratio has been chosen, the column diameter is set large enough to avoid flooding, and the packing height necessary to achieve a given removal can be calculated from the overall mass transfer coefficient. A lower mass transfer coefficient requires a greater length of column (see Equation 6). The purpose of this study was to determine the values and behavior of the overall mass transfer coefficients for several ground water contaminants. This, in turn, will allow calculation of column length necessary for any specified removal efficiency.

The series of runs described in Section 3.0 was designed to allow $K_L a$ to be calculated as each operating parameter was varied and to determine what effect the presence of other organic contaminants would have on the mass transfer rate of an individual contaminant. Knowledge of $K_L a$ over the range of probable operating conditions will allow scaleup under any of these conditions.

In this study, the partition coefficients for the solutes of interest were calculated from solubility and vapor pressure data as reported in EPA (1980). The values, as used in Equation 2, are listed below:

<u>Solute</u>	<u>Partition Coefficient</u>
Trichloroethylene (TCE)	0.41
Methylene chloride (MeCl)	0.32
t-Dichloroethylene (DCE)	0.23

3.0 METHODS AND OPERATION

3.1 EQUIPMENT

The air stripping system used in this study was designed and fabricated by ESE for USATHAMA. It consisted of four packed columns, each supplied with fresh air at the bottom while the liquid feed passed through each column in series, as depicted in Figure 3-1. The major components of the system are described in this section.

3.1.1 Packed Columns

A schematic diagram of a single column is shown in Figure 3-2. The outer shell of each column was a 15-inch (in.) Carlon® polyvinyl chloride (PVC) sewer pipe. The lower end of each column extended into a fiberglass basin containing a submersible pump. Each column was packed with Norton No. 1 Super Intalox® plastic saddles (approximately 1-in. diameter).

The packing was supported by a Norton Model 818 gas-injection support plate at the column bottom. The support plates rested on four gasketed collar bolts extending inside the column. Support plates were located approximately 12 in. above the lower column end, which extended approximately 12 in. into the basin. Water depths in the basin were regulated by level-operated float valves located on the submersible pump discharge of each basin. During most runs, the water level was maintained at 1 to 4 in. above the bottom of the column. At the higher air rates and lower water rates, the float valves were unable to continuously maintain the water level above the bottom of the column. Since all openings into the basin were either threaded fittings or gasketed portals, no air was lost and the accuracy of the flow readings was not affected.

The upper liquid distributor (Norton Model 845 orifice-type) rested on four bolts extending inside the column. The distributors were placed 6 to 8 in. above the top of the packing. The liquid inlet was approximately 8 in. above the distributor plate.

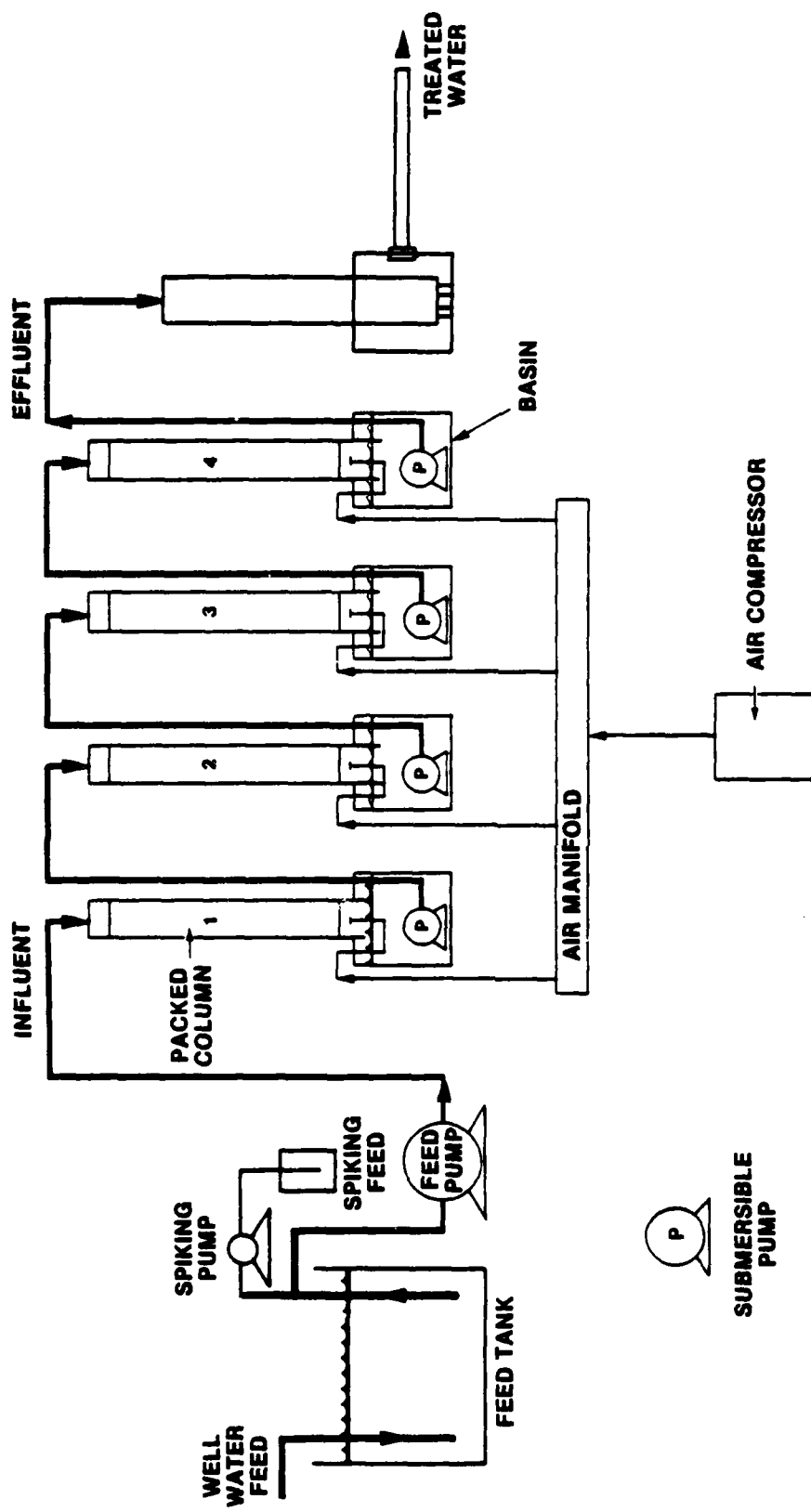


Figure 3-1
SCHEMATIC DIAGRAM OF AIR STRIPPING SYSTEM

SOURCE: ESE, 1984.

USATHAMA

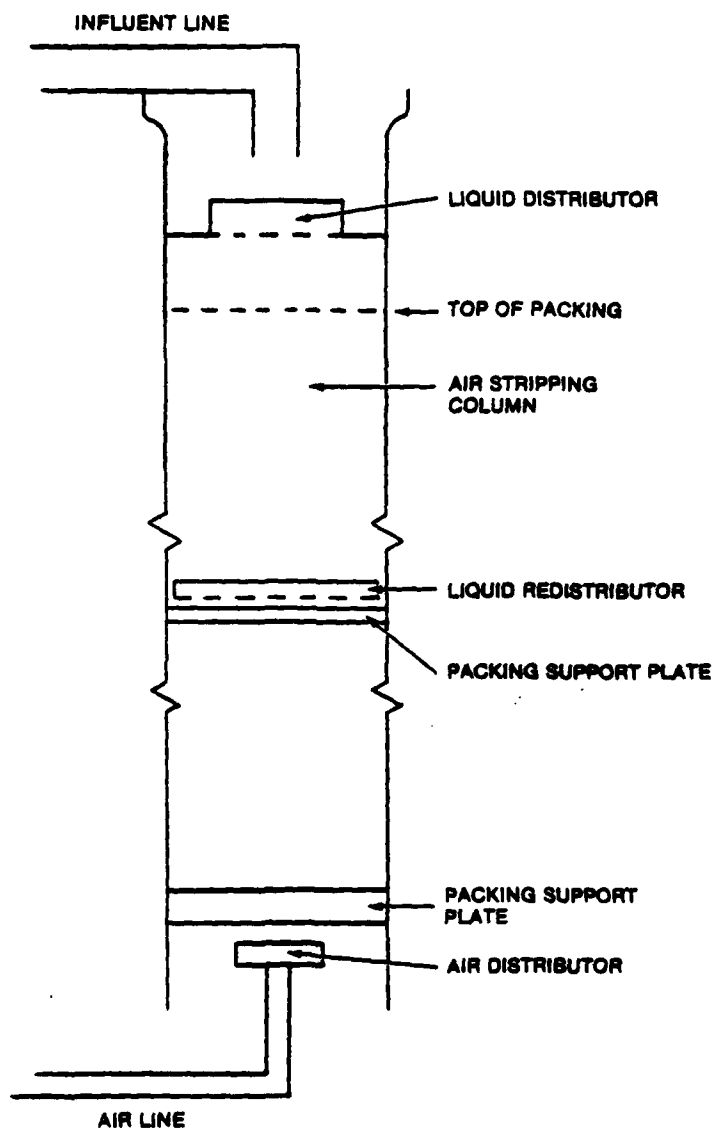


Figure 3-2
SCHEMATIC DIAGRAM OF AIR STRIPPING
PACKED COLUMN

SOURCE: ESE, 1984.

USATHAMA

Initially, all columns contained 10 feet (ft) of packing. During several of the later runs, Columns 1 and 2 were modified to contain 15 ft of packing each, bringing the total packed depth to 50 ft. The original liquid distributor was removed from both columns and replaced in the same manner at the top of the additional packing. The additional 5 ft of packing in Column 2 was placed directly on the first 10 ft of packing. To determine the effect of a redistributor on the performance of columns with 15 ft of packing, a Norton Model 845 orifice-type liquid redistributor and a support plate were put in at the level of the original liquid distributor in Column 1, leaving approximately 8 in. between the top of the original packing and the bottom of the new redistributor.

The PVC column shell was uncoated, but all steel internals and basin covers were epoxy-painted for corrosion resistance.

3.1.2 Liquid Feed System

Water was supplied to the first column from a 300-gallon (gal) fiberglass feed tank through a 2-in. PVC pipe by a 2-horsepower (hp) centrifugal pump. A length of microcapillary tubing was inserted into the pump suction side of the supply line to the first column. A methanol solution of the spiked compounds was introduced into the suction line through this tubing at a controlled rate by a Milroy® positive displacement metering pump. The use of a cosolvent ensured complete solution of spiked compounds; introducing the cosolvent solution prior to the first centrifugal pump allowed the pump to act as a mixer. The sampling point for Column 1 influent was a port in the discharge line of the centrifugal feed pump at about the 5-ft height.

Water was pumped to the liquid distributor at the top of the first column and flowed by gravity through the packing and discharged into the basin below the column. Water was pumped from the basins in series to the top of each column by submersible centrifugal pumps. Effluent from the last column was pumped into a 10-ft section of empty 15-in. PVC pipe

which stood vertically in a basin kept filled with water. During the chromium spiked runs, this final basin contained ion exchange resin to prevent chromium discharge. Treated water from the final basin flowed by gravity through a 3-in. PVC pipe set in the side of the basin into an empty field behind the ESE facility.

3.1.3 Air Feed System

Air was supplied by a rented, diesel compressor and fed through a hose to a 4-in.-diameter galvanized-steel manifold. Manifold outlet air was split through 3/4-in. lines to each column. Air flow was set by a ball valve following an indicating flowmeter in each line. Flowmeter inlet pressure was monitored at the pressure gage on the pressure regulator. Air temperature was sensed by a thermocouple mounted in the pressure regulator just ahead of each flowmeter. These pressure and temperature values were used to correct the indicated flowmeter reading to actual cubic feet per minute (acfm).

Regulated air was fed through the flanged basin cover to a PVC distributor mounted 4 to 6 in. below the column support plate. Air was delivered to the columns through distributors from evenly spaced 1/4-in. holes. All openings in the basin were either gasketed or threaded, thus forcing all delivered air upward through the column.

3.1.4 Support Structure

The air stripping system was supported by three tiers of steel scaffolding. Aluminum catwalks were located on all tiers above the ground, and a safety railing was provided on the uppermost tier. The scaffolding base was stabilized on the ground by a cement slab. The stand was further supported with 4-in.-by-4-in. timber cross beams bolted to the scaffolding. Each column was hung within this rectangular timber framework positioned at the top of the first and second tiers of the scaffolding and held in place by column binders. The column binders consisted of one fixed and two moveable timber cross beams. A threaded rod connected the two adjustable beams and was tightened to hold the columns securely in place.

3.1.5 Instrumentation

Air and water flow rates were measured individually for each column. Flow and pressure were measured at the same points in each column. Thermocouples measured system influent and effluent water temperature. A separate temperature and pressure monitoring system was provided with the compressor to correct flow readings to actual conditions.

3.1.6 Resin Column

During three of the runs, chromium was spiked to the test water, and a side stream from Column 4 effluent was passed through a Dowex MSA-1 anionic resin column. Details of the equipment and operating procedures for this test are presented in Appendix A.

3.2 OPERATION AND SAMPLING

Each day of test runs began with servicing of the air compressor. The fuel tank was topped-off, and all fluid levels were checked. The compressor engine was started and allowed to warm up. Following compressor start, well water was fed to the feed tank, and all system water pumps were started. Water flow rate was set and verified by timing drawdown of the feed tank. Air was supplied to the system by opening the service air valve, and actual air flow rates were set by calibrating the indicated flow rate for air temperature and pressure. Finally, the contaminant spiking pump was started. After each change in test conditions, 60 minutes (min) was allowed for steady state to be reached before the first sample set was taken. A second sample set was taken 30 min after the first.

Samples were collected 60 and 90 min after start of the spiking pump. All samples were collected in duplicate in 65-milliliter (ml) glass volatile organic analysis (VOA) vials with Teflon®-lined rubber septa. Samples were collected at the system influent after the influent pump and at the effluent from each of the four columns.

Samples were analyzed for VOAs by the method described in Appendix B. A measured volume of the water sample was extracted with pesticide-grade

hexane. A measured volume of the hexane was injected into a 20-ft glass column packed with 10-percent SP1000 on Supelcoport. Peak detection was measured with a Hewlett-Packard Ni⁵³ electron capture detector.

The analytical limits of detection were:

TCE	0.31 microgram per liter (ug/l)
MeCl	1.4 ug/l
DCE	3.5 ug/l

Samples that were not analyzed immediately were chilled in laboratory refrigerators.

During the three chromium runs, a separate set of samples was taken at the system influent and at the influent and effluent to the resin column, as discussed in Section 3.1.6.

3.3 SCHEDULE

To develop design criteria and to determine effects of variables on air stripper performance, several column operating conditions were evaluated. A complete schedule of test conditions is presented in Table 3-1. The columns were operated at flow rates of 20 and 40 gallons per minute (gpm) [approximately 8,300 and 16,600 pounds per square foot per hour (lb/ft²-hr)]. The air-to-water ratio was varied from 7.5 to 45.

Various concentrations and combinations of TCE, MeCl, DCE, phenol, and hexavalent chromium (CrVI) were spiked into the influent water to simulate the range of contaminants found in contaminated ground water. TCE, DCE, and MeCl are relatively amenable to air stripping at different depths. Phenol, far less amenable to stripping, was added to investigate its effect on the removal of other compounds. CrVI, in the form of potassium dichromate, was added to the matrix to determine if its presence would have adverse impacts on removal of organic contaminants or if air stripping would reduce the capability of ion exchange resin to remove chromium.

Table 3-1. Schedule of Test Runs

Run Number	Water Flow (gpm)	Air Flow (acfm/ column)	A/W*	Packed Depth (ft)	Water Temp. (°C)	Average Contaminant Concentration (ug/l)				
						TCE	DCE	MeCl	Phenol	CrVI
1	40	40	7.5	40	23	566	<10	<10	<10	<10
2	40	70	13.2	40	23	534	<10	<10	<10	<10
3	40	108	20.2	40	23	580	<10	<10	<10	<10
4	40	180	33.75	40	23	643	<10	<10	<10	<10
5	40	223	42.3	40	23	651	<10	<10	<10	<10
6	40	40	7.5	40	23	619	<10	<10	<10	1,200
7	40	80	15	40	23	587	<10	<10	<10	1,100
8	40	120	22.5	40	23	610	<10	<10	<10	935
9	20	20	7.5	40	23	581	<10	<10	<10	<10
10	20	40	15	40	23	592	<10	<10	<10	<10
11A	20	60	22.5	40	23	602	<10	<10	<10	<10
11B	20	100	37.4	40	23	685	<10	<10	<10	<10
11C	20	120	45	40	23	571	<10	<10	<10	<10
12	40	80	15	50	23	1,180	<10	<10	<10	<10
13	40	107	20	50	23	1,085	<10	<10	<10	<10
14	40	160	30	50	23	924	<10	<10	<10	<10
15	40	53	10	50	23	1,735	<10	<10	<10	<10
16	40	107	20	50	23	1,978	<10	<10	<10	<10
17	40	160	30	50	23	1,675	<10	<10	<10	<10
18	40	53	10	50	23	948	100	<10	<10	<10
19	40	107	20	50	23	937	100	<10	<10	<10
20	40	160	30	50	23	676	100	<10	<10	<10
21	40	53	10	50	23	885	146	<10	<10	<10
22	40	107	20	50	23	986	<10	<10	<10	<10
23	40	160	30	50	23	936	<10	<10	<10	<10
24	40	53	10	50	23	910	805	<10	<10	<10
25	40	107	20	50	23	998	887	<10	<10	<10
26	40	160	30	50	23	863	807	<10	<10	<10
27	40	53	10	50	23	<10	940	<10	<10	<10
28	40	107	20	50	23	<10	711	<10	<10	<10
29	40	160	30	50	23	<10	765	<10	<10	<10
30	40	53	10	50	23	1,038	<10	39	<10	<10
31	40	107	20	50	23	1,008	<10	46	<10	<10
32	40	160	30	50	23	945	<10	37	<10	<10
33	40	53	10	50	23	1,024	<10	59	<10	<10
34	40	107	20	50	23	943	<10	93	<10	<10
35	40	160	30	50	23	987	<10	95	<10	<10
36	40	53	10	50	23	1,103	<10	192	<10	<10
37	40	107	20	50	23	1,036	<10	190	<10	<10
38	40	160	30	50	23	1,078	<10	214	<10	<10
39	40	53	10	50	23	<10	<10	183	<10	<10
40	40	107	20	50	23	<10	<10	226	<10	<10

Table 3-1. Schedule of Test Runs (Continued, Page 2 of 2)

Run Number	Water Flow (gpm)	Air Flow (acfm/ column)	A/W*	Packed Depth (ft)	Water Temp. (°C)	Average Contaminant Concentration (ug/l)				
						DCE	MeCl	Phenol	CrVI	
41	40	160	30	50	23	<10	<10	193	<10	<10
42	40	53	10	50	23	1,117	958	204	<10	<10
43	40	107	20	50	23	882	797	196	<10	<10
44	40	160	30	50	23	1,031	851	186	<10	<10
45	40	53	10	50	23	912	<10	<10	2,930	<10
46	40	107	20	50	23	851	<10	<10	2,882	<10
47	40	160	30	50	23	782	<10	<10	3,100	<10

* Air-to-water ratio.

Source: ESE, 1984.

THAMA-MISC.3/T4I/3.6
3/3/84

In the first few runs, each of the four columns contained 10 ft of packing for a total packed depth of 40 ft. In subsequent runs, 5 additional ft of packing was added to Columns 1 and 2, as described in Section 3.1.1. The additional packing created a total packed depth of 15 ft in each of the first 2 columns and provided an opportunity to check the benefits of additional redistribution.

4.0 RESULTS

This study demonstrated that TCE, DCE, and MeCl can all be removed from water by air stripping and that their concentrations can be reduced by greater than 90 percent at air-to-water ratios less than 20 and with 15 ft of 1-in. Intalox saddles. Additional removals approaching the detection limit for the contaminant can be achieved by either an increase in the packed depth or the air-to-water ratio.

Using the partition coefficients discussed in Section 2.0, the overall mass transfer coefficients of these compounds have been calculated (Table 4-1). With these coefficients, full-scale treatment systems can be designed that will equal the pilot system in performance. The use of these experimentally determined coefficients and their limitations are discussed in Section 4.4. The results for individual runs are tabulated in Appendix C.

In this section, the variations in column performance with experimental conditions are discussed. In all cases, the results are consistent with theory or with previously published correlations. Trends that have a bearing on system design are depicted in figures drawn from the experimental data points.

Concentrations in the effluent streams from the third and fourth columns were often near or below detection limits; consequently, analysis and discussion are limited to data from Columns 1 and 2.

4.1 COLUMN CONFIGURATION

For the equations presented in Section 2.0, it is assumed that there is only one entrance and one exit for air and water along the packed length of the column. However, in Section 3.0, the introduction of fresh air in the pilot system after each 10 or 15 ft of packing was described. For the theoretical equations, it is also assumed that column internals are uniform along the length of the column; however, when Columns 1 and 2 were operated with 15 ft of packing, Column 1 was equipped with a

Table 4-1. Mass Transfer Coefficients for Solutes Studied

Solute	Molecular Weight	$K_L a$ (sec ⁻¹)	
		All Runs	Air Rate > 150 acfm
TCE (20 gpm)	131	0.0108	--
TCE (40 gpm)	131	0.0206	0.0225
MeCl	85	0.0131	0.0176
DCE	97	0.0244	0.0251
Phenol	94	--	--

Source: ESE, 1984.

liquid redistributor whereas Column 2 was not. The effect of these departures from the theoretical configuration is shown in Figure 4-1.

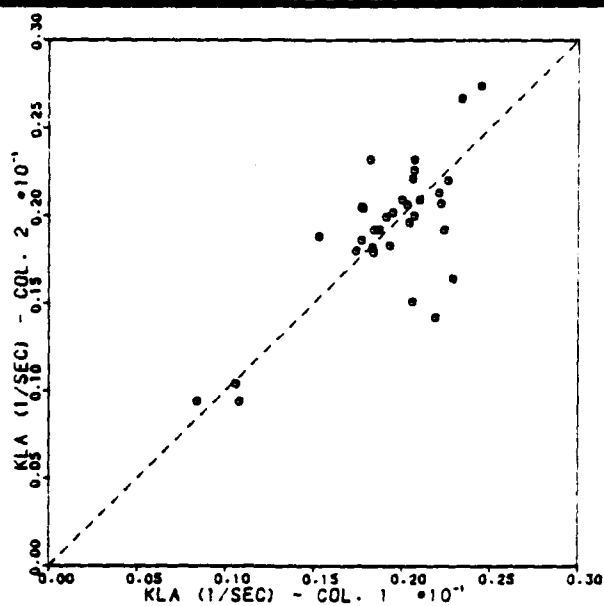
The average ratio of $K_L\alpha$ for Column 1 to that of Column 2 (calculated from simultaneous measurements) was 1.01; however, when statistical tests were applied this was not significantly different from unity (see Figure 4-1, Graph A). Thus, the redistributor in Column 1 apparently did little to affect performance with only 15 ft of packing. Redistributors are generally recommended when the packed-depth-to-diameter ratio is greater than 10 to 1, which for this column would be at approximately the 12-ft depth. In this study, at a depth-to-diameter ratio of 12 to 1, a redistributor was added without a measurable effect on performance.

Graphs B and C in Figure 4-1 show that $K_L\alpha$ values for Columns 1 and 2 individually were slightly lower than $K_L\alpha$ calculated by assuming the total length of both columns was a single column (i.e., by assuming there was only one air inlet and one outlet). This result was to be expected since the introduction of fresh air at a point between the columns provided an advantage over true series operation. The ratio of the $K_L\alpha$ calculated for either Columns 1 or 2 individually to the $K_L\alpha$ calculated overall was 0.97. This was different from unity at a 0.01 level of significance.

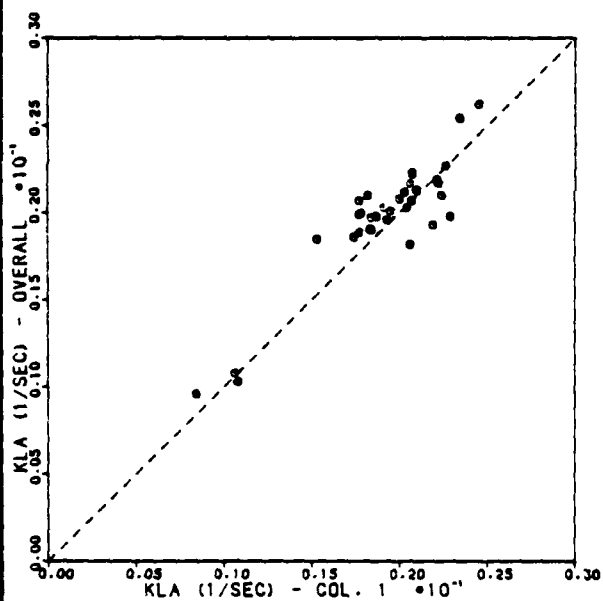
Introducing fresh air at the base of each column was primarily an operational convenience. Unless many columns are to be operated in series, the mass transfer advantage of this configuration is negligible.

4.2 AIR-TO-WATER RATIO

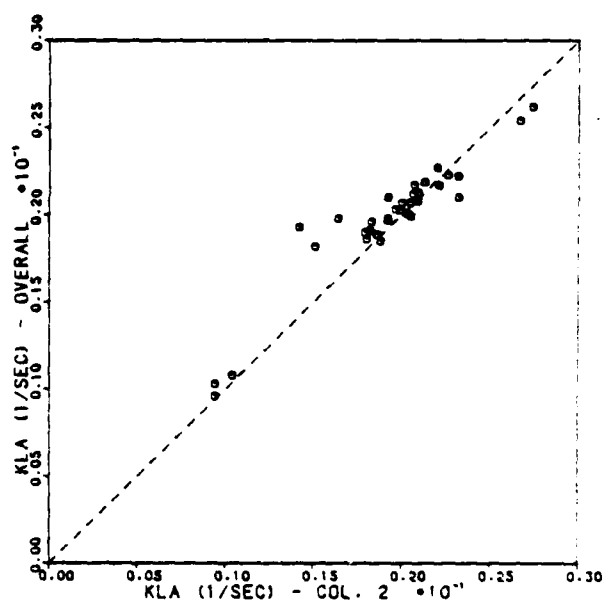
Column performance, expressed as percent removal as a function of air-to-water ratio, is illustrated in Figures 4-2 and 4-3. The trend exhibited was as expected. As the air-to-water ratio is increased, the percent removal increases to an asymptotic limit of 100 percent. Only Column 1 data for MeCl and DCE are shown because the concentrations of



a. COLUMN 1 VERSUS COLUMN 2



b. COLUMN 1 VERSUS COLUMNS 1 AND 2

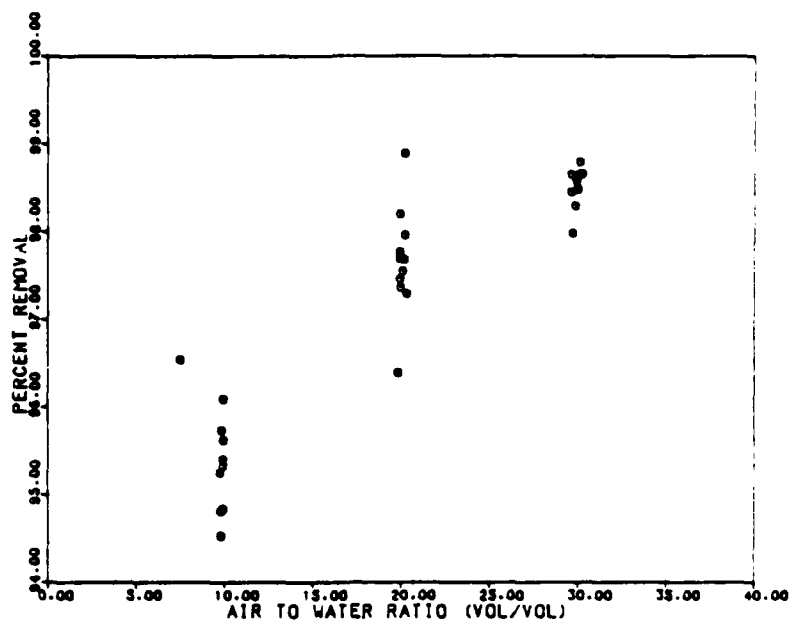


c. COLUMN 2 VERSUS COLUMNS 1 AND 2

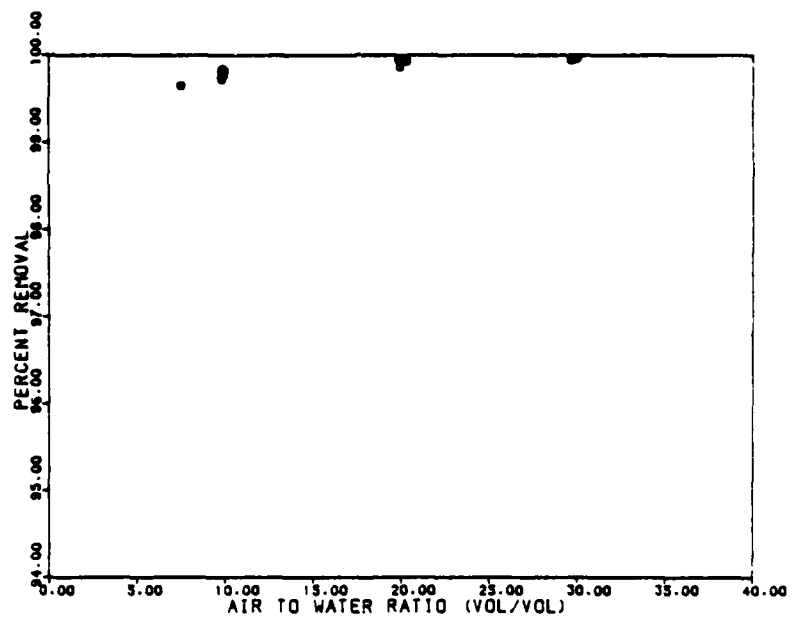
Figure 4-1
OVERALL MASS TRANSFER
COEFFICIENTS

SOURCE: ESE, 1984.

USATHAMA



a. COLUMN 1

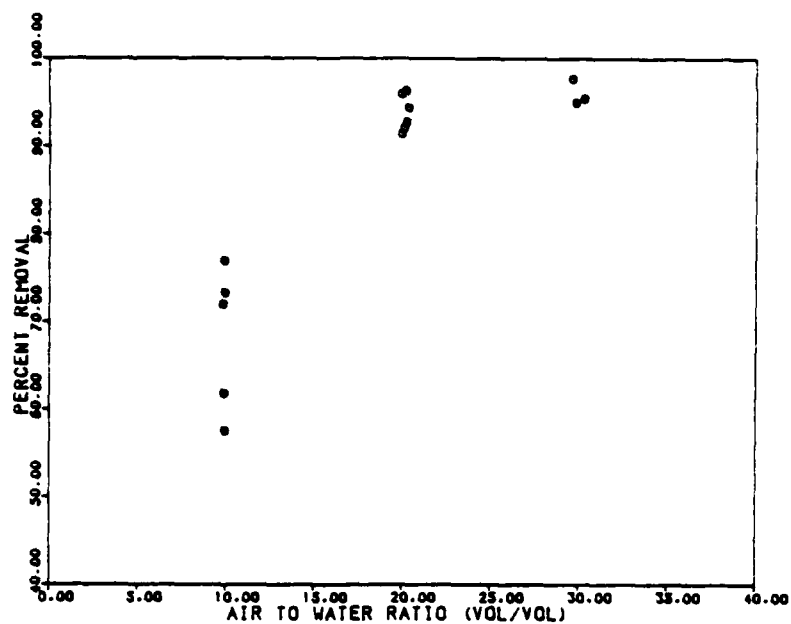


b. COLUMNS 1 AND 2

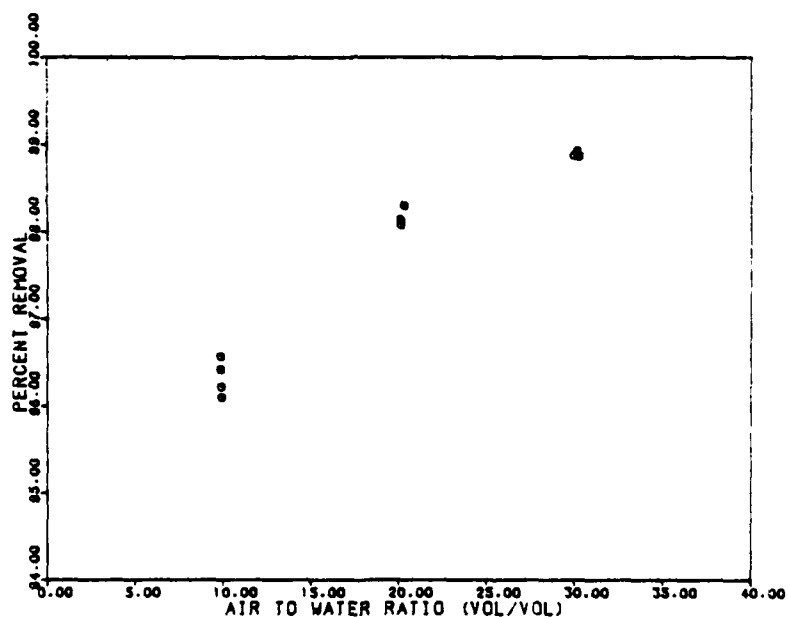
Figure 4-2
TCE REMOVAL VERSUS AIR-TO-WATER
RATIO

SOURCE: ESE, 1984.

USATHAMA



a. MeCl, COLUMN 1



b. DCE, COLUMN 1

Figure 4-3
MeCl AND DCE REMOVAL VERSUS
AIR-TO-WATER RATIO

SOURCE: ESE, 1984.

USATHAMA

these compounds were usually below the detection limit in Column 2 effluent.

4.3 MASS TRANSFER COEFFICIENT

Overall mass transfer coefficients for varying air-to-water ratios are illustrated in Figure 4-4, and the results are summarized in Table 4-1. The effect of doubling the liquid rate was to nearly double the mass transfer coefficient of TCE. Other researchers (Sherwood and Holloway, 1940) have proposed correlations where the mass transfer coefficient varies with liquid loading to the 0.72 power. The effect of liquid loading observed here is slightly greater.

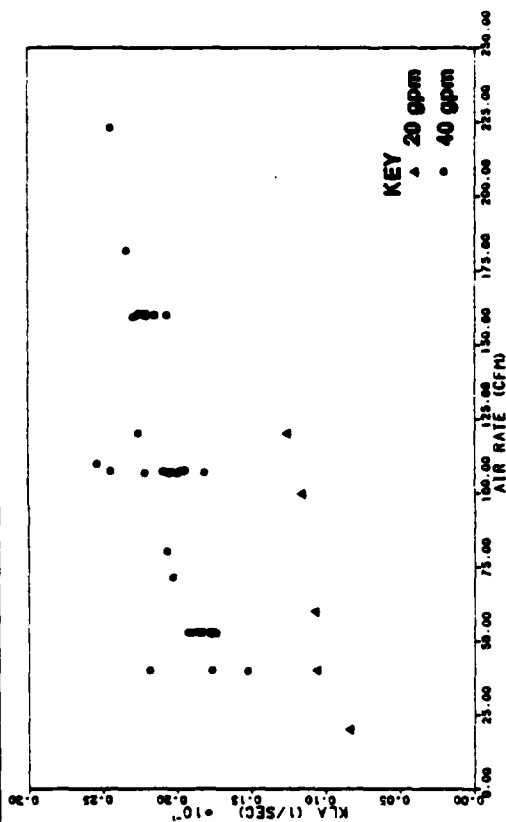
The mass transfer coefficient of all three compounds also appears to be weakly dependent on air rate. Although this is not expected when liquid phase transfer is controlling, the effect has been previously observed (Cooper, Christl, and Perry, 1941). In the referenced article, it was proposed that at high liquid loading rates (greater than 6,000 lb/hr-ft²), the turbulence was sufficient to cause backmixing within the column. Higher air rates would reduce the effect of this backmixing and cause the observed column improvement. In all runs conducted, the liquid loading rate was greater than 8,340 lb/hr-ft²; hence, results could theoretically be affected as observed by air rate.

The relationship of initial concentration to the overall mass transfer coefficient is illustrated in Figure 4-5. No correlation was expected, and none was observed.

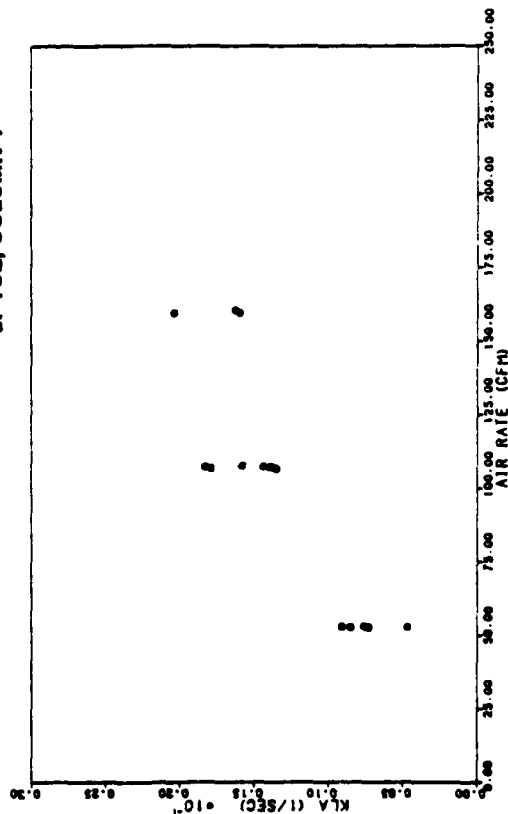
The effect of multiple solutes on column performance is summarized in Table 4-2. The presence of other compounds did not cause any significant change in the mass transfer coefficient for TCE.

4.4 DESIGN IMPLICATIONS

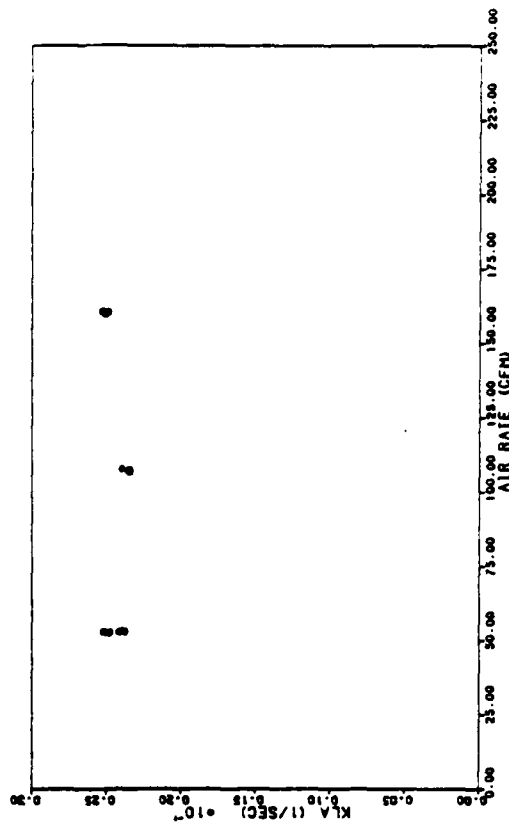
The series of pilot system experiments demonstrated that the equations presented in Section 2.0 and summarized in Table 2-1 describe air



a. TCE, COLUMN 1



b. MeCl, COLUMN 1



c. DCE, COLUMN 1

Figure 4-4
OVERALL MASS TRANSFER
COEFFICIENTS VERSUS AIR RATE

SOURCE: ESE, 1984.

USATHAMA

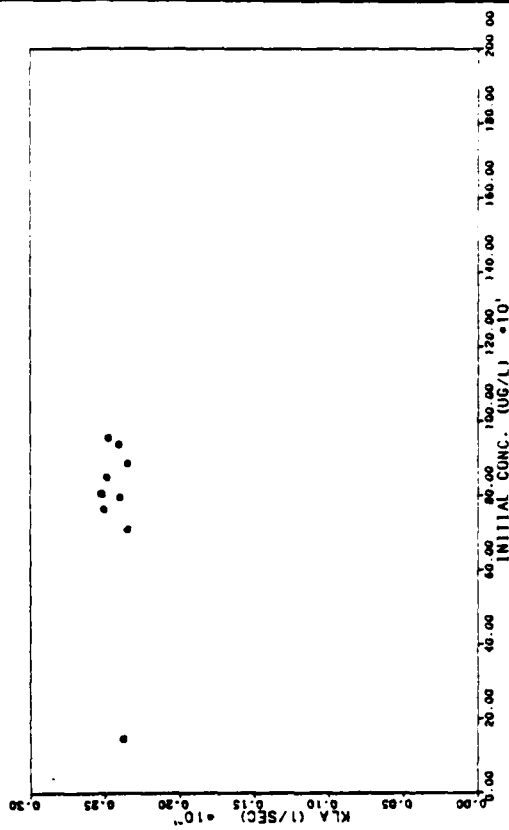
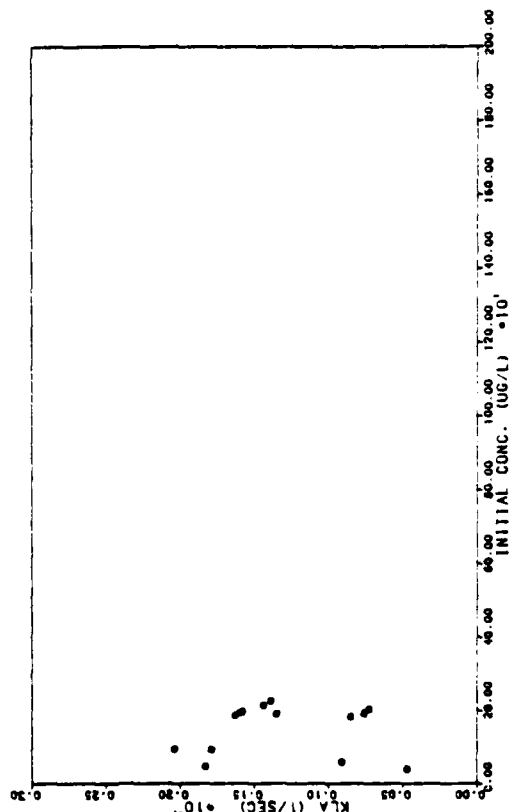
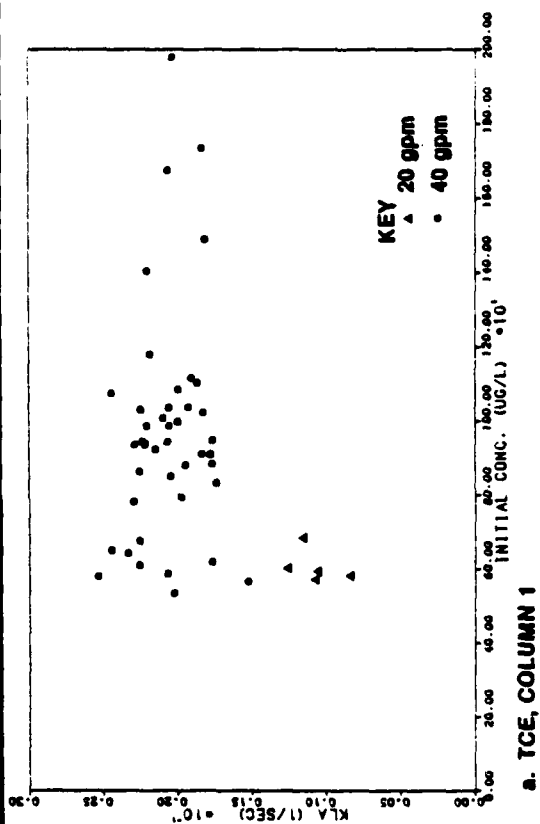


Figure 4-5
OVERALL MASS TRANSFER
COEFFICIENTS VERSUS LIMITED
CONCENTRATION

SOURCE: ESE, 1994.

USATHAMA

Table 4-2. Effect of Multiple Solutes on TCE Mass Transfer Coefficient

Spiked Solute	Mass Transfer Coefficient for TCE, $K_L a$ (sec ⁻¹)	
	With Spiked Solute	Without Spiked Solute
DCE	$\bar{x} = 0.0199$ $n = 7$ $s = 0.0020$	$\bar{x} = 0.0207$ $n = 35$ $s = 0.0023$
MeCl	$\bar{x} = 0.0207$ $n = 10$ $s = 0.0019$	$\bar{x} = 0.0206$ $n = 32$ $s = 0.0023$
CrVI	$\bar{x} = 0.0203$ $n = 3$ $s = 0.0025$	$\bar{x} = 0.0206$ $n = 39$ $s = 0.0022$
Phenol	$\bar{x} = 0.0206$ $n = 3$ $s = 0.0023$	$\bar{x} = 0.0206$ $n = 39$ $s = 0.0023$

- Notes: 1. $\bar{x}$ = average $K_L a$ value.
 n = number of runs contributing to average.
 s = sample standard deviation.
2. Only runs at 40 gpm are included.
3. Solutes were added in varying concentrations according to the schedule in Table 3-1.

Source: ESE, 1984.

stripping behavior well enough to predict the performance of the test runs or to design a treatment system using empirical data from the test runs. The experiments have also provided some of the information necessary to extrapolate system design to other conditions that may be encountered.

A full-scale system may operate at air-to-water ratios, liquid loading rates, or temperatures significantly different from those of the test conditions. It is unlikely that a full-scale system would operate at flow conditions much lower than test conditions, and a short extrapolation would not be seriously in error. Reference to manufacturer's literature (Norton Company, 1973) indicates that the columns in this study were never operated at more than one half of the flooding velocity, even at the highest liquid and air flow rates (Figure 4-6). Theory predicts, and these tests confirm, that operation at higher air-to-water ratios, liquid loading rates, or temperatures will improve performance so that a design based on data in this report would include some reserve removal capability.

Colder air or water temperatures will reduce system performance below that experienced during the test runs. This is mainly due to the temperature effect on the partition coefficient discussed in Section 2.0, but is also partially due to the decrease in the rate of diffusion of solutes in water as temperatures decrease. This effect must be incorporated into a system design for water with a lower temperature either by using theoretical correlations to adjust the empirical design criteria or by conducting a limited number of experiments on the lower-temperature water source.

4.5 CHROMIUM REMOVAL

In all three chromium runs, the Dowex resin was able to reduce air stripper effluent chromium concentrations from approximately 1,000 milligrams per liter (mg/l) to less than 4 ug/l, the instrumental detection limit. Details of the test data for these runs are found in Appendix C.

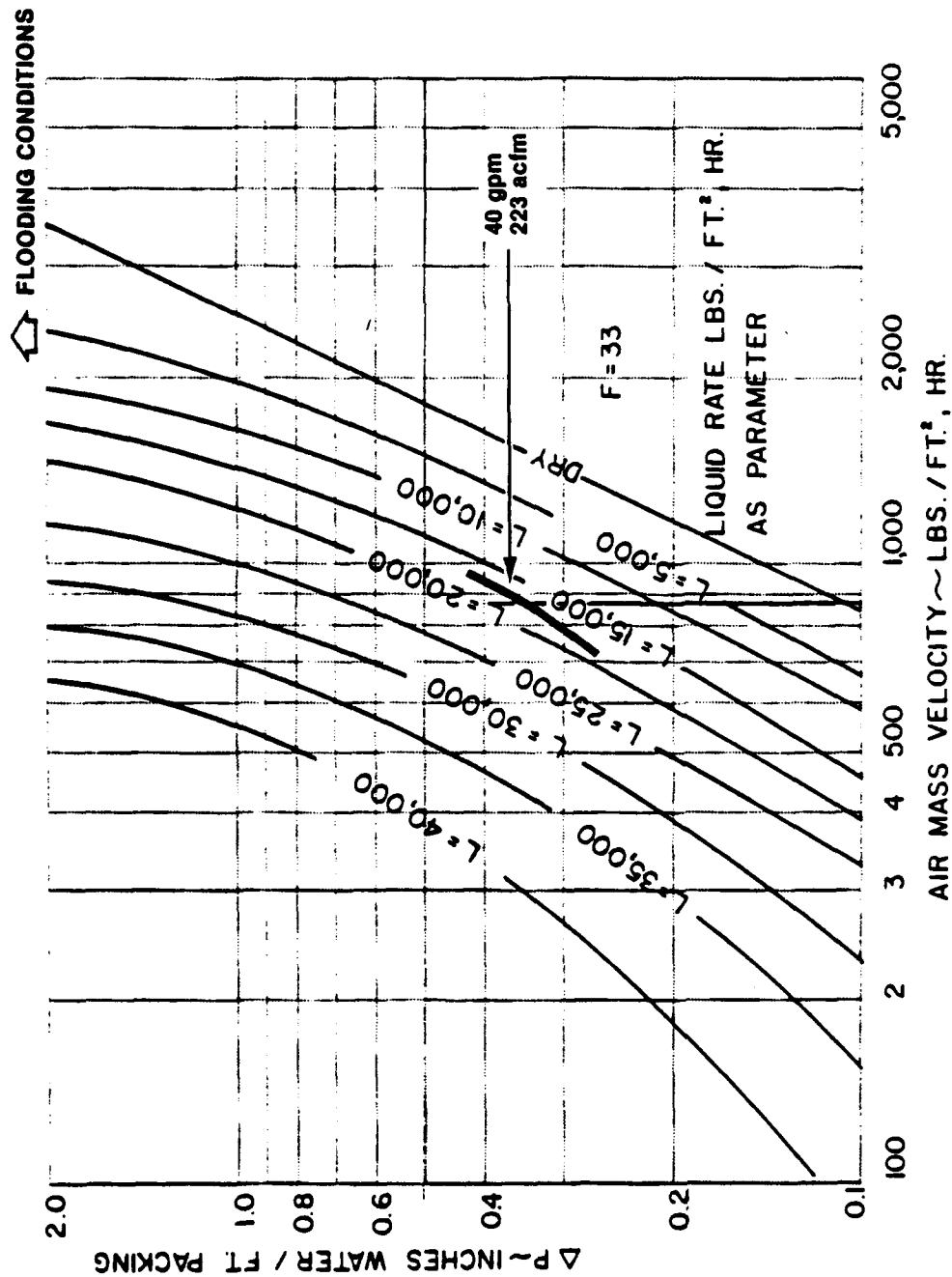


Figure 4-6
 CAPACITY OF PLASTIC No. 1 SUPER INTALOX® SADDLES

SOURCE: NORTON COMPANY, 1973.

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5.0 REFERENCES

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APPENDIX A
ION EXCHANGE RESIN TESTS

APPENDIX A
ION EXCHANGE RESIN TESTS

To verify previous bench-scale ion exchange studies conducted by ESE for USATHAMA, three test runs were conducted with a contaminant matrix containing approximately 1,000 ug/l of CrVI and 500 ug/l of TCE.

SYSTEM DESCRIPTION

The ion exchange resin system used in the study consisted of a feed reservoir, a metering pump, and an ion exchange column. A diagram of the resin system is presented in Figure A-1.

A continuous flow of feed water was supplied to the reservoir through 1/4-in. Teflon® tubing connected to the effluent line of Column 4. Excess feed water was allowed to overflow into the Column 4 basin. Water was drawn from the 3-gal PVC reservoir through 1/4-in. Teflon® tubing to a Wallace/Teirnan positive displacement metering pump. From the pump, water flowed through 1/4-in. Teflon® tubing to the ion exchange column. The column consisted of a 4-in.-inside-diameter (ID), 6-ft-long glass column supported on a portable metal rack. The column was packed from the bottom up with 3 in. of 1/4-in.-diameter glass beads, 3 in. of glass wool, and 2 ft of Dowex MSA-1 16/40-mesh anion exchange resin. The ends of the columns were capped with stainless-steel end caps.

Water entered the top of the columns and flowed by gravity through the resin. Treated water was discharged from the bottom of the column into the effluent pipe of the air stripping system through 1/4-in. Teflon® tubing.

Prior to loading the column, the resin was preconditioned according to the manufacturer's recommended procedures, described in Table A-1.

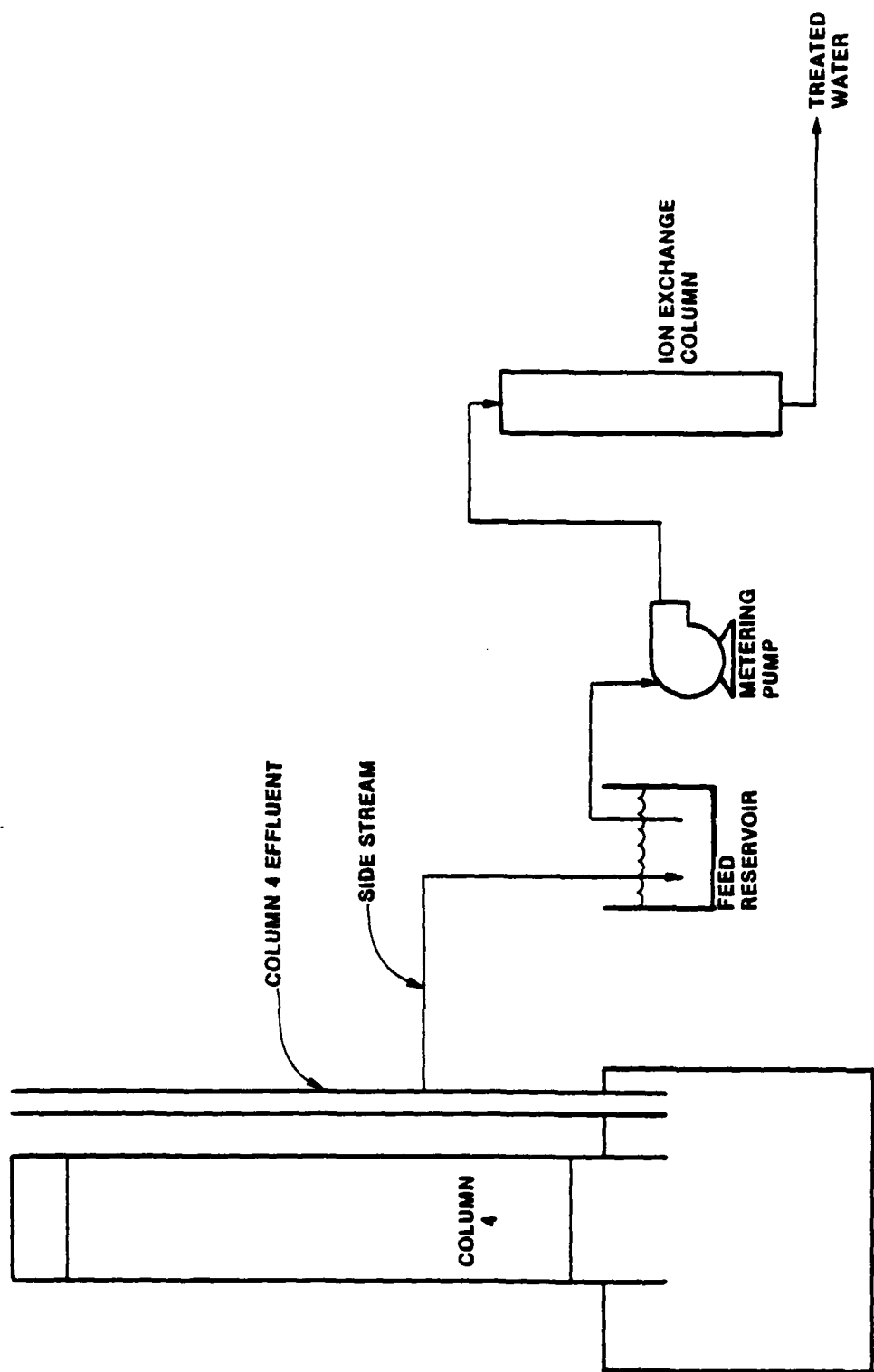


Figure A-1
ION EXCHANGE RESIN SYSTEM

SOURCE: ESE, 1984.

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Table A-1. Preconditioning of Ion Exchange Resin

-
1. Resin was soaked overnight in water.
 2. Two bed volumes of 1.5N NaOH (9.8 liters) were flushed through the resin bed in 20 min.
 3. The caustic solution was washed out with five bed volumes (24.6 liters) of well water in 30 min.
 4. Two bed volumes of 2N HCl were flushed through the resin in 20 min.
 5. The acidic solution was washed with five bed volumes of well water for 30 min.
 6. Steps 2 through 5 were repeated once according to the manufacturer's recommendations.
 7. The resin was loaded into the column and backwashed with well water at a 50-percent bed expansion.

At the end of the conditioning procedure, the exchange resin was in the anionic form (salt form).

Sources: Dow Chemical, 1983.
ESE, 1984.

ION EXCHANGE RESIN TEST PROCEDURES

To provide an empty bed contact time (EBCT) representative of a full-scale system (20 min), feed water to the resin column was supplied at 247 ml/min during each of the chromium runs (Runs 6, 7, and 8). The column was on line a total of 288 min for a total volume processed of 71.1 liters (13.8 gal). Samples were collected at 60 and 90 min after initiation of each run. The sampling points were (1) influent to the air stripping system, (2) effluent from the air stripping system (influent to the resin column), and (3) effluent from the resin column. A 1-liter volume was collected from each sampling point in 1-liter cubitainers.

A spiking solution of CrVI was made. All analyses were for total chromium according to U.S. Environmental Protection Agency (EPA) Method 200.7 (EPA, 1979), USATHAMA Certification: Lab ES, Method 3T. Since the only chromium was that in the spiking solution, the values for total chromium can also be taken to be for CrVI.

RESULTS

The results from these tests are summarized in Table A-2. Chromium concentrations were reduced below detectable limits in all cases, indicating that the laboratory results obtained previously (Report DRXTH-TE-CR-83218) should be valid for field conditions.

REFERENCE

U.S. Environmental Protection Agency. 1979. Inductively Coupled Plasma--Atomic Emission Spectrometric Method for Trace Element Analysis of Water and Wastes--Method 200.7. Methods for Chemical Analysis of Water and Wastes. EPA 600/4-79-020.

Table A-2. Results of Resin Column Tests

Run No.	Total Chromium (ug/l)		
	System Influent	Resin Column Influent	Resin Column Effluent
6	1,200	1,200	<4.0
7	1,100	1,150	<4.0
8	935	970	<4.0

Note: The instrumental detection limit is 4.0 ug/l.

Source: ESE, 1984.

APPENDIX B
ANALYTICAL METHOD FOR VOC

ANALYSIS OF METHYLENE CHLORIDE, T-1,2-DICHLOROETHENE, AND
TRICHLOROETHENE IN WATER BY LIQUID/LIQUID EXTRACTION GC/EC.

1. APPLICATION

This method is applicable to the quantitative determination of methylene chloride, t-1,2-dichloroethene, and trichloroethene in environmental water samples. The described method is based on a liquid/liquid extraction and GC/EC analysis technique.

A. TESTED CONCENTRATION RANGE

The tested concentration ranges in standard water samples are:

<u>Analyte</u>	<u>Abbreviation</u>	<u>Tested Concentration Range (ug/l)</u>
Methylene chloride	CH2CL2	0.72 to 18.0
t-1,2-Dichloroethene	TI2DCE	3.47 to 69.5
Trichloroethene	TRCLE	0.31 to 7.76

B. SENSITIVITY

The integrated area at the standard water detection limits are:

<u>Analyte</u>	<u>Retention Time (minutes)</u>	<u>Area Counts</u>
CH2CL2	4.0	5230
TI2DCE	3.3	1340
TRCLE	5.3	35000

C. DETECTION LIMITS

The detection limits in standard water, calculated according to the USATHAMA detection limit program, are:

<u>Analyte</u>	<u>Detection Limit (ug/l)</u>
CH2CL2	1.4
TI2DCE	3.5
TRCLE	0.31

D. INTERFERENCES

Solvents, reagents, glassware, and other sample processing equipment may yield chromatograms with interfering peaks. All reagents, glassware, and sample handling equipment must be demonstrated to be free from interferences which have retention times equal to that of the compounds of interest.

E. ANALYSIS RATE

After instrument calibration, one analyst can analyze 30 samples in an 8-hour day.

2. CHEMISTRY

A. CHEMICAL ABSTRACT SERVICE (CAS) NUMBER

<u>Compound</u>	<u>CAS Registry Number</u>
CH ₂ CL ₂	75-09-2
Tl ₂ DCE	156-60-5
TRCLE	79-01-6

B. PHYSICAL AND CHEMICAL PROPERTIES

<u>Compound</u>	<u>Formula</u>	<u>Boiling Point (°C)</u>	<u>Density at 20°C (g/ml)</u>
CH ₂ CL ₂	CH ₂ Cl ₂	40	1.33
Tl ₂ DCE	C ₂ H ₂ Cl ₂	48	1.25
TRCLE	C ₂ HCl ₃	87	1.44

3. APPARATUS

A. INSTRUMENTATION

Hewlett-Packard Model 5730A gas chromatograph equipped with an electron capture detector interfaced to a Spectra-Physics Model 4100 computing integrator. Sample injection performed with a Hewlett-Packard 7672A automatic sampler.

B. PARAMETERS

1. Column - 10% SP1000 on 100/120 mesh Supelcoport packed in a 20-foot X 2 mm ID glass column;
2. Detector - Hewlett-Packard Ni⁶³ electron capture detector;
3. Oven Temperature - 125°C.
4. Gas Flow - 30 ml/min with 5-percent methane/argon;
5. Detector Temperature - 300°C; and
6. Injection Port Temperature - 200°C.

C. HARDWARE/GLASSWARE

1. 20-ml culture tubes with Teflon^R-lined screw-caps;
2. 1-ml micro-glass vials with Teflon^R-lined crimp-seal caps;
3. Volumetric flasks, 5 ml and 100 ml;
4. Pipettes, 0.5 ml, 1.0 ml, and 15 ml;
5. Disposable glass pasteur pipettes;
6. Glass chromatographic column, 25 mm X 400 ml;
7. 1-liter flasks with ground glass stoppers;
8. 10- μ l glass microsyringe; and
9. 4-ml glass vials with Teflon^R-lined screw-caps.

D. CHEMICALS

1. Hexane, pesticide grade;
2. Methanol, HPLC grade;
3. Water, HPLC grade;
4. Anhydrous Sodium sulfate, reagent grade;
5. Sodium chloride, reagent grade;
6. Alumina Woelm^R - Super 1; and
7. Purified nitrogen.

4. STANDARDS

A. CALIBRATION

1. Prepare the primary stock calibration standard by weighing the pure analytes into a pre-weighed 5-ml volumetric flask.
2. Add approximately 2 ml of Tl₂DCE to the 5-ml volumetric flask, weigh the flask and record the weight. Add approximately 2 ml of CH₂CL₂ to the flask, weigh the flask and record the weight. Then add enough TRCLE to the flask to bring the total liquid volume to the mark. Weigh the flask and record the weight. Calculate the weight of each analyte by subtracting the weight of the empty flask.
3. The concentration of each analyte in the primary stock calibration standard is listed below:

<u>Analyte</u>	<u>Weight (gm)</u> <u>in 5 ml</u>	<u>Concentration</u> <u>(mg/ml)</u>
CH ₂ CL ₂	2.7005	540
Tl ₂ DCE	2.6064	521
TRCLE	1.1639	233

4. When not in use store this solution at 4°C.
5. Prepare three secondary stock calibration standards by adding microliter amounts of the primary stock calibration standard to hexane contained in separate volumetric flasks and bringing each to volume. Store these secondary stock calibration standards at 4°C. The concentrations of each analyte in each of the secondary stock calibration standards are listed below:

Secondary Stock	Volume (ul) of Primary Stock Diluted to 100 ml with hexane	Analyte	Concentration (ug/ml)
A	100	CH2CL2	540
		T12DCE	521
		TRCLE	233
B	10	CH2CL2	54.0
		T12DCE	52.1
		TRCLE	23.3
C	1	CH2CL2	5.4
		T12DCE	5.2
		TRCLE	2.3

6. Prepare nine levels of working calibration standards from the three secondary stock calibration standards by injecting the following microliter amounts into 1.5 ml hexane contained in 4 ml glass vials with Teflon^R-lined screw caps:

Working Calibration Standard	Volume (ul) of Secondary Stock added to 1.5 ml hexane	Secondary Stock
1	0	—
2	2	C
3	5	C
4	10	C
5	2	B
6	5	B
7	10	B
8	2	A
9	5	A

The concentrations of each analyte in the working calibration standards are listed below:

Working Standard	Concentration (ppb)		
	CH ₂ CL ₂	Tl ₂ DCE	TRCLE
1	0	0	0
2	7.20	6.95	3.10
3	18.0	17.4	7.76
4	36.0	34.8	15.5
5	72.0	69.5	31.0
6	180	174	77.6
7	360	348	155
8	720	695	310
9	1800	1740	776

B. CONTROL SPIKES

1. Control spikes are analyzed in the same manner as the samples described in Section 5.D.
2. Water samples are spiked using the spiking volumes of the appropriate secondary stock as used for preparation of the working calibration standards in Section 4.A.6.

5. PROCEDURE

A. GLASSWARE CLEANUP

1. Rinse all glassware with HPLC-grade methanol prior to analysis.
2. Place glassware in 150°C oven for 30 minutes, remove, and let stand until room temperature equilibrium is achieved.

B. ORGANIC FREE STANDARD WATER PREPARATION

1. Place 800 ml of HPLC-grade water in a 1,000-ml flat-bottomed boiling flask.
2. Purge with prepurified nitrogen and allow purging to continue while the water is boiled for 10 to 15 minutes.
3. Remove heat and allow water temperature to equilibrate with room temperature while purging continues.
4. Stopper flask with ground-glass stopper and remove only to take appropriate aliquot for analysis.
5. Weigh out the appropriate amounts of sulfate and chloride (both reagent grade) to produce a final concentration of 100 mg/l, respectively, and add to purged organic-free, HPLC-grade water.

C. HEXANE PREPARATION

1. Pass one liter of pesticide grade hexane through a 25 mm X 400 mm chromatographic column containing 50 grams of basic alumina.
2. Previously prepare the alumina by heating in a muffle furnace for 8 hours at 550°C. Collect and store in a 1-liter flask with ground-glass stopper.

D. SAMPLE ANALYSIS PROCEDURE

1. Pipette 15-ml of sample into a 20-ml culture tube containing 1.5 ml of hexane.
2. Cap the tube tightly and shake vigorously for 30 seconds. Allow 30 minutes for phase separation.
3. Transfer approximately 1 ml of the hexane extract by means of a Pasteur pipette to a 1-ml micro-glass vial with Teflon^R-lined crimp seal cap.
4. Place the sample vial into the automatic sampler for injection into the isothermally operated gas chromatograph for separation by packed column chromatography and detection by electron capture detector.
5. Quantitate the samples against direct calibration standards prepared in hexane as described in Section 4.

6. CALCULATIONS

1. Determine the concentration of each analyte according to the following formula:

$$\text{Concentration (ppb)} = \frac{(A)(V_t)}{(V_s)}$$

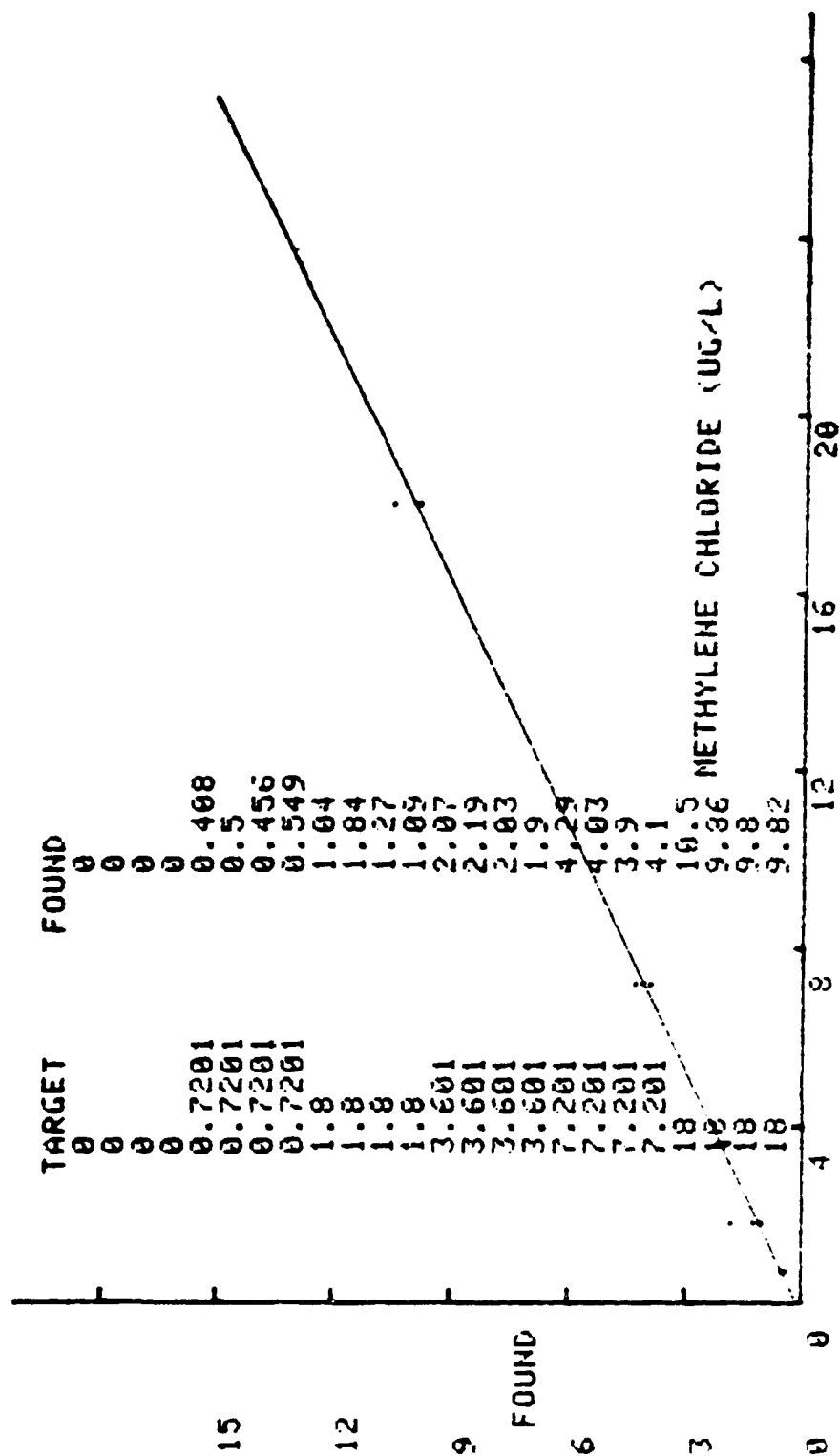
where: A = Concentration of the component found on the sample extract by comparison with the appropriate standard curve (ng/ml)

V_t = Volume of total extract (ml)

V_s = Volume of initial sample extracted (ml)

7. REFERENCES

None



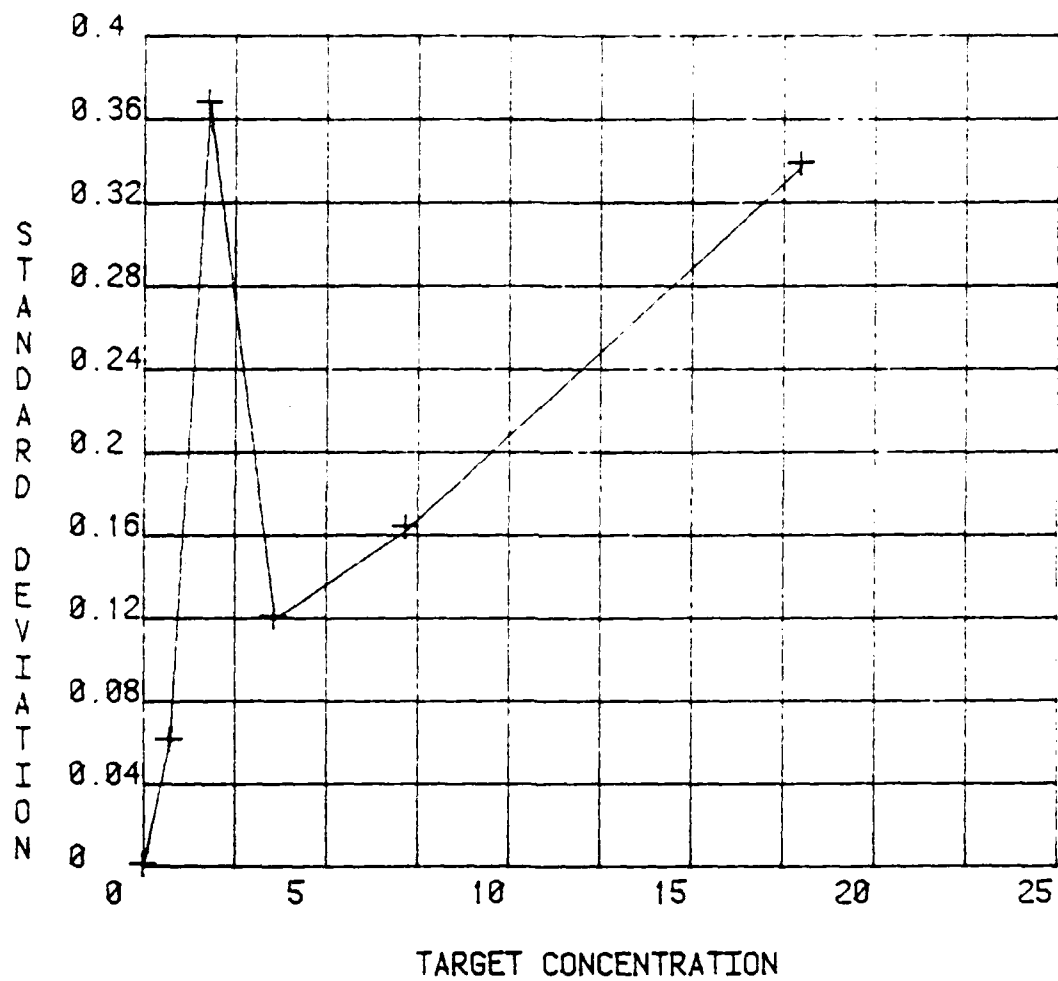
TARGET
 CORR. COEFF. = 0.9980 FOUND = 0.1167+ 0.549467*TARGET
 DETECTION LIMIT = 1.42814

METHYLENE CHLORIDE (UG/L)

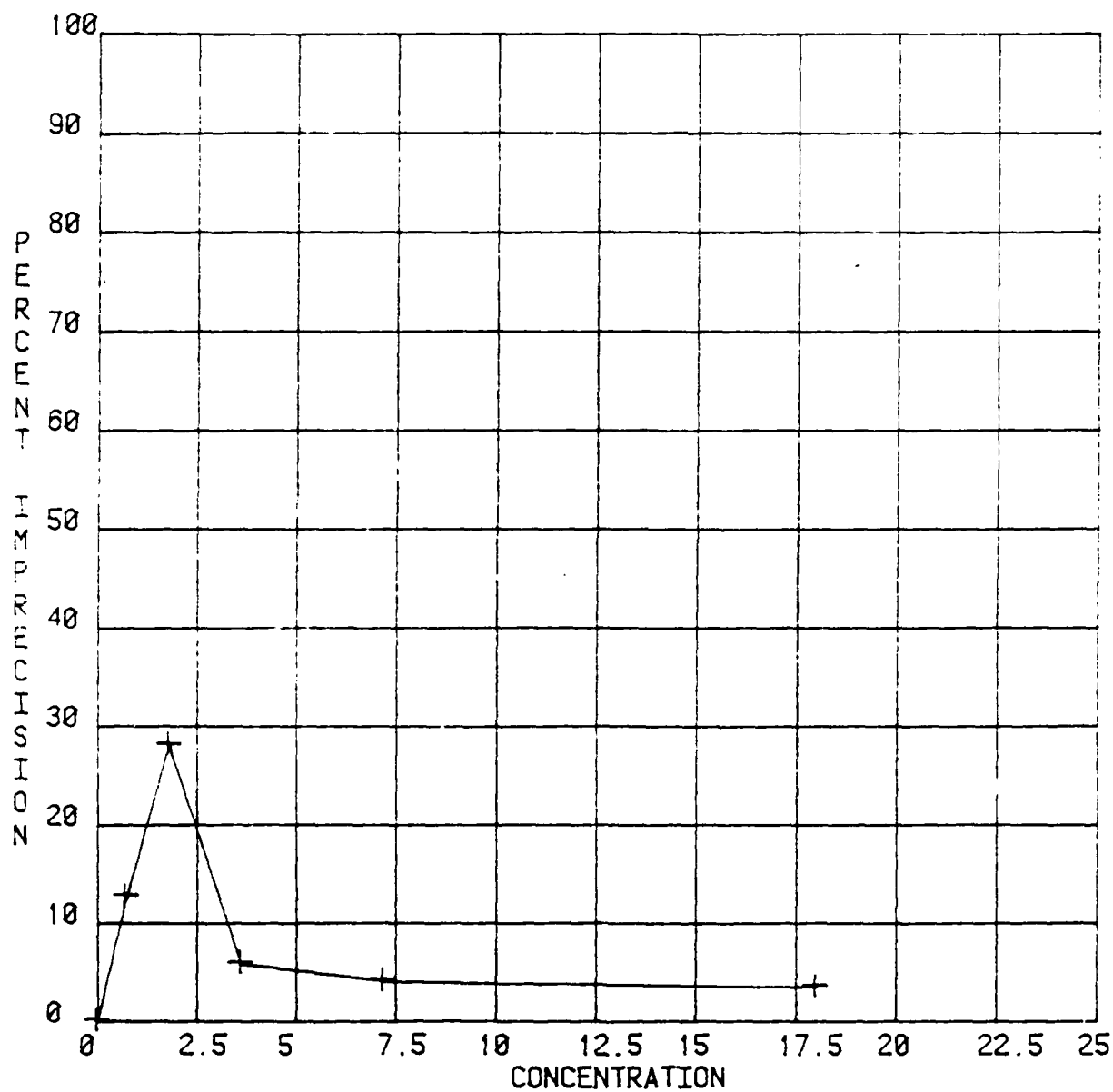
TARGET CONCENTRATION	1	DAY 2	7	4
0.0000	0.0000	0.0000	0.0000	0.0000
0.720	0.404	0.500	0.456	0.544
1.80	1.74	1.84	1.27	1.09
3.60	2.07	2.18	2.03	1.90
7.20	4.09	4.23	3.90	4.10
18.0	10.5	9.86	9.80	9.82

TARGET CONCENTRATION	AVERAGE FOUND VALUE	STANDARD DEVIATION	PERCENT IMPRECISION	PERCENT INACCURACY
0.0000	0.0000	0.0000	0.0000	0.0000
0.720	0.478	0.0603	12.6	-33.6
1.80	1.31	0.367	28.0	-27.2
3.60	2.05	0.120	5.84	-43.1
7.20	4.08	0.163	3.99	-43.3
18.0	9.99	0.338	3.38	-44.5

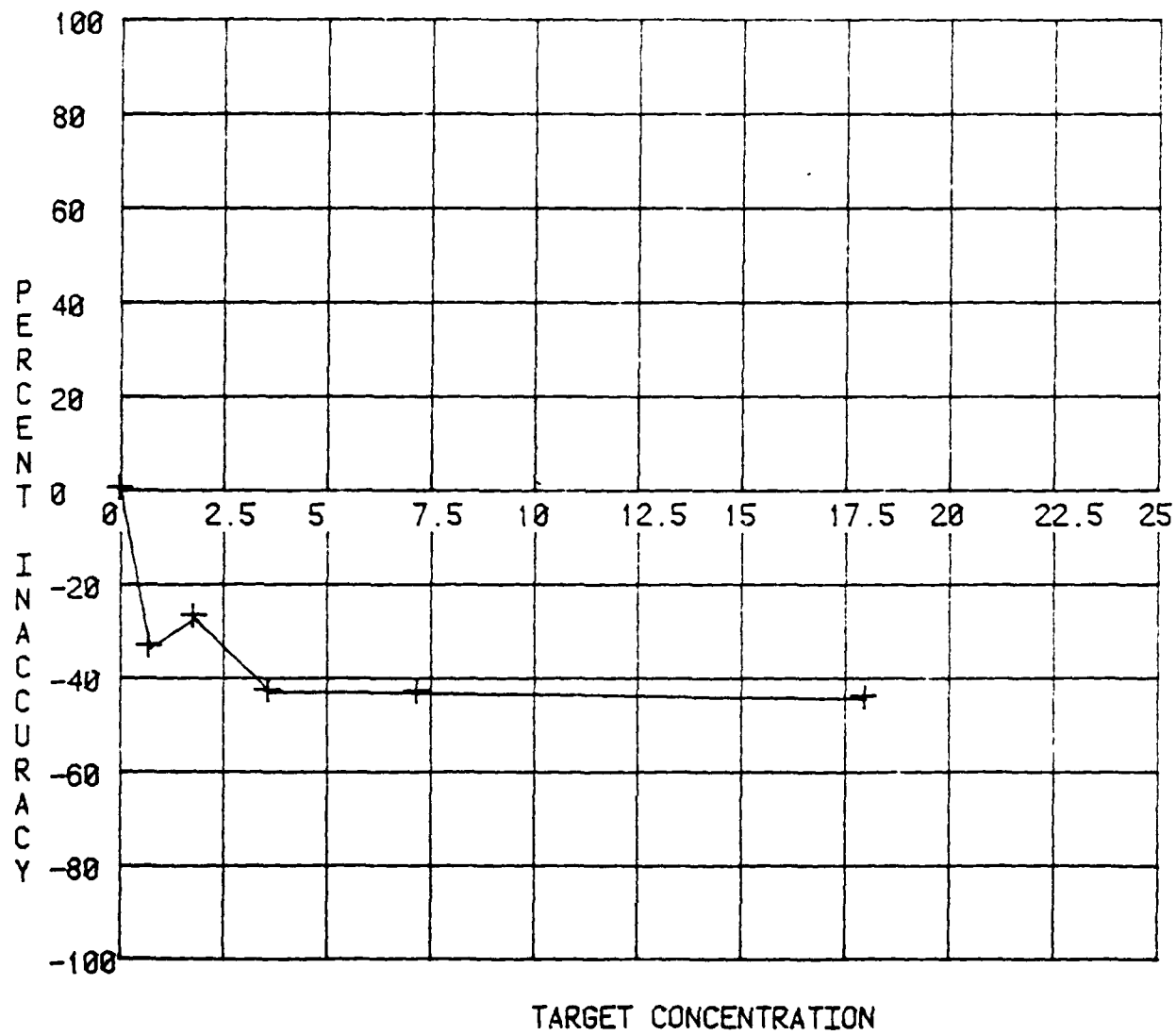
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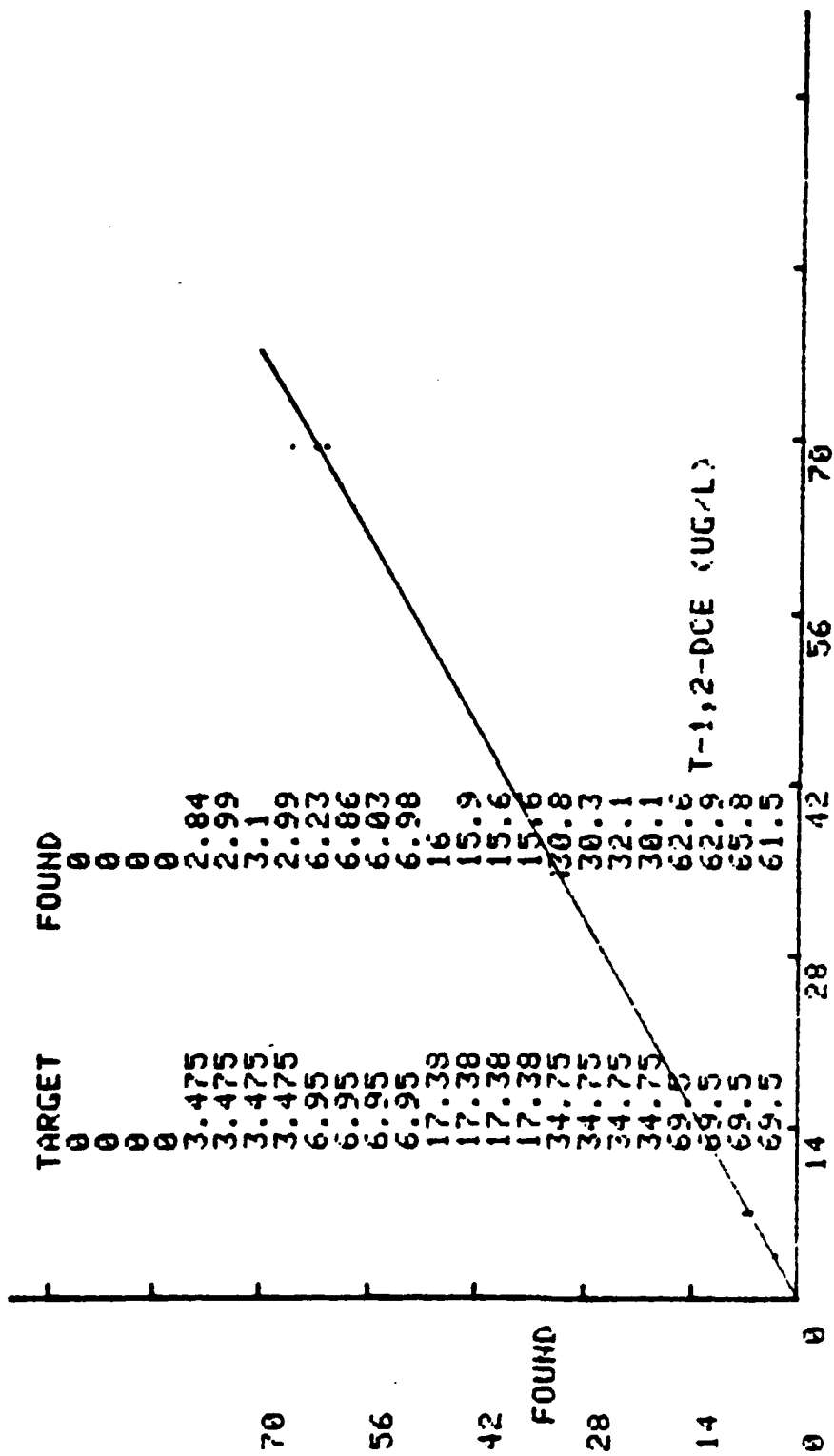
METHYLENE CHLORIDE (UG/L)



METHYLENE CHLORIDE (UG/L)



METHYLENE CHLORIDE (UG/L)



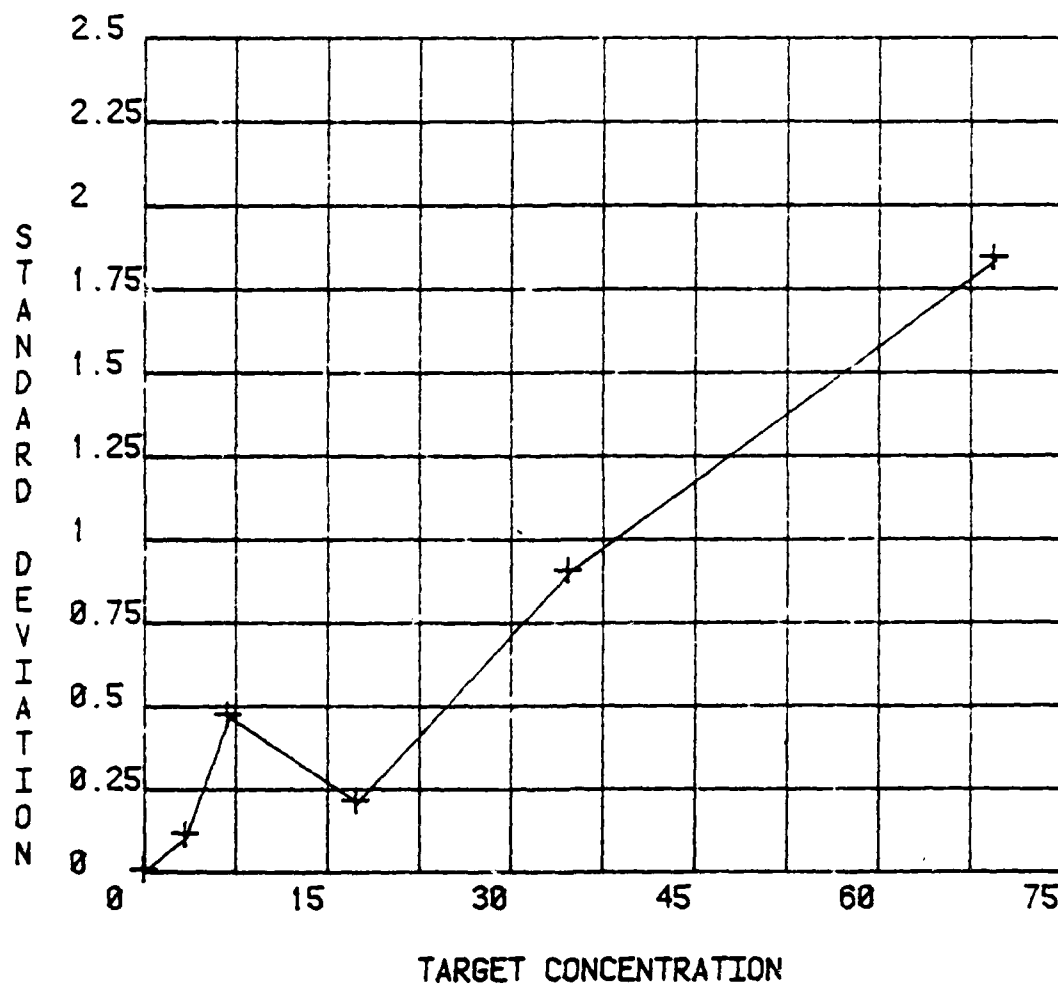
CORR. COEFF. = 0.9993 FOUND = TARGET
 DETECTION LIMIT = 3.475
 -0.0702+ 0.906637*TARGET

T-1,2-DCE (UG/L)

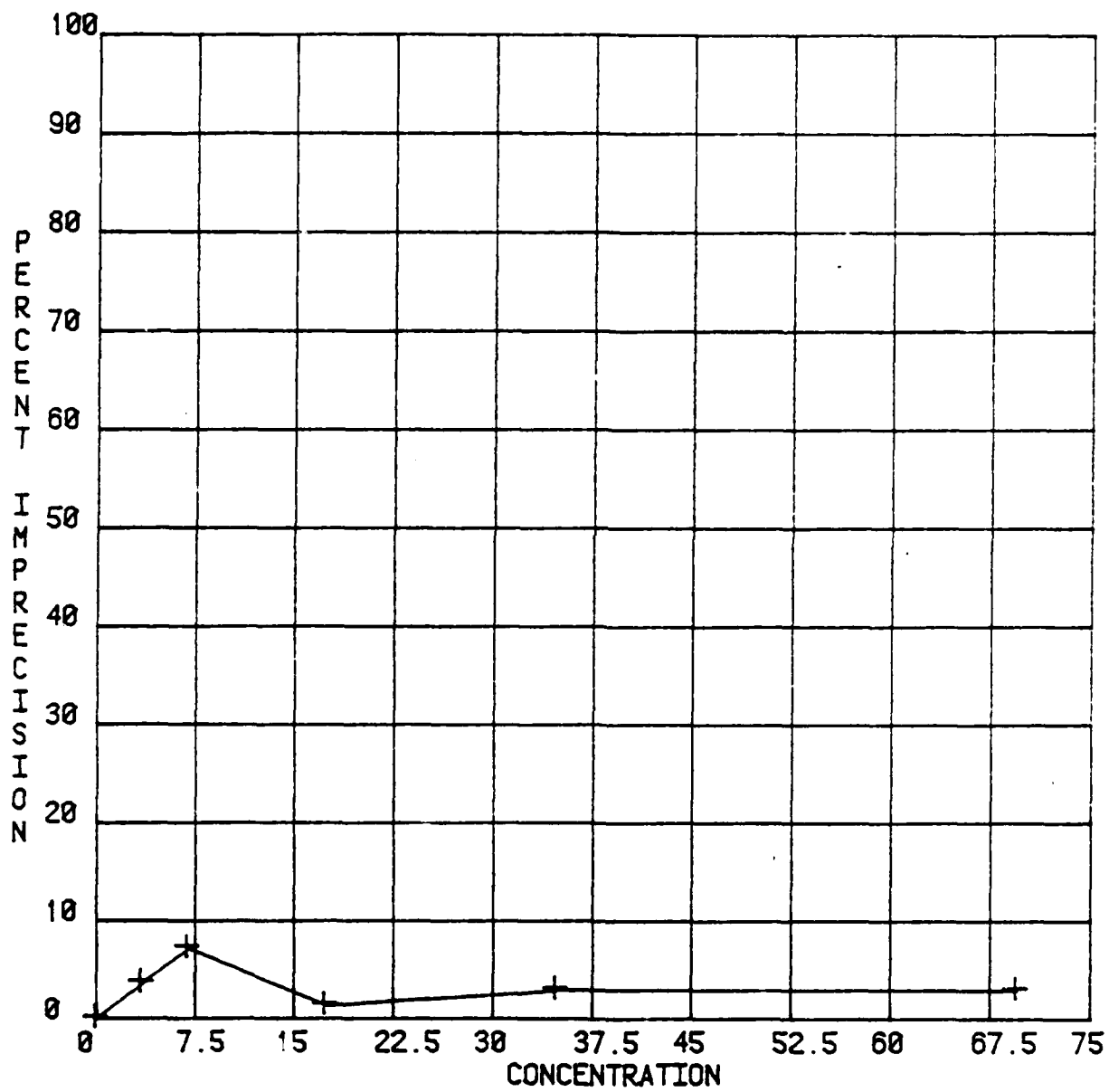
TARGET CONCENTRATION	1	DAY 2	3	4
0.0000	0.0000	0.0000	0.0000	0.0000
3.47	2.84	2.89	2.11	2.79
6.95	6.23	6.86	6.13	6.98
17.4	16.0	16.9	16.6	15.6
34.8	30.8	30.3	32.1	30.1
69.5	62.6	62.9	65.8	61.5

TARGET CONCENTRATION	AVERAGE FOUND VALUE	STANDARD DEVIATION	PERCENT IMPRECISION	PERCENT INACCURACY
0.0000	0.0000	0.0000	0.0000	0.0000
3.47	2.98	0.107	3.58	-14.2
6.95	6.52	0.466	7.14	-6.12
17.4	15.8	0.206	1.31	-9.23
34.8	30.8	0.899	2.92	-11.3
69.5	63.2	1.84	2.90	-9.06

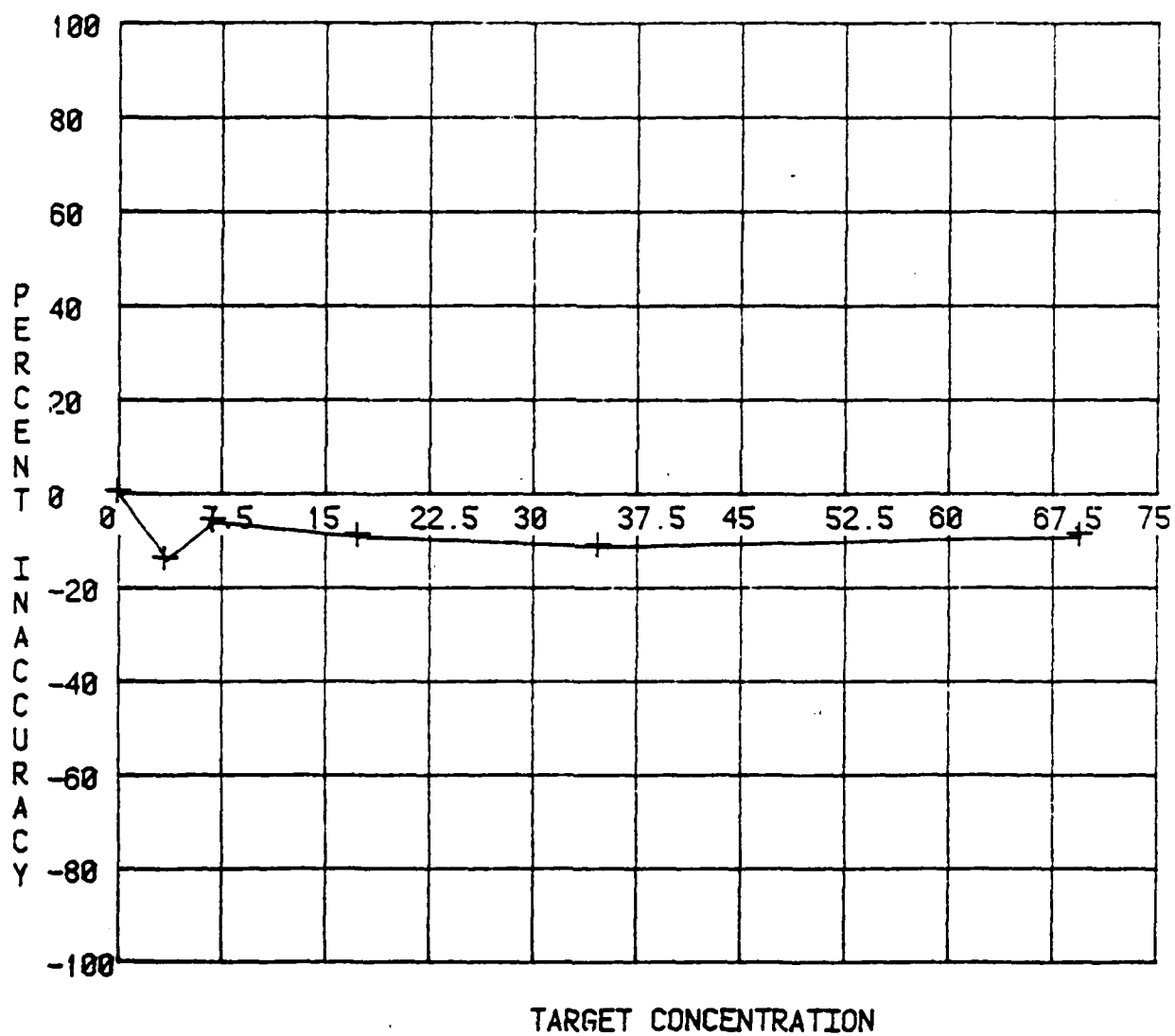
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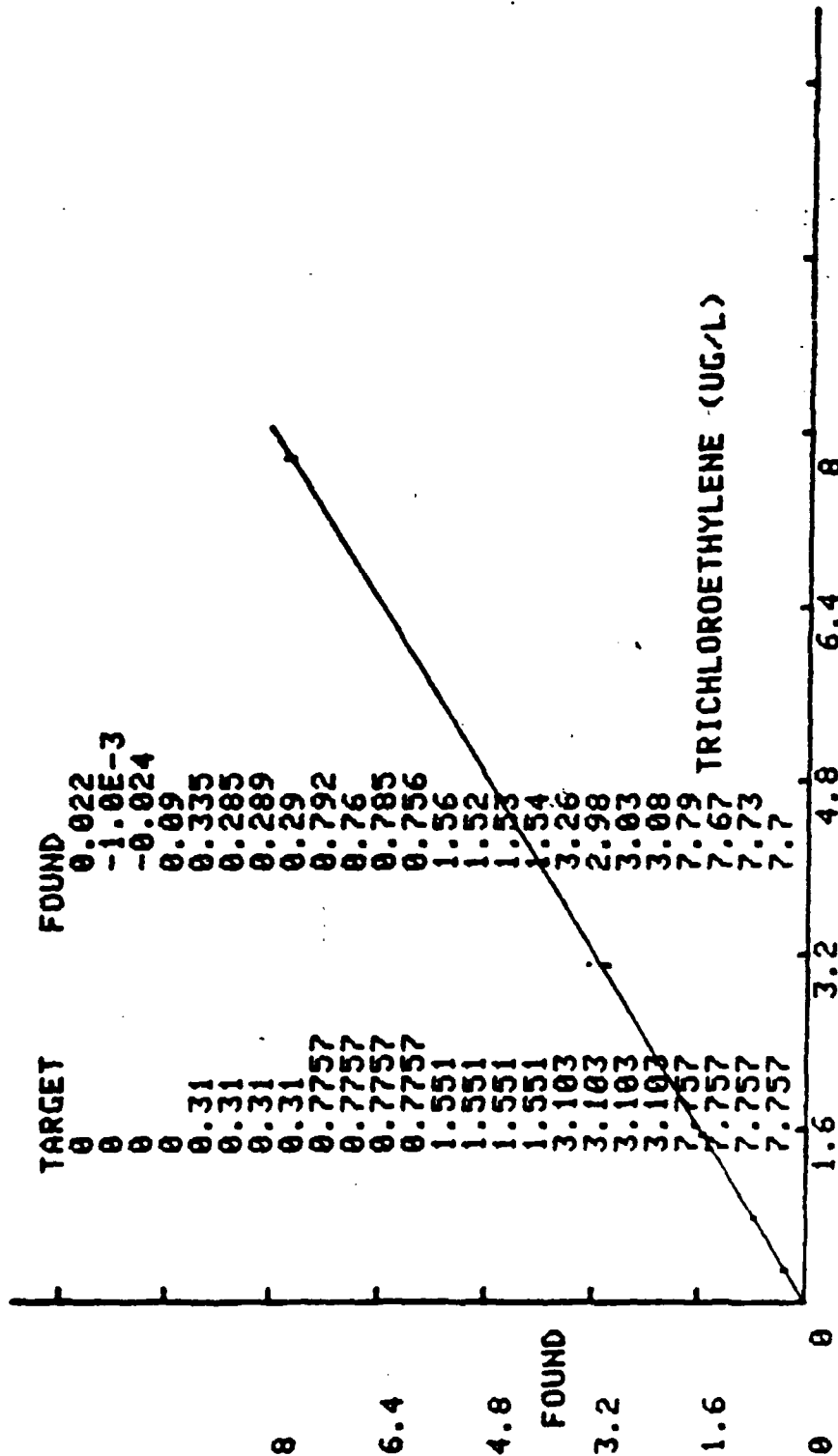
T-1,2-DCE (UG/L)



T-1,2-DCE (UG/L)



T-1,2-DCE (UG/L)

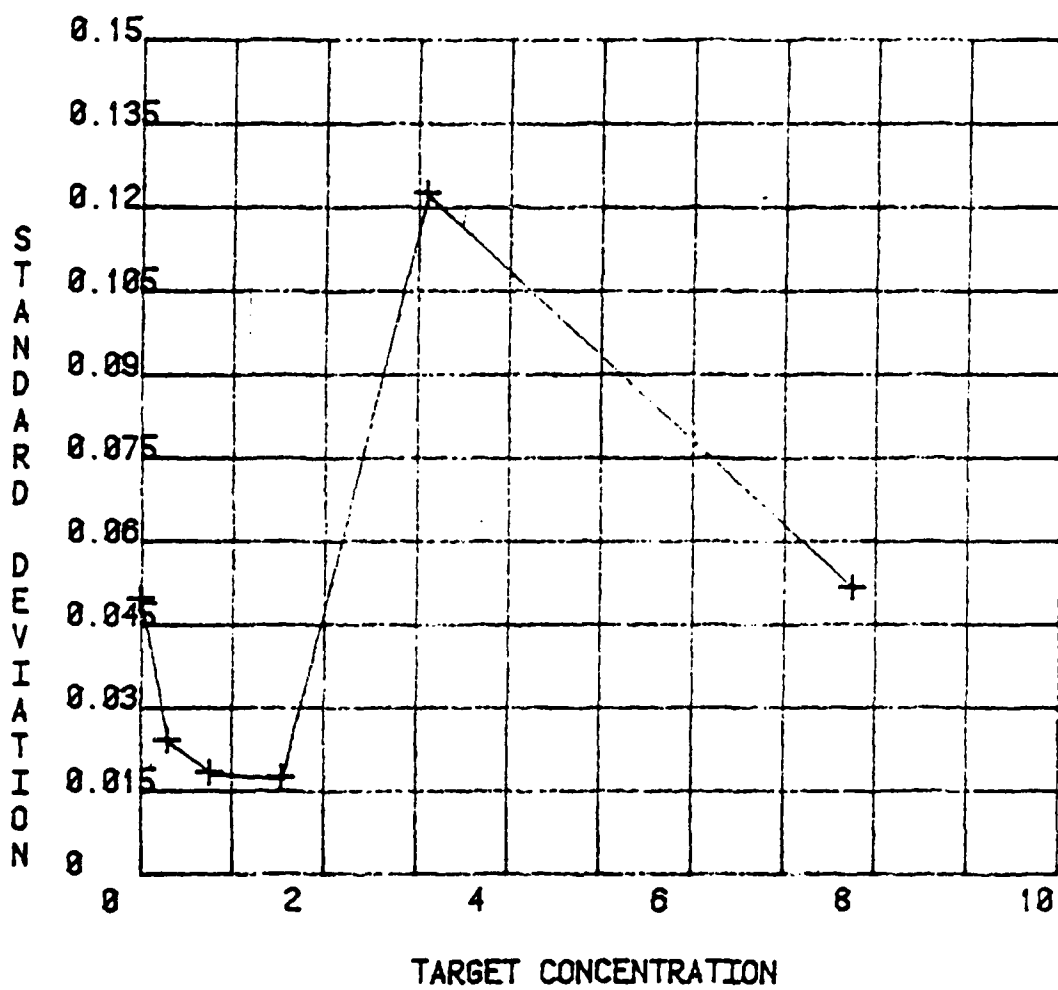


TARGET
 CORR. COEFF. = 0.9998 FOUND = 0.0025+ 0.994846*TARGET
 DETECTION LIMIT = 0.31

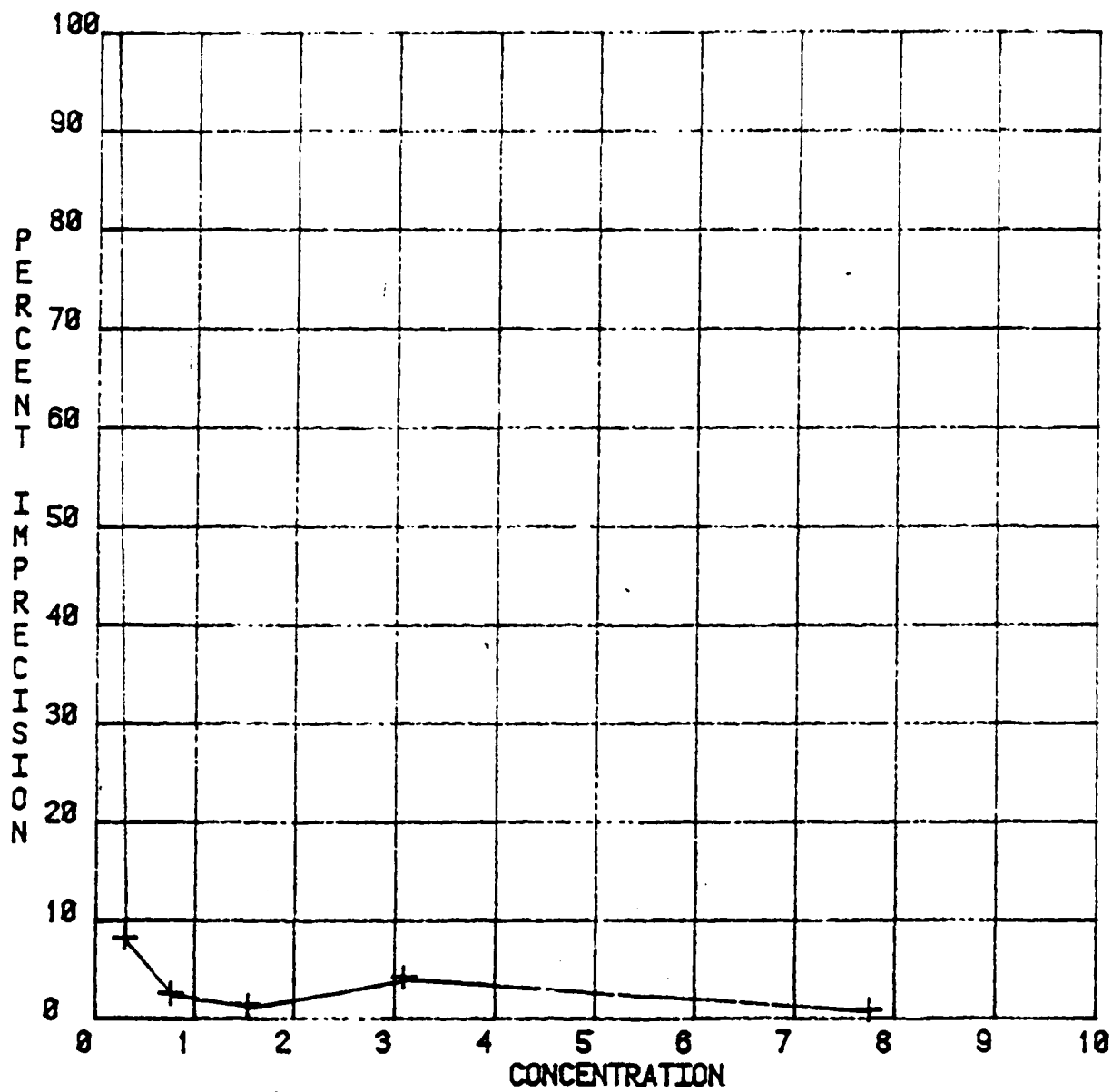
TRICHLOROETHYLENE (UG/L)

TARGET CONCENTRATION	DAY			
	2	3	4	
0.0000	0.0220	-0.0010	-0.0240	0.0000
0.310	0.335	0.285	0.285	0.280
0.776	0.792	0.760	0.785	0.756
1.55	1.56	1.52	1.53	1.54
3.10	3.26	2.98	3.03	3.08
7.76	7.79	7.67	7.73	7.70

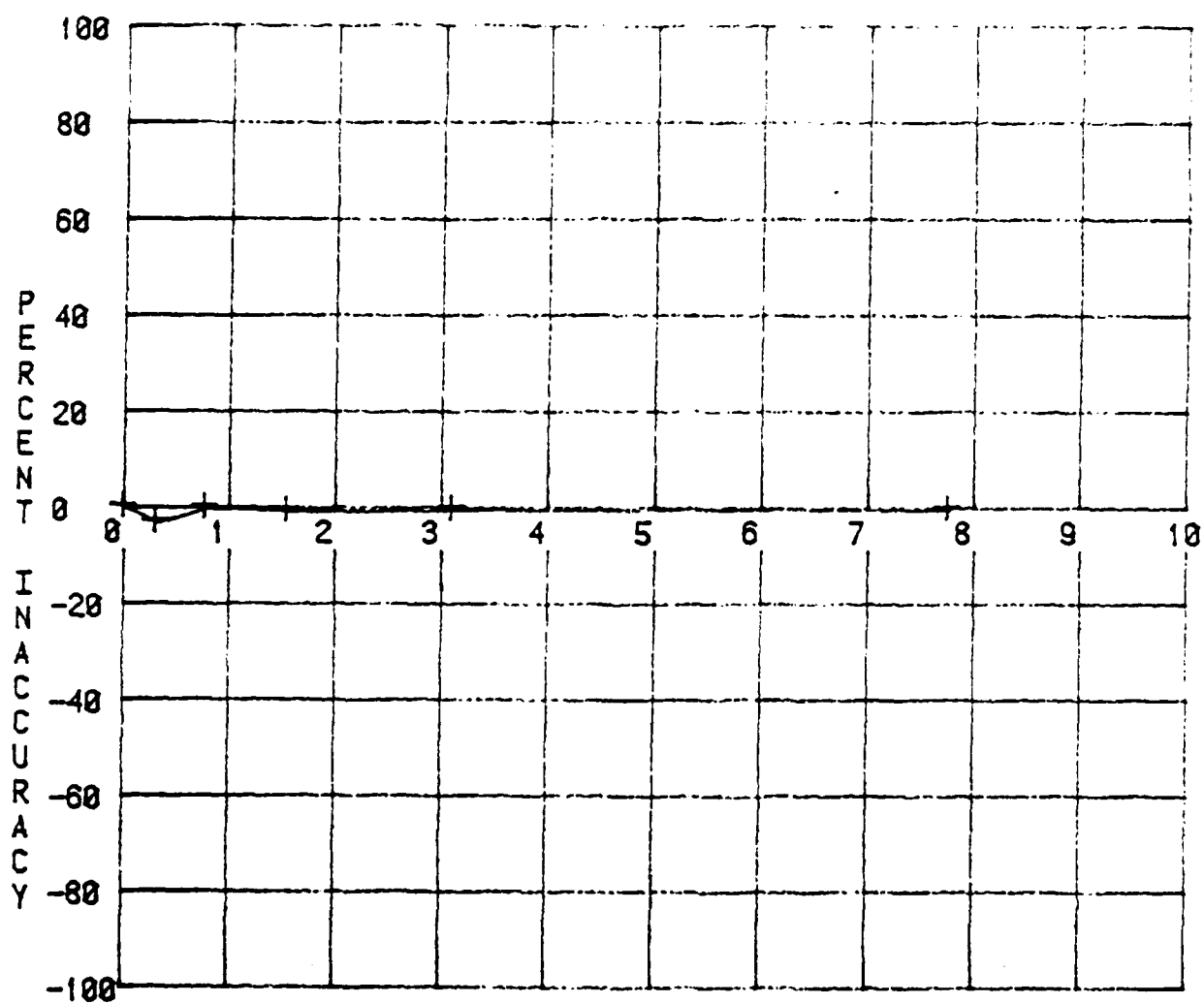
TARGET CONCENTRATION	AVERAGE FOUND VALUE	STANDARD DEVIATION	PERCENT IMPRECISION	PERCENT INACCURACY
0.0000	0.0217	0.0492	226	0.0000
0.310	0.300	0.0236	7.87	-3.31
0.776	0.773	0.0179	2.32	-0.316
1.55	1.54	0.0171	1.11	-0.870
3.10	3.09	0.122	3.95	-0.500
7.76	7.72	0.0512	0.663	-0.445



TRICHLOROETHYLENE (UG/L)



TRICHLOROETHYLENE (UG/L)



TARGET CONCENTRATION

TRICHLOROETHYLENE (UG/L)

APPENDIX C
INDIVIDUAL TEST RESULTS

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 IC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

RUN #1

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	PACKED DEPTH (FT)	ICE		
				X REM (UG/L)	CONC. (L/M-F3)(1/SEC)	KLA
256160			0.0		559.0	
256165			0.0		573.0	
256161	40.3	39.9	7.4 10.0	82.39	99.7	26.85 0.0158
256166	40.3	39.9	7.4 10.0	80.57	110.0	25.15 0.0148
256162	40.3	39.9	7.4 20.0	97.51	14.1	31.25 0.0184
256167	40.3	39.9	7.4 20.0	97.60	13.6	31.59 0.0186

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

RUN #2

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	PACKED DEPTH (FT)	ICE		
				X REM (UG/L)	CONC. (L/M-F3)(1/SEC)	KLA
256170			0.0		508.0	
256175			0.0		560.0	
256171	40.8	71.6	13.1 10.0	91.05	47.8	35.14 0.0207
256176	40.8	71.6	13.1 10.0	90.28	51.9	33.86 0.0199
256172	40.8	71.6	13.1 20.0	99.16	4.5	36.06 0.0212
256177	40.8	71.6	13.1 20.0	99.16	4.5	36.06 0.0212

RUN #3

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MCEL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIRP (GPM)	PACKED A/W (FT3/DEPTH)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256180		0.0		576.0	
256185		0.0		584.0	
256181	40.8	105.8	95.40	26.7	43.18 0.0254
256186	40.8	105.9	95.41	26.6	43.23 0.0254

RUN #4

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MCEL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIRP (GPM)	PACKED A/W (FT3/DEPTH)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256190		0.0		649.0	
256195		0.0		638.0	
256191	40.8	181	94.73	33.9	39.77 0.0234
256196	40.8	181.7	94.76	33.7	39.85 0.0235
256192	40.8	181.7	99.84	1.0	44.13 0.0260
256197	40.8	181.7	99.79	1.4	42.14 0.0248

RUN #5

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIP (GPM)	A/W PACKED AIP (FT3/DEPTH)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256230	40.4	223.0	0.0	644.0	
256205	40.4	223.0	0.0	658.0	
256201	40.4	223.0	41.3	28.0	41.73 0.0246
256206	40.4	223.0	41.3	28.6	41.44 0.0244
256202	40.4	218.0	40.4	0.9	44.28 0.0261
256207	40.4	218.0	40.4	0.8	44.75 0.0263

RUN #11C

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIP (GPM)	A/W PACKED AIP (FT3/DEPTH)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256220	19.7	120.2	0.0	603.0	
256225	19.7	120.2	0.0	601.0	
256221	19.7	120.2	45.6	21.5	21.48 0.0126
256226	19.7	120.2	45.6	21.1	21.60 0.0127

RUN #11P

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCF = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3) (FT)	A/U PACKED	Z REM	ICE		KLA (L/M-F3) (1/SEC)
				CONC. (UG/L)	KLA	
256230		0.0		658.0		
256235		0.0		712.0		
256231	19.7	99.7	37.9	10.0	95.53	30.6
256236	19.7	99.7	37.9	10.0	94.91	34.9
						20.18
						0.0119
						19.31
						0.0114

RUN #11A

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCF = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3) (FT)	A/U PACKED	Z REM	ICE		KLA (L/M-F3) (1/SEC)
				CONC. (UG/L)	KLA	
256240		0.0		576.0		
256245		0.0		566.0		
256241	19.8	60.0	22.7	10.0	93.66	36.2
256245	19.8	60.0	22.7	10.0	93.40	37.7
256242	19.8	60.1	22.7	20.0	99.41	3.4
256247	19.8	60.1	22.7	20.0	99.42	3.3
						17.58
						0.0103
						18.52
						0.0109
						18.24
						0.0107
						17.51
						0.0103
						17.58
						0.0103

RUN #1P

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIP (GPM)	A/W PACKED AIP (FT3/ DEPTH (CFM)FT3) (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256250		0.0		579.0	
256255		0.0		606.0	
256251	20.1	40.0 14.9 10.0	92.30	45.6	18.16 0.0107
256256	20.1	40.0 14.9 10.0	91.95	47.7	17.82 0.0105
256252	20.1	40.2 15.0 20.0	99.42	3.4	19.81 0.0111
256251	20.1	40.2 15.0 20.0	99.28	4.3	17.99 0.0106

RUN #9

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIP (GPM)	A/W PACKED AIP (FT3/ DEPTH (CFM)FT3) (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256260		0.0		576.0	
256265		0.0		586.0	
256261	19.9	20.1 7.6 10.0	84.84	88.1	14.49 0.0085
256266	19.9	20.1 7.6 10.0	84.34	91.0	14.21 0.0084
256262	19.9	20.0 7.5 20.0	98.06	11.3	16.49 0.0097
256257	19.9	20.0 7.5 20.0	98.00	11.6	16.37 0.0096

RUN #6

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)(FT3) (FT)	A/W PACKED DEPTH (FT)	ICE		
				X REM (UG/L)	CONC. (L/M-F3)(1/SEC)	KLA (1/SEC)
256270			0.0		606.0	
256275			0.0		633.0	
256271	40.6	40.1	7.4 10.0	85.08	92.4	30.00 0.0177
256276	40.6	40.1	7.4 10.0	85.20	91.7	30.14 0.0177
256272	40.6	40.1	7.4 20.0	98.27	10.7	34.97 0.0206
256277	40.6	40.1	7.4 20.0	98.34	10.3	35.33 0.0208

RUN #7

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)(FT3) (FT)	A/W PACKED DEPTH (FT)	ICE		
				X REM (UG/L)	CONC. (L/M-F3)(1/SEC)	KLA (1/SEC)
256280			0.0		615.0	
256285			0.0		559.0	
256281	40.6	40.3 14.8 10.0	10.0	91.43	50.3	35.09 0.0207
256286	40.6	40.3 14.8 10.0	10.0	91.60	49.3	35.39 0.0208
256282	40.6	40.3 14.8 20.0	20.0	99.39	3.6	37.68 0.0222
256287	40.6	40.3 14.8 20.0	20.0	99.44	3.3	38.31 0.0225

RUN #8

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	A/V PACKED (FT3/DEPTH)	(CFM)FT3 (FT)	ICE		
				% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256290			0.0		594.0	
256295			0.0		626.0	
256291	40.5	120.2	22.2 10.0	93.80	37.8	38.26 0.0225
256296	40.5	120.2	22.2 10.0	93.97	36.8	38.64 0.0227
256292	40.5	120.2	22.2 20.0	99.59	2.5	38.53 0.0227
256297	40.5	120.2	22.2 20.0	99.60	2.4	38.73 0.0228

RUN #12

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	A/V PACKED (FT3/DEPTH)	(CFM)FT3 (FT)	ICE		
				% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256300			0.0		1100.0	
256305			0.0		1260.0	
256301	40.1	40.2	7.5 15.0	96.54	40.8	37.25 0.0219
256306	40.1	40.1	7.5 15.0	96.54	40.8	37.28 0.0219
256302	40.1	40.1	7.5 30.0	99.66	4.1	32.94 0.0194
256307	40.1	40.1	7.5 30.0	99.64	4.2	32.68 0.0192

RUN #13

PC ICE = 0.41
 PC DCE = 0.23
 PC MECL = 0.32
 DIAMETER = 14.85 INCHES
 SPEC. AREA = 63.00 FT2/FT3
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3) (GPM)	PACKED DEPTH (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266310		0.0		1020.0	
266315		0.0		1150.0	
266321	40.1	106.8	97.71	24.8	35.00 0.0206
266316	40.1	106.8	97.21	30.3	33.04 0.0195

C-3

RUN #14

PC ICE = 0.41
 PC DCE = 0.23
 PC MECL = 0.32
 DIAMETER = 14.85 INCHES
 SPEC. AREA = 63.00 FT2/FT3
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3) (GPM)	PACKED DEPTH (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266320		0.0		930.0	
266325		0.0		917.0	
266321	40.1	160.0	98.29	15.8	36.50 0.0215
266326	40.1	160.0	98.30	15.7	36.56 0.0215

RUN #15

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCF = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3/ DEPTH	PACKED (CFM) (FT3) (FT)	ICE			KLA		
			% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)	% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)
266330		0.0		1750.0				
266325		0.0		1720.0				
266331	40.4	52.7	95.07	85.5	30.95	0.0182		
266336	40.4	52.7	95.44	79.1	31.82	0.0187		
266332	40.4	52.7	99.75	4.3	32.32	0.0190		
266337	40.4	52.7	99.75	4.3	32.34	0.0190		

RUN #16

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCF = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3/ DEPTH	PACKED (CFM) (FT3) (FT)	ICE			KLA		
			% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)	% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)
266350		0.0		1500.0				
266355		0.0		1480.0				
266351	40.4	107.0	96.70	47.8	32.02	0.0188		
266356	40.4	107.0	96.00	59.6	29.90	0.0176		
266352	40.4	107.0	99.94	0.8	35.58	0.0209		
266357	40.4	107.0	99.95	0.8	35.94	0.0212		

RUN #17

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	PACKED (CFM)	DEPTH (FT)	ICE		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266360			0.0		1630.0	
266365			0.0		1720.0	
266361	40.3	159.9	29.7	97.98	33.9	35.15 0.0207
266366	40.3	159.9	29.7	97.99	33.7	35.21 0.0207
266362	40.3	159.9	29.7	99.97	0.4	37.79 0.0222
266367	40.3	159.9	29.7	99.97	0.4	37.68 0.0222

RUN #21

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	PACKED (CFM)	DEPTH (FT)	ICE		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266400			0.0		906.0	
266405			0.0		863.0	
266401	40.1	53.1	9.9	94.84	45.6	30.13 0.0177
266406	40.1	53.1	9.9	94.84	45.6	30.13 0.0177
266402	40.1	53.2	9.9	99.75	2.2	31.85 0.0187
266407	40.1	53.2	9.9	99.79	1.9	32.69 0.0192

X REM	DCE		KLA (L/M-F3)(1/SEC)
	CONC. (UG/L)	KLA	
	152.0		
	140.0		
96.15	5.6	47.62	0.0239
96.05	5.8	40.29	0.0237

RUN #22

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM/FT3)	DEPTH (FT)	ICE		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256410	40.2	107.0	19.9	97.76	22.1	35.28
256415	40.2	107.0	19.9	97.63	23.4	34.74
256416	40.2	106.8	19.9	99.86	1.4	30.89
256417	40.2	106.8	19.9	99.86	1.4	31.03

X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
98.19	2.8*	4.70
98.10	2.9*	40.18

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RUN #23

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM/FT3)	DEPTH (FT)	ICE		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256420	40.3	159.6	29.6	98.59	13.2	38.48
256425	40.3	159.6	29.6	98.72	12.0	39.36
256426	40.3	159.6	29.6	99.94	0.5	33.55
256427	40.3	159.6	29.6	99.94	0.5	33.96

X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)

RUN #24

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) FT3 (FT)	PACKED AIR (FT3/DEPTH)	ICE			DCE		
			% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)	% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)
256430	0.0	0.0		872.0				
256435	0.0	0.0		948.0				
256441	40.3	53.0	94.98	45.7	30.61	0.0180	96.76	26.1
256446	40.3	53.0	94.67	48.5	29.95	0.0176	96.39	29.1
256452	40.3	52.9	99.82	1.6	33.94	0.0200		
256457	40.3	52.9	99.82	1.6	33.97	0.0200		

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RUN #25

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) FT3 (FT)	PACKED AIR (FT3/DEPTH)	ICE			DCE		
			% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)	% REM	CONC. (UG/L)	(L/M-F3) (1/SEC)
256440	0.0	0.0		1003.0				
256445	0.0	0.0		993.0				
256441	39.8	106.8	97.59	24.1	34.19	0.0201	98.21	15.9
256446	39.8	106.8	97.52	24.8	33.92	0.0200	98.08	17.0
256442	39.8	107.1	99.95	0.5	35.39	0.0208		
256447	39.8	107.1	99.95	0.5	35.49	0.0209		

RUN #26

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3)	PACKED DEPTH (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256450		0.0		877.0	
256455		0.0		849.0	
256451	39.9	160.6	30.1	12.1	38.11 0.0224
256456	39.9	160.6	30.1	11.2	38.81 0.0228

% REM	DCE	
	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
	810.0	
	805.0	
98.86	9.2	42.28 0.0249
99.00	9.0	43.59 0.0257

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RUN #27

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3)	PACKED DEPTH (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256460		0.0			
256465		0.0			
256461	40.0	52.9	9.9	15.0	
256466	40.0	52.9	9.9	15.0	
256462	40.0	52.8	9.9	30.0	
256467	40.0	52.8	9.9	30.0	

% REM	DCE	
	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
	927.0	
	952.0	
96.10	36.6	40.57 0.0239
96.34	34.4	41.28 0.0243

RUN #20

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3)	PACKED DEPTH (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256470		0.0			
266475		0.0			
256471	40.0	107.4	20.1	15.0	
266476	40.0	107.4	20.1	15.0	
266472	40.0	107.4	20.1	30.0	
266477	40.0	107.4	20.1	30.0	

% REM	DCE		
	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	KLA
	741.0		
	681.0		
98.14	15.2	40.14	0.0236
98.03	14.0	39.51	0.0233

RUN #29

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFM) (FT3)	PACKED DEPTH (FT)	ICE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256480		0.0			
266485		0.0			
256481	39.9	159.7	29.9	15.0	
266486	39.9	159.7	29.9	15.0	
266482	39.9	159.7	29.9	30.0	
266487	39.9	159.7	29.9	30.0	

% REM	DCE		
	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	KLA
	729.0		
	800.0		
98.86	8.7	42.34	0.0249
98.91	8.3	42.75	0.0252

RUN #16R

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	PACKED DEPTH (FT)	ICE		
				% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
275040			0.0		2123.0	
275045			0.0		1834.0	
275041	39.8	107.3	20.2	97.33	52.9	33.21 0.0195
275046	39.8	107.3	20.2	98.04	38.8	36.15 0.0213
275042	39.8	107.3	20.2	99.94	1.2	34.41 0.0203
275047	39.8	107.3	20.2	99.94	1.2	34.57 0.0203

RUN #17R

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	PACKED DEPTH (FT)	ICE		
				% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
275050			0.0		1750.0	
275055			0.0		1059.0	
275051	40.0	160.4	30.0	98.23	24.9	36.04 0.0212
275056	40.0	160.4	30.0	98.74	17.7	39.19 0.0231
275052	40.0	160.2	30.0	99.98	0.3	37.64 0.0222
275057	40.0	160.2	30.0	99.97	0.4	36.79 0.0217

RUN #18

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPFC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

A/N PACKED
 SAMPLE WATER AIR (FT3/ DEPTH
 NUMBER (GPM) (CFM) (FT3) (FT)

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	DEPTH (FT)	ICE			DCE		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256370			0.0		793.0				15.0
256375			0.0		873.0				20.3
256371	40.3	52.7	9.8 15.0	94.49	45.9	29.62	0.0174		
256376	40.3	52.7	9.8 15.0	94.57	45.2	29.79	0.0175		
256372	40.3	52.7	9.8 30.0	99.72	2.4	31.43	0.0185		
256377	40.3	52.7	9.8 30.0	99.73	2.2	31.75	0.0187		

RUN #18R

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPFC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

A/N PACKED
 SAMPLE WATER AIR (FT3/ DEPTH
 NUMBER (GPM) (CFM) (FT3) (FT)

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	DEPTH (FT)	ICE			DCE		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
275060			0.0		1080.0				84.1
275065			0.0		817.0				76.2
275061	40.0	52.3	9.8 15.0	94.92	48.2	30.29	0.0178		
275055	40.0	52.3	9.8 15.0	94.70	50.3	29.82	0.0176		
275062	40.0	52.3	9.8 30.0	99.87	1.2	35.52	0.0209		
275057	40.0	52.3	9.8 30.0	99.77	2.2	32.29	0.0190		

RUN #19

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM) (CFM) (FT3)	PACKED DEPTH (FT)	ICE		
			X REM	CONC. (UG/L)	KLA (L/M-F3) (1/SEC)
256380		0.0		850.0	
266385		0.0		738.0	
256381	40.3	107.5	97.34	21.1	33.72 0.0198
256386	40.3	107.5	97.38	20.8	33.86 0.0199

X REM	DCE	
	CONC. (UG/L)	KLA (L/M-F3) (1/SEC)
	19.6	
	19.6	

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RUN #19R

PC TCF = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM) (CFM) (FT3)	PACKED DEPTH (FT)	ICE		
			X REM	CONC. (UG/L)	KLA (L/M-F3) (1/SEC)
275070		0.0		960.0	
275075		0.0		914.0	
275071	40.1	106.8	97.65	22.0	34.74 0.0204
275076	40.1	106.8	98.75	11.7	40.78 0.0240
275072	40.1	106.6	99.96	0.4	36.95 0.0217
275077	40.1	106.6	99.96	0.4	36.82 0.0217

X REM	DCE	
	CONC. (UG/L)	KLA (L/M-F3) (1/SEC)
	95.0	
	95.8	

RUN #20

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	PACKED AIR (FT3/DEPTH (CFM)FT3) (FT)	ICE			DCE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256390		0.0		805.0				22.9
256395		0.0		546.0				14.2
256391	40.1	160.2	98.43	10.6	37.29			
256396	40.1	160.2	98.78	8.2	39.62			
		15.0			0.0219			
		15.0			0.0233			

1. RUN #30

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	PACKED AIR (FT3/DEPTH (CFM)FT3) (FT)	ICE			MECL		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256490		0.0		1022.0			40.2	
256495		0.0		1054.0			38.9	
256491	39.8	52.9	96.11	40.4	32.94	54.63	17.9	7.23
256496	39.8	52.9	96.08	40.7	32.86	60.46	15.6	8.73
256492	39.8	52.9	99.82	1.9	33.38	82.08	7.1	8.65
256497	39.8	52.9	99.82	1.9	33.38	81.06	7.5	8.34
		30.0			0.0196			0.0051
		30.0			0.0196			0.0049

RUN #31

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPH)	AIR (CFM)	DEPTH (FT)	A/W PACKED	ICE			MECL		
					X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266500				0.0		1009.0			49.1	
266505				0.0		1007.0			43.6	
266501	39.8	107.4	20.2	15.0	97.95	20.7	35.71	96.07	1.8	30.38
266506	39.8	107.4	20.2	15.0	97.97	20.5	35.80	96.59	1.6	31.77
266502	39.8	107.3	20.2	30.0	99.96	0.4	36.24			
266507	39.8	107.3	20.2	30.0	99.96	0.4	36.24			

RUN #32

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPH)	AIR (CFM)	DEPTH (FT)	A/W PACKED	ICE			MECL		
					X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266510				0.0		973.0			39.7	
266515				0.0		917.0			34.0	
266511	40.1	160.4	29.9	15.0	98.58	13.4	38.21			
266516	40.1	160.4	29.9	15.0	98.54	13.8	37.95			
266512	40.1	160.4	29.9	30.0	99.96	0.3	35.93			
266517	40.1	160.4	29.9	30.0	99.96	0.4	35.54			

RUN #33

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFH) (FT3)	A/M PACKED (FT3/DEPTH)	ICE			MECL		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256520		0.0		1009.0			108.0	
256525		0.0		1038.0			103.0	
256521	40.1	53.0	95.30	48.1	31.16	78.20	23.0	15.24
256526	40.1	53.0	95.36	47.5	31.29	78.96	22.2	15.64
256522	40.1	52.8	99.77	2.4	32.32	97.45	2.7	20.33
256527	40.1	52.8	99.78	2.2	32.66	96.88	3.3	19.10

RUN #34

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (CFH) (FT3)	A/M PACKED (FT3/DEPTH)	ICE			MECL		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256530		0.0		947.0			89.9	
256535		0.0		940.0			97.0	
256531	40.1	106.8	97.73	21.4	35.07	96.25	3.5	31.12
256536	40.1	106.8	97.81	20.7	35.39	95.66	4.0	29.67
256532	40.1	106.6	99.95	0.5	35.54			
256537	40.1	106.6	99.94	0.6	34.99			

RUN #35

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE WATER NUMBER (GPH)	A/W PACKED AIR (FT3/ DEPTH (CFM)/FT3) (FT)	ICE		MECL	
		% REM	CONC. (UG/L)	% REM	CONC. (UG/L)
266540	0.0		938.0		88.4
266545	0.0		1036.0		101.0
266541	40.3 159.6 29.6 15.0	98.55	14.3	97.86	2.0
266546	40.3 159.6 29.6 15.0	98.36	16.2	97.57	2.3
					35.32 0.0208
					34.09 0.0201

RUN #36

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE WATER NUMBER (GPH)	A/W PACKED AIR (FT3/ DEPTH (CFM)/FT3) (FT)	ICE		MECL	
		% REM	CONC. (UG/L)	% REM	CONC. (UG/L)
266550	0.0		1114.0		195.0
266555	0.0		1093.0		189.0
266551	40.0 53.1 9.9 15.0	95.51	49.5	73.18	51.5
266556	40.0 53.1 9.9 15.0	95.74	47.0	73.39	51.1
266552	40.0 53.1 9.9 30.0	99.83	1.9	95.13	9.4
266557	40.0 53.1 9.9 30.0	99.82	2.0	94.43	10.7
					12.91 0.0076
					12.99 0.0076
					16.32 0.0096
					15.52 0.0091

RUN #37

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (FT3/ DEPTH (CFM)FT3) (FT)	A/V PACKED	ICE			MECL		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266560	0.0			1034.0			190.0	
266565	0.0			1038.0			190.0	
266561	40.0 106.6 19.9 15.0		97.89	21.9	35.66 0.0210	91.58	16.0	23.08 0.0136
266566	40.0 106.6 19.9 15.0		97.61	24.8	34.47 0.0203	91.26	16.6	22.72 0.0134
266562	40.0 106.6 19.9 30.0		99.96	0.4	36.61 0.0215			
266567	40.0 106.6 19.9 30.0		99.96	0.4	37.20 0.0219			

RUN #38

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (FT3/ DEPTH (CFM)FT3) (FT)	A/V PACKED	ICE			MECL		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266570	0.0			1174.0			214.0	
266575	0.0			977.0			213.0	
266571	39.8 107.4 20.2 15.0		99.08	9.9	43.31 0.0255	93.02	14.9	24.77 0.0146
266576	39.8 107.4 20.2 15.0		99.70	14.0	40.03 0.0236	92.51	16.0	24.07 0.0142

RUN #39

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM/FT3)	A/W PACKED DEPTH (FT)	ICE			MECL		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266580			0.0					173.0	
266585			0.0					193.0	
266591	39.8	52.8	9.9 15.0				75.74	44.4	13.94 0.0082
266596	39.8	52.8	9.9 15.0				78.14	40.0	15.09 0.0089
266592	39.8	52.8	9.9 30.0				93.61	11.7	14.63 0.0086
266597	39.8	52.8	9.9 30.0				92.46	13.8	13.66 0.0080

RUN #40

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM/FT3)	A/W PACKED DEPTH (FT)	ICE			MECL		
				X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	X REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266590			0.0					225.0	
266595			0.0					227.0	
266591	40.0	107.3	20.1 15.0				92.08	17.9	23.67 0.0139
266596	40.0	107.3	20.1 15.0				92.04	18.0	23.61 0.0139
266592	40.0	107.3	20.1 30.0				99.36	1.4	24.26 0.0143
266597	40.0	107.3	20.1 30.0				99.30	1.6	23.80 0.0140

RUN #41

PC ICE = 0.41 DIAMETER = 14.85 INCHES
PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
PC MECL = 3.32
VISCOSITY = 0.95 CP
DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	PACKED AIR (FT3/DEPTH (CFM)/FT3) (FT)	ICE			MECL		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256600		0.0					194.0	
256605		0.0					192.0	
256601	40.1	159.6 29.8 15.0				95.09	9.5	27.34 0.0161
256606	40.1	159.6 29.8 15.0				94.89	9.9	26.96 0.0159
256602	40.1	159.6 29.8 30.0						
256507	40.1	159.6 29.8 30.0						

RUN #42

PC ICE = 0.41 DIAMETER = 14.85 INCHES
PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
PC MECL = 0.32
VISCOSITY = 0.95 CP
DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (GPM)	PACKED AIR (FT3/DEPTH (CFM)/FT3) (FT)	ICE			MECL			DCE		
			% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
256616		0.0		1158.0			207.0			965.0	
256615		0.0		1075.0			201.0			950.0	
256511	40.1	52.7 9.8 15.0	94.82	57.8	30.13 0.0177	70.00	61.2	11.74 0.0069	95.82	40.0	39.58 0.0233
256616	40.1	52.7 9.8 15.0	96.65	37.4	34.93 0.0206	73.92	53.2	13.27 0.0076	97.02	28.5	44.55 0.0262
256512	40.1	52.6 9.8 30.0	99.87	1.5	35.42 0.0208	93.82	12.6	15.00 0.0088			
256617	40.1	52.6 9.8 30.0	99.82	2.1	33.64 0.0198	93.82	12.6	15.00 0.0088			

RUN #43

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	A/W PACKED WATER AIR (FT3/ DEPTH (CFM)FT3) (FT)	ICE			MECL			DCE		
		% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
266620	0.0		787.0			195.0			732.0	
266625	0.0		976.0			197.0			862.0	
266621	39.7 107.7 20.3 15.0	97.87	18.0	35.24	94.18	11.4	26.46	98.44	12.4	41.62
266626	39.7 107.7 20.3 15.0	96.72	28.9	31.19	94.59	10.6	27.17	98.16	14.7	39.82
266622	39.7 107.7 20.3 30.0	99.93	0.6	33.61						0.0234
266527	39.7 107.7 20.3 30.0	99.94	0.5	34.87						

RUN #44

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	A/W PACKED WATER AIR (FT3/ DEPTH (CFM)FT3) (FT)	ICE			MECL			DCE		
		% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)	% REM	CONC. (UG/L)	KLA (L/M-F3)(1/SEC)
275000	0.0		1077.0			182.0			865.0	
275005	0.0		984.0			100.0			835.0	
275001	39.7 160.5 30.2 15.0	98.60	14.4	37.94	95.94	7.6	28.78	98.79	10.3	41.45
275006	39.7 160.5 30.2 15.0	98.72	13.2	38.73	95.00	9.3	26.87	98.96	8.9	42.91

RUN #45

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	PACKED DEPTH (FT)	ICE		
				X REM (UG/L)	CONC. (L/M-F3)	KLA (1/SEC)
275010			0.0		772.0	
275015			0.0		1051.0	
275011	40.0	52.9	9.9 15.0	95.01	45.5	30.41 0.0179
275016	40.0	52.9	9.9 15.0	95.80	38.3	32.30 0.0190
275012	40.0	52.8	9.9 30.0	99.81	1.7	33.48 0.0197
275017	40.0	52.8	9.9 30.0	99.81	1.7	33.41 0.0197

RUN #46

PC TCE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER (GPM)	AIR (CFM)	PACKED DEPTH (FT)	ICE		
				X REM (UG/L)	CONC. (L/M-F3)	KLA (1/SEC)
275020			0.0		657.0	
275025			0.0		1044.0	
275021	40.0	107.7	20.0 15.0	97.79	18.8	35.22 0.0207
275026	40.0	107.0	20.0 15.0	97.60	20.4	34.44 0.0203

RJN #47

PC ICE = 0.41 DIAMETER = 14.85 INCHES
 PC DCE = 0.23 SPEC. AREA = 63.00 FT2/FT3
 PC MECL = 0.32
 VISCOSITY = 0.95 CP
 DENSITY = 1.00 GM/CC

SAMPLE NUMBER	WATER AIR (FT3/DEPTH (CFM) (FT3) (FT)	A/W PACKED	ICE		KLA	KLA
			X REM	CONC.		
			(UG/L)	(L/M-F3)(1/SEC)		
275030		0.0	711.0			
275035		0.0	853.0			
275031	39.6 159.3 30.1 15.0		98.88	8.8	39.83	0.0234
275036	39.6 159.3 30.1 15.0		98.70	10.2	38.48	0.0226

APPENDIX D

FORMS OF HENRY'S LAW CONSTANT

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AIR STRIPPING PILOT STUDY OF VOC (VOLATILE ORGANIC
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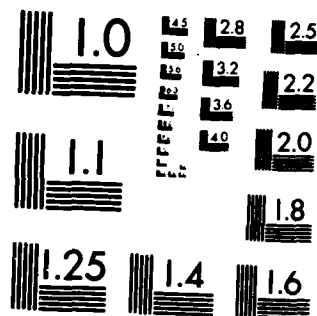
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APPENDIX D

FORMS OF HENRY'S LAW CONSTANT

Two common forms of Henry's Law for which Henry's Constant has been tabulated are:

$$p_a = H_1 x_a \quad \text{Ia} \qquad p_a = H_2 [Ca] \quad \text{IIa}$$

$$y_a = \frac{H_1}{P_t} x_a \quad \text{Ib} \qquad y_a = \frac{H_2}{P_t} [Ca] \quad \text{IIb}$$

where: p_a = partial pressure of a in atmospheres
 x_a = mole fraction of a in liquid phase
 $[Ca]$ = molar concentration of a (in kg-moles/m³)
 y_a = mole fraction of a in gas phase
 P_t = total pressure in atmospheres
 H_1 = proportionality constant with units of atmospheres
 H_2 = proportionality constant with units of (atmospheres-m³/kg-mole)

If ambient conditions are such that the density of air can be approximated by 1.2 kg/m³ (0.0416 kg-mole/m³) and the density of water can be approximated by 1,000 kg/m³ (55.5 kg-moles/m³), then H_1 and H_2 are related by:

$$H_1 = 55.5 \left(\frac{\text{kg-mole}}{\text{m}^3} \right) H_2 \text{ (dilute solutions)}$$

H_1 and H_2 are related to the dimensionless partition coefficient β defined as $\beta \equiv V_a/C_a$,

where: V_a = concentration in air (mg/m³), and

C_a = concentration in water (mg/m³), as follows:

$$\beta = H_1 (\text{atm}) \left[\frac{1}{P_t (\text{atm})} \right] \left[\frac{1 \text{ m}^3}{55.5 \text{ kg-moles water}} \right] \left[\frac{0.0416 \text{ kg-mole air}}{\text{m}^3} \right]$$

$$\beta = H_2 \left[\frac{\text{atm-m}^3}{\text{kg-moles}} \right] \left[\frac{1}{P_t (\text{atm})} \right] \left[\frac{0.0416 \text{ kg-mole air}}{\text{m}^3 \text{ air}} \right]$$

when the total pressure is 1 atm:

$$\beta = 0.00075 H_1 \qquad \beta = 0.0416 H_2$$

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