FINAL REPORT

POTABLE WATER TREATABILITY STUDY
NAVAL AIR STATION, WILLOW GROVE

CONTRACT NO. N62472-84-C-1226

PREPARED FOR:
NORTHERN DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
BUILDING 77L
U.S. NAVAL BASE
PHILADELPHIA, PENNSYLVANIA 19112

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EXECUTIVE SUMMARY

THE FOLLOWING REPORT PROVIDES CONCEPTUAL DESIGN CRITERIA WHICH WHEN IMPLEMENTED WILL ALLOW REMOVAL OF VOLATILE ORGANIC CHEMICALS FROM THE POTABLE WATER SUPPLIES AT WILLOW GROVE NAVAL AIR STATION. PREVIOUSLY SUBMITTED SUMMARY REPORTS ON WATER QUALITY AND TREATMENT ALTERNATIVES ARE INCLUDED AS APPENDICES. A REVIEW OF ALTERNATIVE WATER SUPPLIES IS ALSO PROVIDED IN APPENDIX FORM. THIS REPORT FULFILLS THE OBLIGATIONS OF PSC WATER SERVICES, INC., AS A SUBCONTRACTOR TO EARTH DATA, INC., OF WEST CHESTER, PENNSYLVANIA, FOR NAVY CONTRACT N62472-84-C-1226.

PACKED TOWER AERATION IS RECOMMENDED AS THE MOST COST-EFFECTIVE TREATMENT ALTERNATIVE FOR POTABLE WATER TREATMENT AT THE WILLOW GROVE NAVAL AIR STATION. THIS REPORT IS DIVIDED INTO FIVE SECTIONS. THE FIRST SECTION PROVIDES A GENERAL INTRODUCTION TO THE STUDY. THE SECOND DESCRIBES PACKED TOWER AERATION PROCESSES FOR TREATMENT OF POTABLE WATER. THE THIRD SECTION ADDRESSES DESIGN CRITERIA FOR IMPLEMENTATION OF PACKED TOWER AERATION AT WILLOW GROVE. THE FOURTH SECTION EVALUATES THE POSSIBLE IMPACTS AIR STRIPPING WOULD HAVE ON AIR QUALITY. THE FINAL SECTION PROVIDES A GENERAL SUMMARY FOR THE PROJECT.

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A. Water Quality Considerations
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1.0 INTRODUCTION

1.1 Project Description

This report presents the analyses, findings, and conclusions for the Treatability Study portion of the overall investigation into the contamination of the potable water supply at the Willow Grove Naval Air Station. The project is a two-part effort to determine the cause and resolution of the contamination problem.

The Naval Air Station at Willow Grove, Pennsylvania, receives its potable water supply from three on-site wells. These wells have become contaminated with volatile organic compounds trichloroethene and tetrachloroethene (TCE and PCE). The goal is to provide water to the facility having low enough concentrations of volatile organic contaminants to be considered potable according to EPA standards. This study has grown out of that desire and encompasses a comprehensive investigation of two primary but interrelated phases -- the Hydrogeologic Investigation and the Treatability Study.

The Hydrogeologic Investigation, issued separately as the Hydrogeologist's Report, is a comprehensive endeavor to characterize the hydraulic characteristics of groundwater within the Stockton Formation sandstones which comprise the aquifer being tapped by the three wells. The Hydrogeologist's Report provides the basic information for the subsequent comparisons and recommendations for potential contaminant source clean up activities. The Treatability Study provided herein focused on the determination of the optimum treatment method for removal of the volatile organics from the groundwater supply derived from the three wells.

1.2 SITE DESCRIPTION

A COMPLETE DISCUSSION ON THE CHARACTERISTICS OF THE SITE, INCLUDING THE EXISTING WELLS, IS CONTAINED IN THE HYDROGEOLOGIST'S REPORT. THE REPORT ALSO DISCUSSES THE CONDITION AND NATURE OF THE THREE EXISTING POTABLE WATER SUPPLY WELLS.

1.3 NATURE OF CONTAMINATION

IN THE FALL OF 1979, TRACE LEVELS OF VOLATILE HALOGENATED ORGANICS (VOCS) WERE DETECTED IN THE POTABLE WATER SUPPLIES OF THE WILLOW GROVE NAVAL AIR STATION. EXTENSIVE TESTING DURING THIS STUDY HAS CONFIRMED THAT THESE ORGANICS ARE THE ONLY SIGNIFICANT WATER QUALITY CONCERN AT THE NAVAL AIR STATION.

TABLE 1.1 LISTS THE SPECIFIC ORGANIC CHEMICALS ALONG WITH THE OBSERVED CONCENTRATION RANGES (IN PPB) FOR EACH SPECIES BY LOCATION. THE HISTORICAL DATA BASE WHICH IS SUMMARIZED IN TABLE 1.1 WAS INCLUDED IN TABLES 9 THROUGH 11 AND APPENDIX D OF THE "HYDROGEOLOGIST'S REPORT: POTABLE WATER TREATABILITY STUDY - WILLOW GROVE NAVAL AIR STATION".

TABLE 1.1
OBSERVED RANGES FOR VOLATILE ORGANIC CHEMICALS
WILLOW GROE NAVAL AIR STATION (PPB)

CHEMICAL	LOCATION		
	NAVY WELL #1	NAVY WELL #2	AIR FORCE WELL
TETRACHLOROETHENE (PCE)	ND - 92.4	ND - 49.1	ND - 9.4
TRICHLOROETHENE (TCE)	ND - 66.7	ND - 44.7	ND - 23.7
1,1,1-TRICHLOROETHANE	ND - 6.1	ND - 2.8	ND - 6.1
1,2-DICHLOROETHENE*	4.1	0.8	0.3
1,1-DICHLOROETHENE*	0.6	0.1	0.1
1,1-DICHLOROETHANE*	0.5	0.2	0.4
CARBON TETRACHLORIDE*	0.5	0.4	0.5

* - DETECTED DURING CURRENT STUDY
ND - NONE DETECTED

TRICHLOROETHENE (TCE) AND TETRACHLOROETHENE (PCE) ARE SHOWN TO BE THE MAJOR CONTAMINANTS AND HISTORICALLY NEITHER HAS BEEN DETECTED AT A CONCENTRATION EXCEEDING 100 MICROGRAMS PER LITER OF WATER (UG/L OR PPB).[1]

THE CHEMICALS OF PRIMARY CONCERN AT THE WILLOW GROVE NAVAL AIR STATION ARE LISTED IN TABLE 1.2 ALONG WITH SOME OF THEIR PHYSICAL PROPERTIES. THE LAST COLUMN OF THE TABLE PROVIDES HENRY'S CONSTANTS WHICH GIVE AN INDICATION OF HOW READILY A CHEMICAL WILL TRANSFER FROM WATER TO AIR. HENRY'S CONSTANTS ARE DISCUSSED FURTHER IN SECTION 2.1. THE VALUES REPORTED WERE OBTAINED FROM LITERATURE REFERENCES OR OBTAINED USING AN ANTOINE CORRELATION WITH SOLUBILITY AND VAPOR PRESSURE DATA.

TABLE 1.2
PHYSICAL PROPERTIES OF VOLATILE ORGANIC CHEMICALS
WILLOW GROVE NAVAL AIR STATION

CHEMICAL	MOLECULAR WEIGHT	DENSITY (G/CC)	SOLUBILITY (PPM)	HENRY'S K
TRICHLOROETHENE (TCE)	131.4	1.466	1,100	0.5
TETRACHLOROETHENE (PCE)	165.9	1.623	140	1.1
1,2-DICHLOROETHENE	97.0	1.291	3,500	0.2
1,1,1-TRICHLOROETHANE	133.4	1.339	720	1.5
CARBON TETRACHLORIDE	153.8	1.595	800	1.3

1 NOTE: A TCE VALUE OF 300 PPB WAS REPORTED FOR A SAMPLE TAKEN ON 03/01/82. THIS VALUE IS CONSIDERED AN ANALYTICAL ARTIFACT SINCE NO CONCURRENT PCE INCREASE WAS OBSERVED AND STATISTICALLY AND INTUITIVELY IT APPEARS AS AN OUTLIER. SIMILARLY, THE HIGHEST TCE AND PCE VALUES (17.3 AND 32.7) FOR THE AIR FORCE WELL IN MARCH OF 1981 ARE INTERPRETED AS A MISLABELED SAMPLE SINCE NO TCE OR PCE WERE REPORTED IN NAVY WELL #1 FOR THAT PERIOD.

1.4 Treatment Alternatives

Three possible treatment alternatives were considered for VOC removal from the potable water supplies at the Willow Grove Naval Air Station. The three treatments evaluated were reverse osmosis, granular activated carbon (GAC) adsorption, and packed tower aeration. Packed tower aeration was determined to be the most efficient and effective for treatment of the VOCs encountered at the Willow Grove Naval Air Station. The evaluation of treatment alternatives is included as Appendix B.

Reverse osmosis was dismissed as a possible treatment alternative because of its demonstrated: 1) inability to remove VOCs, 2) complexity of operation, and 3) high capital and operating costs.

Granular activated carbon was found to be a viable treatment alternative but was not selected due to its 1) cost, 2) potential for causing other water quality problems, and 3) performance levels for highly-volatile organics.

Packed tower aeration was selected as the method of choice for treatment to remove the volatile halogenated organics present at the Willow Grove Naval Air Station. Aeration was selected because of its 1) inherent simplicity, 2) high efficiency, and 3) cost effectiveness.

1.5 Treatment Location

Based on the findings of the hydrogeologist, it was recommended to provide treatment to the Navy wells. As long as the Navy wells are operational, the groundwater

CONE OF CONTAMINATION SHOULD BE KEPT AWAY FROM THE AIR FORCE WELL. THIS CONCLUSION IS BASED ON DATA DERIVED DURING THE COURSE OF THIS STUDY AND THE LOCAL CHARACTERISTICS OF GROUNDWATER MOVEMENT. WITHOUT KNOWING THE EXACT LOCATION AND SOURCE OF THE VOLATILE ORGANICS IN THE WATER SUPPLY, IT CANNOT BE STATED WITH CERTAINTY THAT A FUTURE INCIDENCE OF CONTAMINATION WOULD NOT IMPACT THE AIR FORCE WELL.

MONITORING OF CONTAMINANT LEVELS IN THE AIR FORCE WELL SHOULD BE CONTINUED. TO DATE, NO FIRM MINIMUM CONTAMINANT LEVEL (MCL) HAS BEEN DEVELOPED FOR VOLATILE ORGANICS. THESE ARE EXPECTED TO BE PROPOSED BY U.S. EPA IN THE NEAR FUTURE. MCLS ON THE ORDER OF FIVE PARTS PER BILLION ARE LIKELY TO BE MANDATED FOR SUCH VOLATILE ORGANICS AS TCE AND PCE. IT IS SUGGESTED THAT THIS LEVEL BE USED AS THE THRESHOLD FOR TRIGGERING CONSIDERATION OF TREATMENT AT THE AIR FORCE WELL. ALSO, TREATMENT SHOULD BE PROVIDED IF THE NAVY WELLS ARE EITHER ABANDONED OR TAKEN OUT OF SERVICE FOR AN EXTENDED PERIOD.

2.0 PACKED TOWER AERATION

2.1 PROCESS PRINCIPLES

AERATION IS A COST-EFFECTIVE, NATURAL PROCESS FOR REMOVAL OF VOLATILE ORGANICS FROM WATER. VOLATILE ORGANICS WHICH ARE FREQUENTLY "TRAPPED" IN GROUNDWATER ARE SELDOM ENCOUNTERED IN SURFACE WATERS DUE TO NATURAL STREAM AERATION. AERATION UNIT PROCESSES ARE ENGINEERED TO OPTIMIZE AIR AND WATER CONTACT AND THEREBY ACCELERATE THIS NATURAL PROCESS.

IN A PACKED TOWER AERATOR, WATER AND AIR ARE BROUGHT INTO CONTACT WITH EACH OTHER FOR THE PURPOSE OF TRANSFERRING VOLATILE SUBSTANCES DISSOLVED IN THE WATER INTO THE AIR. THE RATE OF TRANSFER DEPENDS UPON THE COEFFICIENT OF MASS TRANSFER, THE EFFECTIVE AREA OF CONTACT BETWEEN THE GAS AND THE LIQUID, AND THE DIFFERENCE IN CONCENTRATION BETWEEN THE SUBSTANCE IN THE LIQUID AND GASEOUS PHASES.

REMOVAL OF VOLATILE ORGANIC CHEMICALS BY AERATION HAS BEEDN FOUND TO CLOSELY FOLLOW HENRY'S LAW. HENRY'S LAW STATES: "IN A DILUTE SOLUTION, THE VAPOR PRESSURE OF THE SOLUTE (CONTAMINANT) IS APPROXIMATELY PROPORTIONAL TO ITS MOLE FRACTION". BY CONTINUALLY RENEWING THE AIR ADJACENT TO A CONTAMINATED WATER, AN EQUILIBRIUM IMBALANCE BETWEEN THE AIR AND WATER IS MAINTAINED (I.E. THE CONTAMINANT'S VAPOR PRESSURE ABOVE THE WATER IS ZERO). THIS EQUILIBRIUM DRIVING FORCE CAUSES THE VOLATILE ORGANICS TO PARTITION FROM THE WATER INTO THE AIR.

IN THEORY, TWO RATE CONSTANTS DEFINE THIS DIFFUSION FROM THE WATER INTO THE AIR: THE DIFFUSION FROM THE BULK OF SOLUTION TO THE AIR-WATER INTERFACE AND DIFFUSION ACROSS THE INTERFACE INTO THE GAS PHASE. IN A PROPERLY DESIGNED AERATOR, SUFFICIENT INTERFACIAL AREA IS PROVIDED SO THAT DIFFUSION IN THE BULK LIQUID CONTROLS THE REMOVAL RATE FOR HIGHLY VOLATILE ORGANICS.

THE PREFERENTIAL CONFIGURATION FOR PACKED TOWER AERATION IS COUNTERCURRENT FLOW. WATER IS INTRODUCED AT THE TOP OF THE TOWER AND AIR AT THE BOTTOM. THIS ALLOWS THE "PUREST" AIR TO CONTACT THE "PUREST" WATER. THEREBY, MAINTAINING AN EQUILIBRIUM DRIVING FORCE FOR REMOVAL OF CONTAMINANTS EVEN AT LOW LEVELS.

AN EFFICIENT PACKING MATERIAL WILL PROVIDE A LARGE SURFACE AREA FOR THE AIR AND WATER TO INTERFACE. AT THE SAME TIME IT SHOULD OFFER LITTLE RESISTANCE TO AIR FLOW (POSSESS A LARGE VOID VOLUME) AND FURTHER MAXIMIZE INTERFACIAL AREA BY ALLOWING THE WATER TO FORM A THIN FILM AS IT PASSES OVER THE MATERIAL. ADDITIONALLY, THE PACKING MATERIAL SHOULD BE CHEMICALLY INERT, POSSESS SUFFICIENT STRUCTURAL STRENGTH FOR EASY HANDLING, AND REPRESENT LOW COST.

WATER IS DISTRIBUTED EVENLY AT THE TOP OF A PACKED TOWER AERATOR AND ALLOWED TO PERCOLATE DOWN THROUGH THE PACKING MATERIAL. FIGURE 2.1 PROVIDES A SCHEMATIC OF A TYPICAL PACKED TOWER AERATOR. LIQUID RE-DISTRIBUTORS ARE OFTEN USED IN SMALL DIAMETER TOWERS (LESS THAN THREE FEET) TO PREVENT CHANNELING OF THE WATER DOWN THE SHELL OF THE TOWER. PACKING SUPPORTS SHOULD BE DESIGNED TO PROVIDE SEPARATE PASSAGES FOR AIR AND WATER AND MUST HAVE AMPLE FREE AREA SO THAT FLOW RESTRICTIONS ARE MINIMIZED.

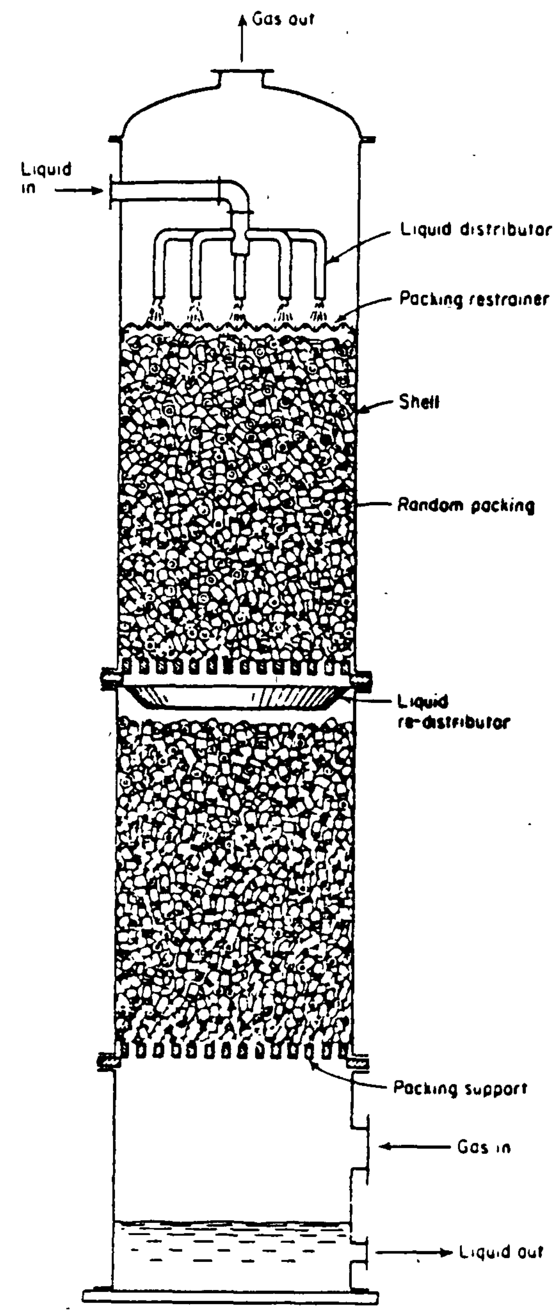

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FIGURE 2-1

SCHEMATIC
PACKED TOWER AERATOR

2.2 DESIGN CONSIDERATIONS

TWO DISTINCT BUT RELATED DESIGN COMPONENTS ARE ESSENTIAL TO DEVELOPING AN OPTIMIZED PACKED TOWER AERATION SYSTEM. THE HYDRAULIC DESIGN AND MASS TRANSFER DESIGN COMPONENTS ARE DISCUSSED IN THIS SUBSECTION ALONG WITH OTHER IMPACTS OF DESIGN ON WATER QUALITY. THE HYDRAULIC DESIGN CALCULATIONS PROVIDE THE REQUIRED TOWER DIAMETER AND THE MASS TRANSFER CALCULATIONS DICTATE THE HEIGHT OF THE TOWER.

2.2.1 HYDRAULIC DESIGN

PROPER HYDRAULIC DESIGN OF A PACKED TOWER AERATOR WILL ENSURE THAT NEITHER "FLOODING" OF THE TOWER NOR ENTRAINMENT OF AIR IN THE TREATED WATER WILL OCCUR. FLOODING OCCURS WHEN THE UPWARD TRAVELING AIR PREVENTS THE WATER FROM PERCOLATING THROUGH THE PACKING MATERIAL. THE RESULTING LIQUID HOLD-UP IS RELATED TO IMPROPER AIR VELOCITY AND RESULTS IN POOR REMOVAL EFFICIENCIES. CONVERSELY, A WATER RATE THAT IS TOO HIGH COUPLED WITH A LOW AIR VELOCITY CAN CAUSE ENTRAINMENT OF THE AIR IN THE WATER AS IT PASSES THROUGH THE TOWER.

THE HYDRAULIC DESIGN IS IMPACTED PRIMARILY BY THREE PARAMETERS AND THEIR INTERACTIONS: AQUEOUS LOADING, PACKING MATERIAL, AND THE AIR-TO-WATER RATIO. THERE IS A DECIDED ECONOMY OF SCALE WITH INCREASED AQUEOUS FLOW RATES THROUGH A PACKED TOWER AERATOR. THE RELATIONSHIP BETWEEN INCREASING DIAMETER OF A TOWER AND INCREASED AQUEOUS LOADING IS DIRECTLY PROPORTIONAL TO THE INCREASED SURFACE AREA AFFORDED BY A LARGER TOWER. FOR THIS REASON, ONE LARGE TOWER IS MORE EFFICIENT THAN SEVERAL SMALL TOWERS. THE PACKING MATERIAL AND THE

OPERATIONAL AIR-TO-WATER RATIO DIRECTLY AFFECT THE HYDRAULIC DESIGN BECAUSE OF THEIR COMBINED RESISTANCE TO WATER FLOW.

2.2.2 Mass Transfer Design

The transfer of contaminants from the water to the air is impacted by several factors including the packing material, air-to-water ratio, and water temperature. Since aeration is an equilibrium process, the efficiency of removal is independent of concentration. However, the desired treatment efficiency is selected based upon the prevailing concentrations. Therefore, higher levels of contamination will dictate higher removal efficiencies to attain desired levels in the tower effluent.

The packing material directly affects mass transfer within the tower due to its available surface area, wettability, and tortuosity of path provided for air and water. The optimum air-to-water ratio is a function of the mass transfer coefficient for the particular organic to be removed. The water temperature directly affects the Henry's Law constant for an organic contaminant and the equilibrium driving force is lowered with decreasing temperature. Air temperature has little impact of removals by air stripping because of its insignificant heat capacity (compared to water) and its increased density with decreasing temperature.

2.2.3 Additional Water Quality Considerations

Aeration unit processes are not only useful for removal of VOCs but often enhance general water quality.

GROUNDWATERS OFTEN CONTAIN SIGNIFICANT LEVELS OF DISSOLVED CARBON DIOXIDE WHICH ARE REMOVED BY AIR STRIPPING, THEREBY PROVIDING AN INCREASED PH AND BUFFERING CAPACITY IN THE TREATED WATER.

THE ADDITION OF FREE CHLORINE PRIOR TO AIR STRIPPING IS UNDESIRABLE, AS THE CHLORINE WILL BE STRIPPED FROM THE WATER. THEREFORE, CHLORINATION SHOULD BE CONDUCTED FOLLOWING PACKED TOWER AERATION. THE ABSENCE OF DISINFECTANT WITHIN THE PACKED TOWER COULD POSSIBLY ALLOW MICROBIAL OR ALGAL GROWTH TO OCCUR WITHIN THE TOWER. FOR THIS REASON, DESIGN PROVISIONS TO ALLOW EASY CLEANING OF THE TOWER ARE REQUIRED.

THE INDICATORS FOR TOWER CLEANING ARE EXCESSIVE BACTERIAL, ALGAL, OR MINERAL BUILD-UP INSIDE THE TOWER OR ON THE PACKING MATERIAL. THESE INDICATORS CAN BE NOTED VISUALLY THROUGH THE INSPECTION PARTS. MECHANICALLY, THE TOWER WOULD ALSO EXPERIENCE A REDUCED AIR FLOW CAPABILITY.

DEPENDING UPON THE CHARACTERISTICS OF THE ORGANIC OR MINERAL INTERFERENCE, TWO ALTERNATIVE METHODS CAN BE USED TO IMPLEMENT TOWER CLEANING:

A. SUPER CHLORINATE THE PACKED BED -- UNDER MOST CIRCUMSTANCES THIS METHOD WILL BE EFFECTIVE. FIRST, THE TOWER OUTLET TO THE CLEAR WELL MUST BE CLOSED. THEN, USING THE WATER CIRCULATION PUMP, WASH THE BED AND INTERIOR TOWER WALLS WITH A HIGH DOSE OF CHLORINATED WATER. THIS WILL CAUSE THE ORGANIC GROWTH TO SLOUGH OFF THE TOWER AND BECOME SUSPENDED IN THE CIRCULATING WATER. FINALLY, THE CIRCULATING WATER IS CAPTURED AND CONVEYED TO A WASTE DISPOSAL SITE (E.G., A WASTEWATER TREATMENT PLANT).

B. ACID WASH THE PACKED BED -- THIS PROCEDURE SHOULD BE USED IF THERE IS EXCESSIVE MINERAL BUILD-UP OR FIXED ORGANIC GROWTH THAT CANNOT BE REMOVED THROUGH CHLORINATION. THE MANNER OF APPLICATION IS THE SAME AS METHOD A. HOWEVER, IN THIS ALTERNATIVE AN ACID SOLUTION IS USED TO WASH THE BED (E.G., DILUTE HYDROCHLORIC ACID).

METHOD A CAN BE DONE BY IN-HOUSE MAINTENANCE PERSONNEL; METHOD B WOULD REQUIRE THE SERVICES OF AN OUTSIDE CONTRACTOR. WITH EITHER METHOD, EXPECTED DOWN TIME WOULD BE NO MORE THAN ONE DAY.

UNDER NORMAL CIRCUMSTANCES, TOWER CLEANING IS NOT NECESSARY FOR EXTENDED PERIODS OF TIME. THE EXPERIENCE OF THE PHILADELPHIA SUBURBAN WATER COMPANY AT ITS UPPER MERION RESERVOIR HAS SHOWN NO EVIDENCE OF ORGANIC GROWTH OR SCALE BUILD-UP AFTER TWO YEARS OF CONTINUOUS OPERATION. THE FREQUENCY OF CLEANING IS SITE SPECIFIC TO THE WATER SOURCE BEING UTILIZED AND THE POTENTIAL FOR AIRBORNE CONTAMINATION. FOR PLANNING PURPOSES, A FIVE-YEAR CLEANING CYCLE IS SUGGESTED. ROUTINE MAINTENANCE OF THE STRIPPING TOWER IS MINIMAL. THE ONLY MOVING MECHANICAL COMPONENT IS THE BLOWER. ASSUMING 24-HOUR PER DAY OPERATION AND A 2 HP MOTOR, ANNUAL ELECTRIC COSTS SHOULD BE IN THE $1,000 TO $1,200 RANGE. THE ONLY OTHER ROUTINE ITEMS ARE A MONTHLY INSPECTION OF THE AIR INLET SCREEN AND A SEMI-ANNUAL EXERCISING OF VALVES.

THE PACKING MATERIAL ITSELF SHOULD LAST INDEFINITELY. IT IS A HIGH GRADE PLASTIC MATERIAL NOT SUBJECT TO DEGRADATION OR WEAR UNDER NORMAL OPERATING CONDITIONS.

2.3 PILOT TESTING - WILLOW GROVE NAVAL AIR STATION

PILOT TESTING OF AERATION WAS CONDUCTED AT THE WILLOW GROVE NAVAL AIR STATION IN FEBRUARY AND JULY OF 1985. THE PURPOSES FOR THIS TESTING WERE FOURFOLD: 1) TO VERIFY AIR STRIPPING FEASIBILITY, 2) TO SELECT OPTIMUM PACKING MATERIALS, 3) TO OBTAIN MASS TRANSFER DATA ON OPTIMUM PACKING, AND 4) TO CALIBRATE THE COMPUTER MODEL UTILIZED FOR FULL-SCALE DESIGN.

THE PILOT TESTING APPARATUS CONSISTED OF TWO 3-INCH ID PIPES FILLED WITH APPROPRIATE PACKING MATERIALS AND FITTED WITH IDENTICAL FANS. ALL PILOT COLUMN EVALUATIONS WERE CONDUCTED UTILIZING COUNTERCURRENT FLOW. DIFFERENT BED DEPTHS OF PACKING MATERIALS WERE USED TO FURTHER DEFINE THE HEIGHT OF A TRANSFER UNIT (HTU) FOR SPECIFIC ORGANIC CONTAMINANTS. THE LOW LEVELS OF 1,2-DICHLOROETHENE PRESENT IN THE WATER PRECLUDED COLLECTION OF MEANINGFUL PILOT DATA ON THIS CRITICAL CONTAMINANT. THE RESULTS FROM PILOT AERATION TESTING AT WILLOW GROVE ARE GIVEN IN TABLES 2.1 AND 2.2 FOR TRICHLOROETHENE, TETRACHLOROETHENE, AND 1,1,1-TRICHLOROETHANE.

TABLE 2.1
PILOT AERATION TEST
WILLOW GROVE NAVY WELL #2 - 2/13/85

SAMPLE	% REMOVED TCE	PCE	1,1,1-TCE
UNTREATED (PPB)	13.4	25.8	0.96
FLEXIRINGS			
3' BED DEPTH	73	76	55
4' BED DEPTH	84.5	86	62
PLASTIC SADDLES			
3' BED DEPTH	63	66	53
4' BED DEPTH	67	70	52

TABLE 2.2
PILOT AERATION TESTING
BOILER BUILDING (FINISHED WATER)
WILLOW GROVE - JULY 17, 1985

SAMPLE	% REMOVED TCE	PCE	1,1,1-TCE
UNTREATED (PPB)	9.3	6.9	4.2
FLEXIRINGS			
3' BED DEPTH	85	83	69
4' BED DEPTH	87	80	69
PLASTIC SADDLES			
3' BED DEPTH	74	75	57
4' BED DEPTH	78	78	67

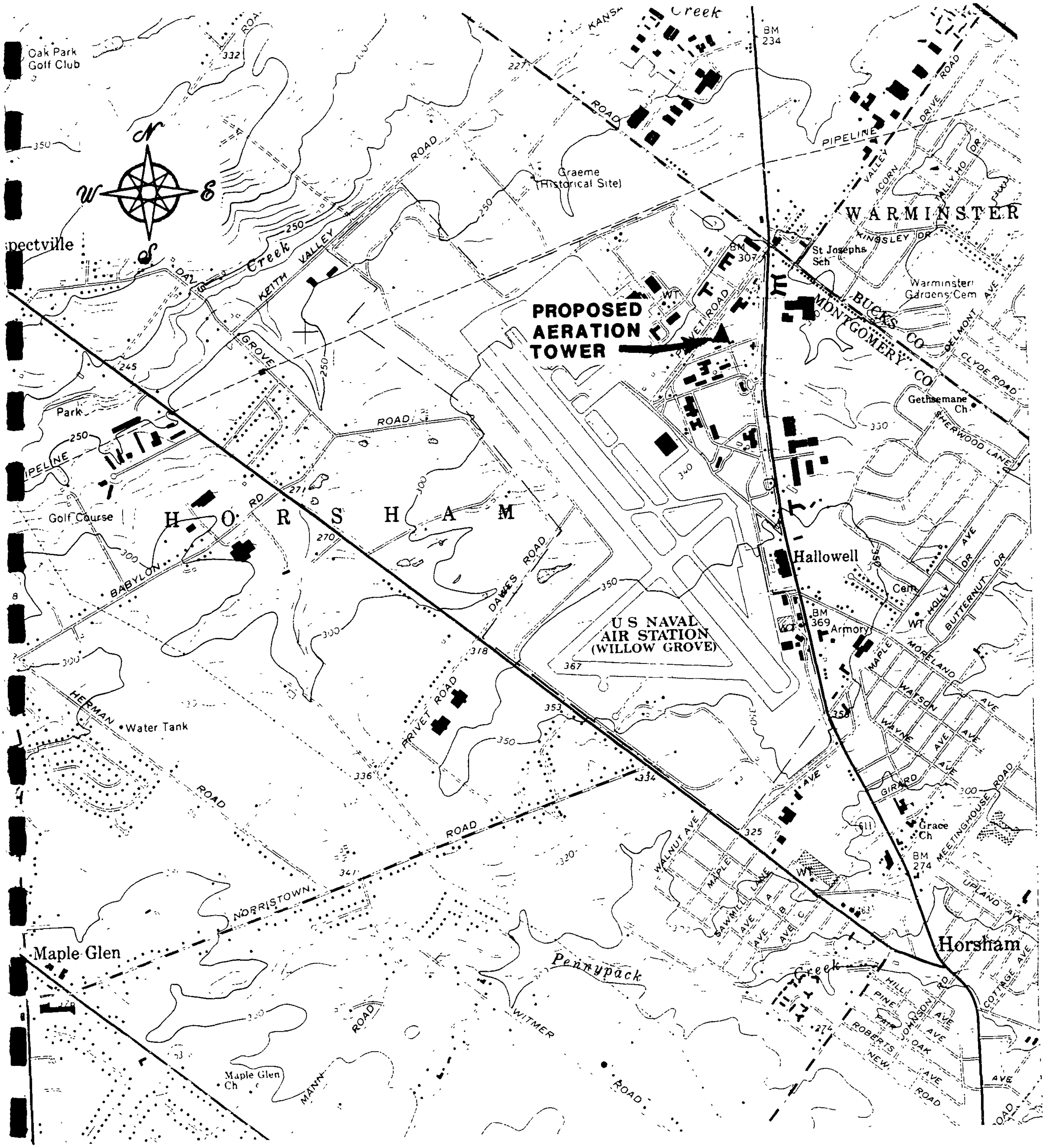

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FIGURE 3-1
PROPOSED AERATION
TOWER LOCATION

3.0 DESIGN RECOMMENDATIONS - PACKED TOWER AERATION WILLOW GROVE NAVAL AIR STATION

THIS SECTION PROVIDES SPECIFIC DESIGN RECOMMENDATIONS FOR IMPLEMENTATION OF PACKED TOWER AERATION AT THE WILLOW GROVE NAVAL AIR STATION.

3.1 TOWER LOCATION

THE MOST LOGICAL LOCATION FOR A PACKED TOWER AERATION UNIT AT THE WILLOW GROVE NAVAL AIR STATION IS ATOP THE 500,000 GALLON RESERVOIR ADJACENT TO NAVY WELL #2 (BUILDING #32). AN INSTALLATION AT THIS LOCATION WILL: 1) ALLOW CONSTRUCTION OF ONLY ONE TOWER TO TREAT BOTH NAVY WELLS, 2) NEGATE THE NEED FOR ANY REPUMPING, 3) NEGATE THE NEED TO RESTAGE EXISTING PUMPS, AND 4) ALLOW ADEQUATE DISINFECTION OF WATER PRIOR TO ITS DISTRIBUTION. THE PROPOSED TOWER LOCATION IS SHOWN ON FIGURE 3.1.

A STRUCTURAL EVALUATION OF THE EXISTING RESERVOIR COVER WILL BE REQUIRED TO DETERMINE LOCATIONS WITH SUFFICIENT BEARING CAPACITY FOR THE PROPOSED TOWER. IN THE PROPOSED CONFIGURATION, PIPING MODIFICATIONS WOULD BE REQUIRED TO BRING THE WELL PUMP DISCHARGES TO THE TOP OF THE TOWER AND TO RELOCATE THE POINT OF CHLORINE ADDITION TO THE EFFLUENT FROM THE PACKED TOWER.

3.2 DESIGN CALCULATIONS

CONCEPTUAL AERATION DESIGNS WERE OBTAINED BY APPLYING STANDARD ENGINEERING PRACTICES (CHEMICAL ENGINEERING HANDBOOK, SECTION 18). THE PACKING CONSTANTS WERE OBTAINED DIRECTLY FROM MANUFACTURER'S LITERATURE OR

FROM TREYBAL ("MASS-TRANSFER OPERATIONS", 3RD EDITION, MCGRAW-HILL, 1980). HENRY'S LAW CONSTANTS WERE OBTAINED BY CALCULATION OF ANTOINE CORRELATIONS (REID, ET.AL. "THE PROPERTIES OF GASSES AND LIQUIDS", 3RD EDITION, MCGRAW-HILL, 1977) USING SOLUBILITY DATA REPORTED BY DILLING (ENVIRONMENTAL SCIENCE AND TECHNOLOGY, VOL. 11, NO. 4).

A COMPUTER PROGRAM WAS USED TO GENERATE THE OPTIMIZED SPECIFICATIONS OUTLINED IN THE FOLLOWING SECTION. THE RESULTS FROM REPRESENTATIVE COMPUTER RUNS FOR CRITICAL DESIGN PARAMETERS ARE GIVEN IN TABLES 3.1 THROUGH 3.5.

3.3 TOWER SPECIFICATIONS

A.	TREATMENT CAPACITY	300 GPM
B.	TYPE OF TREATMENT	COUNTER-CURRENT AERATION
C.	AIR-TO-WATER RATIO	20-30:1
D.	TOWER DIAMETER	36 INCHES
E.	PACKING MATERIAL	KOCH FLEXIRINGS OR EQUIVALENT
F.	PACKING HEIGHT	16 FEET OVERALL

3.4 TOWER APPURTENANCES

3.4.1 CHLORINATION

A NEW 3/4" PVC CHLORINATION LINE SHOULD BE INSTALLED FROM THE EXISTING POINT OF CHLORINE ADDITION TO THE TOWER DISCHARGE SO THAT CHLORINE WILL BE ADDED IMMEDIATELY AFTER AIR STRIPPING.

3.4.2 AIR FILTRATION

AIR FILTRATION IS NECESSARY TO PREVENT THE INCURSION OF EXTERNAL AIRBORNE CONTAMINANTS INTO THE WATER SUPPLY. FILTER SIZE SHOULD BE ABOUT ONE MICRON. BASED ON A

TABLE 3.1
TCE REMOVAL AT 20:0 AIR-WATER RATIO

PACKED TOWER DESIGN FOR .432 MGD WITH 1 IN. PLASTIC INTALOX

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HYDRAULIC DESIGN

AQUEOUS FLOWRATE 300 GPM   AIR/WATER RATIO 20:1
1 IN. PLASTIC INTALOX   WATER TEMP 12

FLOODING SURFACE AREA 3.92538 SQ. FT.

FORCED SURFACE AREA 7.06858 SQ. FT.
DIAMETER 3 (FEET) SURFACE LOADING 42.4413 (GPM/SQ. FT.)
PRESSURE DROP: 0.22 INCHES OF H2O PER FOOT
LIQUID MASS RATE 21238.5 (LB./HR.-SQ.FT.)
AIR MASS RATE 526.346 (LB./HR-SQ. FT.)
BLOWER REQUIREMENT 802.032 CFM

MASS TRANSFER DESIGN

DESIGN CRITERIA TRICHLOROETHENE (TCE) AT 100 UG/L
HENRY'S CONSTANT AT 12 DEG. = 343.2 ATM.
REQUIRED BED DEPTH 16.0827 (FT.) FOR 99% REMOVAL TO 1 UG/L
NUMBER OF TRANSFER UNITS 5.42175
HEIGHT OF TRANSFER UNIT 2.96633 (FT.)
BED VOLUME 113.682 (CU.FT.)
EMPTY BED CONTACT TIME 2.83485 (MIN.)
STRIPPING COEFFICIENT (R) 5.29748 (OPTIMUM 1.2 TO 5)
PACKING AREA 63 (SQ.FT./CU. FT.)
PACKING CONSTANTS M= 160 N= .28 CF= 33

TABLE 3.2

TCE REMOVAL AT 30:1 AIR-WATER RATIO

PACKED TOWER DESIGN FOR .432 MGD WITH 1 IN. PLASTIC INTALOX

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HYDRAULIC DESIGN

AQUEOUS FLOWRATE 300 GPM   AIR/WATER RATIO 30:1
1 IN. PLASTIC INTALOX   WATER TEMP 12

FLOODING SURFACE AREA 4.99951 SQ. FT.

FORCED SURFACE AREA 7.06858 SQ. FT.
DIAMETER 3 (FEET) SURFACE LOADING 42.4413 (GPM/SQ. FT.)
PRESSURE DROP: 0.39 INCHES OF H20 PER FOOT
LIQUID MASS RATE 21238.5 (LB./HR.-SQ.FT.)
AIR MASS RATE 789.519 (LB./HR-SQ. FT.)
BLOWER REQUIREMENT 1203.05 CFM

MASS TRANSFER DESIGN

DESIGN CRITERIA TRICHLOROETHENE (TCE) AT 100 UG/L
HENRY'S CONSTANT AT 12 DEG. = 343.2 ATM.
REQUIRED BED DEPTH 15.1756 (FT.) FOR 99% REMOVAL TO 1 UG/L
NUMBER OF TRANSFER UNITS 5.11593
HEIGHT OF TRANSFER UNIT 2.96633 (FT.)
BED VOLUME 107.272 (CU.FT.)
EMPTY BED CONTACT TIME 2.67495 (MIN.)
STRIPPING COEFFICIENT (R) 7.94622 (OPTIMUM 1.2 TO 5)
PACKING AREA 63 (SQ.FT./CU. FT.)
PACKING CONSTANTS M= 160 N= .28 CF= 33

TABLE 3.3

1,2 DICHLOETHENE REMOVAL AT 20:1 AIR-WATER RATIO

PACKED TOWER DESIGN FOR .432 MGD WITH 1 IN. PLASTIC INTALOX

===

HYDRAULIC DESIGN

AQUEOUS FLOWRATE 300 GPM AIR/WATER RATIO 20:1
1 IN. PLASTIC INTALOX WATER TEMP 12

FLOODING SURFACE AREA 3.92538 SQ. FT.

FORCED SURFACE AREA 7.06858 SQ. FT.
DIAMETER 3 (FEET) SURFACE LOADING 42.4413 (GPM/SQ. FT.)
PRESSURE DROP: 0.22 INCHES OF H20 PER FOOT
LIQUID MASS RATE 21238.5 (LB./HR.-SQ.FT.)
AIR MASS RATE 526.346 (LB./HR-SQ. FT.)
BLOWER REQUIREMENT 802.032 CFM

MASS TRANSFER DESIGN

DESIGN CRITERIA 1,2-DICHLOROETHENE AT 10 UG/L
HENRY'S CONSTANT AT 12 DEG. = 160.766 ATM.
REQUIRED BED DEPTH 12.2528 (FT.) FOR 95% REMOVAL TO .5 UG/L
NUMBER OF TRANSFER UNITS 4.20945
HEIGHT OF TRANSFER UNIT 2.91079 (FT.)
BED VOLUME 86.6099 (CU.FT.)
EMPTY BED CONTACT TIME 2.15976 (MIN.)
STRIPPING COEFFICIENT (R) 2.48151 (OPTIMUM 1.2 TO 5)
PACKING AREA 63 (SQ.FT./CU. FT.)
PACKING CONSTANTS M= 160 N= .28 CF= 33

TABLE 3.4

1,2 DICHLOETHENE REMOVAL AT 30:1 AIR-WATER RATIO

PACKED TOWER DESIGN FOR .432 MGD WITH 1 IN. PLASTIC INTALOX

==

HYDRAULIC DESIGN

AQUEOUS FLOWRATE 300 GPM | AIR/WATER RATIO 30:1
1 IN. PLASTIC INTALOX | WATER TEMP 12

FLOODING SURFACE AREA 4.99951 SQ. FT.

FORCED SURFACE AREA 7.06858 SQ. FT.
DIAMETER 3 (FEET) SURFACE LOADING 42.4413 (GPM/SQ. FT.)
PRESSURE DROP: 0.39 INCHES OF H20 PER FOOT
LIQUID MASS RATE 21238.5 (LB./HR.-SQ.FT.)
AIR MASS RATE 789.519 (LB./HR-SQ. FT.)
BLOWER REQUIREMENT 1203.05 CFM

MASS TRANSFER DESIGN

DESIGN CRITERIA 1,2-DICHLOROETHENE AT 100 UG/L
HENRY'S CONSTANT AT 12 DEG. = 160.766 ATM.
REQUIRED BED DEPTH 17.0981 (FT.) FOR 99% REMOVAL TO .1 UG/L
NUMBER OF TRANSFER UNITS 5.87406
HEIGHT OF TRANSFER UNIT 2.91079 (FT.)
BED VOLUME 120.86 (CU.FT.)
EMPTY BED CONTACT TIME 3.01383 (MIN.)
STRIPPING COEFFICIENT (R) 3.72226 (OPTIMUM 1.2 TO 5)
PACKING AREA 63 (SQ.FT./CU. FT.)
PACKING CONSTANTS M= 160 N= .28 CF= 33

TABLE 3.5

1,2 DICHLOETHENE REMOVAL AT 97.5%

PACKED TOWER DESIGN FOR .432 MGD WITH 1 IN. PLASTIC INTALOX

==

HYDRAULIC DESIGN

AQUEOUS FLOWRATE 300 GPM   AIR/WATER RATIO 30:1
1 IN. PLASTIC INTALOX   WATER TEMP 12

FLOODING SURFACE AREA 4.99951 SQ. FT.

FORCED SURFACE AREA 7.06858 SQ. FT.
DIAMETER 3 (FEET) SURFACE LOADING 42.4413 (GPM/SQ. FT.)
PRESSURE DROP: 0.39 INCHES OF H20 PER FOOT
LIQUID MASS RATE 21238.5 (LB./HR.-SQ.FT.)
AIR MASS RATE 789.519 (LB./HR-SQ. FT.)
BLOWER REQUIREMENT 1203.05 CFM

MASS TRANSFER DESIGN

DESIGN CRITERIA 1,2-DICHLOROETHENE AT 10 UG/L
HENRY'S CONSTANT AT 12 DEG. = 160.766 ATM.
REQUIRED BED DEPTH 13.4731 (FT.) FOR 97.5% REMOVAL TO .25 UG/L
NUMBER OF TRANSFER UNITS 4.62866
HEIGHT OF TRANSFER UNIT 2.91079 (FT.)
BED VOLUME 95.2353 (CU.FT.)
EMPTY BED CONTACT TIME 2.37485 (MIN.)
STRIPPING COEFFICIENT (R) 3.72226 (OPTIMUM 1.2 TO 5)
PACKING AREA 63 (SQ.FT./CU. FT.)
PACKING CONSTANTS M= 160 N= .28 CF= 33

SIMILAR INSTALLATION, THE FILTER SHOULD BE ABLE TO REMOVE HYDROCARBON CONTAMINATION. IT IS NOT EXPECTED THAT AIRBURNE EMISSIONS FROM THE HEATING PLANT WILL IMPACT TOWER OPERATIONS.

3.4.3 TOWER CLEANING PROVISIONS

TO CLEAN THE TOWER, A WATER CIRCULATION PUMP WILL BE PROVIDED. ALSO, THE DESIGN WILL INCLUDE AN ACCESS MANWAY AND INSPECTION PORTS.

3.4.4 EMERGENCY ELECTRIC SUPPLY

AN EMERGENCY ELECTRICAL SUPPLY SHOULD NOT BE NEEDED UNLESS IT IS EXPECTED THAT PRIMARY ELECTRICAL SERVICE WOULD BE DISRUPTED FOR AN EXTENDED PERIOD (GREATER THAN 24 HOURS). IF EMERGENCY POWER IS REQUIRED, ONLY THE 2 HP BLOWER MOTOR WOULD NEED THE SERVICE. IT MAY BE MORE COST EFFECTIVE SIMPLY TO PROVIDE A HOOK-UP FOR A PORTABLE GENERATOR.

3.5 PROJECTED PERFORMANCE

IMPLEMENTATION OF THE DESIGN RECOMMENDATIONS PUT FORTH IN THIS SECTION WILL PROVIDE A GREATER THAN 95% REDUCTION IN THE TOTAL CONCENTRATION OF VOLATILE ORGANICS. TABLE 3.6 PROVIDES A BREAKDOWN OF THE ESTIMATED REMOVAL EFFICIENCIES FOR SPECIFIC ORGANICS AND PROJECTS THEIR "WORST CASE" CONCENTRATIONS WITH THE RECOMMENDED TREATMENT FACILITY ON-LINE.

TABLE 3.6
PROJECTED REMOVAL EFFICIENCIES AND MAXIMUM
EFFLUENT LEVELS FOR VOCS

	MAXIMUM CONC. (PPB)	HENRY'S K	% REMOVED	EFFLUENT CONC. (PPB)
TRICHLOROETHENE (TCE)	100	0.5	99	1.0
TETRACHLOROETHENE (PCE)	100	1.1	99+	1.0
1,2-DICHLOROETHENE	10	0.2	97.5	0.3
1,1,1-TRICHLOROETHANE	10	1.5	99+	0.1
CARBON TETRACHLORIDE	5	1.3	99+	0.1
TOTAL	225		98+	2.5

3.6 PRELIMINARY COST ESTIMATES

THE COST ESTIMATES PROVIDED IN THIS SECTION ARE TAKEN DIRECTLY FROM APPENDIX B AND ARE FACTORED ESTIMATES. NO VENDOR QUOTATIONS HAVE BEEN OBTAINED.

TABLE 3.7
PRELIMINARY COST ESTIMATES - PACKED TOWER
WILLOW GROVE NAVAL AIR STATION

ENGINEERING AND DESIGN	$13,500
STRUCTURAL ANALYSIS	
DRAFTING	
ELECTRICAL ENGINEERING	
PERMITS	
FABRICATION AND INSTALLATION	45,600
TOWER SHELL	
LIQUID DISTRIBUTOR, REDISTRIBUTORS	
PACKING SUPPORT TRAY	
PACKING	
DEMISTER	
BLOWER	
PIPING	
ELECTRICAL	
ERECTION	
SHEET METAL WORK	
SITE PREPARATION	
SUBTOTAL	$59,100
CONTINGENCY @ 15%	7,100
ESTIMATED COSTS	$66,200

4.0 ATMOSPHERIC DISPERSION ESTIMATES

4.1 INTRODUCTION

THE PURPOSE OF THIS SECTION IS TO PROVIDE RELIABLE MAXIMUM ESTIMATES FOR GROUND LEVEL AMBIENT AIR LEVELS OF TRICHLOROETHYLENE (TCE) AND TETRACHLOROETHYLENE (PCE) THAT WILL BE PRODUCED IF AERATION IS IMPLEMENTED AT THE WILLOW GROVE NAVAL AIR STATION. ESTIMATES WERE MADE USING A BINORMAL CONTINUOUS PLUME DISPERSION MODEL AT MAXIMUM POSSIBLE EMISSIONS CONSIDERING THREE ATMOSPHERIC CONDITIONS.

THE THREE ATMOSPHERIC CONDITIONS EVALUATED ARE:

CASE I -- ABNORMALLY STABLE ATMOSPHERE WITH AN INVERSION 30 METERS ABOVE THE GROUND AND WINDS OF 2 MPS.

CASE II -- NORMAL NIGHTTIME OR OVERCAST ATMOSPHERIC STABILITY, WIND SPEEDS OF 5-6 MPS.

CASE III -- NORMAL DAYTIME ATMOSPHERIC CONDITIONS, WIND SPEED OF 4 MPS.

FOR THE PURPOSE OF CALCULATIONS, ASSUMPTIONS WHICH WOULD YIELD THE MAXIMUM DISCHARGE OF CONTAMINANTS TO THE ATMOSPHERE WERE USED. AN EFFECTIVE DISCHARGE HEIGHT LESS THAN THE ACTUAL TOWER HEIGHT WAS USED SINCE THE TOWER DISCHARGE WILL OFTEN BE AT A LOWER TEMPERATURE THAN THE AMBIENT AIR.

4.2 General Assumptions

A. Treatment Flow - 300 gpm (continuous
B. Aqueous TCE Concentration - 100 ppb
C. Stripping Efficiency - 100% (maximum possible)
D. Air-to-Water Ratio - 20:1
E. Effective Emission Height - 5 meters

4.3 Calculation Procedures

The procedures used to estimate the atmospheric dispersion of TCE were taken directly from U.S. Public Health Service Publication Number 999-AP-26. The model assumes that dispersion is Gaussian in both the horizontal and vertical planes and there is no deposition or reaction at the surface. The general form of the equation for the concentration at any point downwind of an emission source is:

$$\chi\ (x, y, z; H) = \frac{Q}{2\pi\sigma_y\ \sigma_z\ u}\ e^{-1/2\left(\frac{y}{\sigma_y}\right)^2}\left[e^{-1/2\left(\frac{z-H}{z}\right)^2} + e^{-1/2\left(\frac{z+H}{z}\right)^2}\right]$$

where:

χ = atmospheric concentration (grams/cubic meter)
x = distance on x-axis (meters - horizontally downwind)
y = distance on y-axis (meters - perpendicular to wind)
z = vertical distance (meters - height above ground)
H = effective height of discharge (meters)
Q = emission rate (grams/sec)
u = wind velocity (meters/sec)
σ_y = plume standard deviation in the horizontal
σ_z = plume standard deviation in the vertical
e = base of natural logrithms

4.4 CALCULATION RESULTS

INITIAL CALCULATIONS ARE PROVIDED TO ESTIMATE THE INSTANTANEOUS EMISSION RATE FROM THE PROPOSED TOWER AND THE RESULTANT CONCENTRATION AT THE TOWER OUTLET PRIOR TO ANY ATMOSPHERIC DISPERSION. ALL CALCULATIONS ARE FOR TCE ASSUMING THE WORST CASE CONDITIONS.

THE RESULTS OF THE CALCULATIONS FOR EACH SPECIFIC ATMOSPHERIC CONDITION ARE PRESENTED GRAPHICALLY BY FIGURE 4.1. THE TABULAR VALUES DERIVED TO OBTAIN EACH POINT ARE GIVEN IN TABLES 4.1A THROUGH 4.3A CORRESPONDING TO THE THREE RESPECTIVE CASES. FIGURE 4.2 PROVIDES THE CROSSWIND DISPERSION ESTIMATES AT THE POINT OF MAXIMUM GROUNDLEVEL CONCENTRATIONS. THE TABULAR VALUES FOR THIS FIGURE ARE TAKEN FROM TABLES 4.1B THROUGH 4.3B.

A. GENERAL SOLUTIONS

1. MAXIMUM EMISSION RATE (Q)

$$\frac{4.32 \times 10^5 \text{ GAL}}{\text{DAY}} \; \frac{1 \text{ DAY}}{86{,}400 \text{ SEC}} \; \frac{3.785 \ \ell}{\text{GAL}} \; \frac{1.0 \times 10^{-4} \text{G TCE}}{\ell} = \frac{0.002 \text{G TCE}}{\text{SEC}}$$

2. CONVERT TCE AIR CONCENTRATION (UG/M^3) TO PPM IN AIR

A. 1 PPM TCE AT 13 C. (AVERAGE GROUNDWATER TEMPERATURE)

$$\frac{1 \text{ PART}}{10^6 \text{ PARTS}} \; \frac{131.4 \text{G}}{\text{MOLE}} \; \frac{10^6 \text{ UG}}{\text{G}} \; \frac{10^3 \text{ l}}{\text{M}^3} \; \frac{0.082 \text{ l-ATM}}{\text{MOLE } ^0\text{K}}^{-1} \; 286 \ ^0\text{K}^{-1} = \frac{5600 \text{ UG}}{\text{M}^3}$$

3. MAXIMUM CONCENTRATION AT TOWER OUTLET

$$\frac{1.0\text{E-04 G TCE}}{1 \text{ WATER}} \longrightarrow \frac{1.0\text{E-04 G}}{20 \text{ l AIR}} \; \frac{1000 \text{ l AIR}}{\text{M}^3} \; \frac{\text{M}^3}{5.6\text{E-03 G}} = 0.89 \text{ PPM}$$

B. Case I: Extremely Stable Atmosphere

Assumptions: H = 5 meters
L = 30 meters
u = 2 meters/sec

Table 4.1a
Derived functions and Downwind Levels - Case I

X (M)	U (M/SEC)	σ_Y (M)	σ_Z (M)	$\frac{H}{\sigma_Z}$	$E^{-1/2\left(\frac{H}{\sigma_Z}\right)^2}$	χ (G/M^3)
40	2	1.8	1.1	4.54	3.3E-05	5.3E-09
80	2	3.5	1.9	2.63	3.2E-02	1.5E-06
160	2	6.2	3.4	1.47	0.339	5.1E-06
300	2	11	5.6	0.89	0.673	3.5E-06
500	2	18	8.4	0.60	0.835	1.8E-06
1 KM	2	38	14.1	0.35	0.941	5.6E-07
2 KM	2	64	30			2.1E-07
10 KM	2	275	30			4.9E-08

Table 4.1b
Determination of Crosswind Dispersion - Case I

X (M)	$\frac{Y}{\sigma_Y}$	$E^{-1/2\left(\frac{Y}{\sigma_Y}\right)^2}$	χ (G/M^3)
5	0.81	0.72	3.6E-06
10	1.61	0.27	1.4E-06
15	2.42	0.05	2.7E-07
20	3.23	5.0E-03	2.7E-08
25	4.03	3.0E-04	1.5E-09

Maximum concentration as PPM:

$$\frac{5.1\text{ED-06 G}}{\text{M}^3} \cdot \frac{1 \text{ PPM}}{5.6\text{E-03 G/M}^3} = 0.00091 \text{ PPM}$$

C. Case II: Nighttime or Overcast Atmosphere

Assumptions: H = 5 meters
L = 1500 meters
U = 5-6 meters/sec

Table 4.2a
Derived functions and Downwind Levels - Case II

X (M)	U (M/SEC)	σY (M)	σZ (M)	$\frac{H}{\sigma Z}$	$E^{-1/2\left(\frac{H}{\sigma Z}\right)^2}$	χ (G/M^3)
40	6	3.5	2.1	2.38	0.059	8.5E-07
70	6	6	3.5	1.43	0.360	2.0E-06
150	6	12	6.6	0.76	0.749	1.0E-06
300	6	22.5	12	0.42	0.916	3.6E-07
500	6	36	18.5	0.27	0.964	1.6E-07
1 KM	6	69	31.5	0.16	0.987	4.8E-08
2 KM	6	130	50	0.10	0.995	1.6E-08
10 KM	6	540	135			1.5E-09

Table 4.2b
Determination of Crosswind Dispersion - Case II

X (M)	$\frac{Y}{\sigma Y}$	$E^{-1/2\left(\frac{Y}{\sigma Y}\right)^2}$	χ (G/M^3)
5	0.833	0.709	1.4E-06
10	1.67	0.249	5.0E-07
15	2.5	0.044	8.8E-08
20	3.33	3.9E-03	7.8E-09
25	4.16	1.7E-04	3.5E-10

Maximum concentration as PPM:

$$\frac{2E\text{-}06\ G}{M^3} \cdot \frac{1\ PPM}{5.6E\text{-}03\ G/M^3} = 0.00036\ PPM$$

D. CASE III: NORMAL DAYTIME CONDITIONS

ASSUMPTIONS: H = 5 METERS
L = NOT BOUNDED
U = 4 METERS/SEC

TABLE 4.3A
DERIVED FUNCTIONS AND DOWNWIND LEVELS - CASE III

X (M)	U (M/SEC)	σY (M)	σZ (M)	$\frac{H}{\sigma Z}$	$E^{-1/2\left(\frac{H}{\sigma Z}\right)^2}$	χ (G/M^3)
20	4	4	2	2.50	0.044	9.6E-07
40	4	9	5	1.00	0.607	2.4E-06
100	4	19	11	0.45	0.904	7.6E-07
200	4	36	20	0.25	0.969	2.4E-07
500	4	83	51	0.10	0.995	4.1E-08
1 KM	4	155	110	0.05	0.999	1.0E-08
2 KM	4	290	230			2.6E-09
10 KM	4	1200	1350			1.1E-10

TABLE 4.3B
DETERMINATION OF CROSSWIND DISPERSION - CASE III

X (M)	$\frac{Y}{\sigma Y}$	$E^{-1/2\left(\frac{Y}{\sigma Y}\right)^2}$	χ (G/M^3)
5	0.56	0.85	2.0E-06
10	1.11	0.54	1.3E-06
15	1.67	0.25	6.0E-07
20	2.22	0.09	2.2E-07
25	2.77	0.02	4.8E-08

MAXIMUM CONCENTRATION AS PPM:

$$\frac{2.4E\text{-}06 \text{ G}}{\text{M}^3} \cdot \frac{1 \text{ PPM}}{5.6E\text{-}03 \text{ G/M}^3} = 0.00043 \text{ PPM}$$

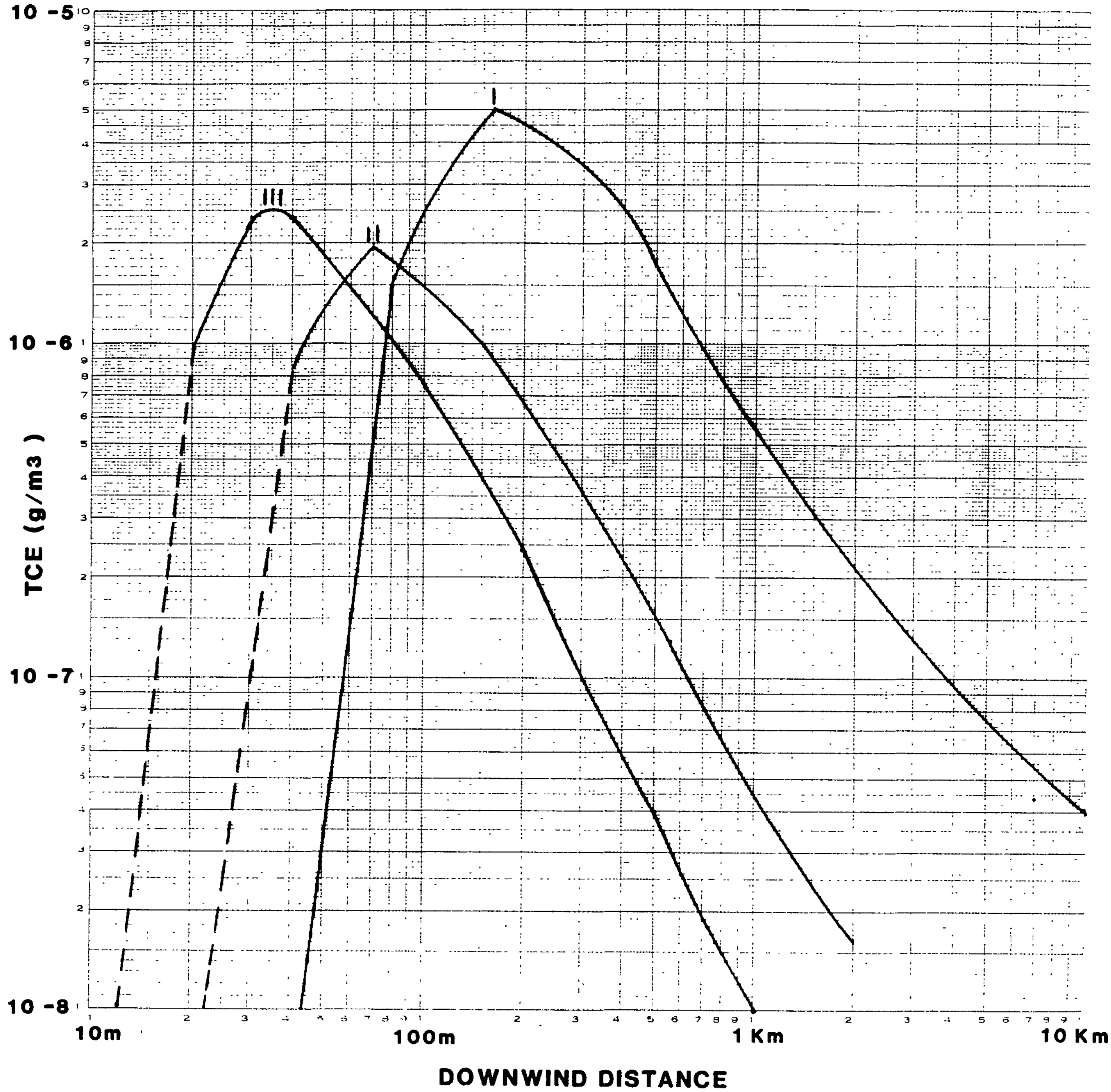
4.5 Discussion of Results

All estimates presented in this section are maximas and by design will most likely overestimate actual downwind ambient levels of trichloroethylene. The calculations assume: maximum emission rate, level terrain, no groundlevel deposition, and continuity of wind direction and velocity. The degree of validity for these assumptions will directly determine the amount of deviation between these estimates and the lower "true" levels of TCE.

An abrupt rise in concentration and a more gradual tailing off as one travels directly downwind from the aerators is shown in Figure 4.1. This phenomena is due to dispersion of the TCE in the direction of travel. Figure 4.2 shows that the concentration will dissipate rapidly in a crosswind direction and illustrates the Gaussian (normal distribution) function used for crosswind dispersion estimates. One would have to be directly downwind at the specified distance (on the plume centerline) to experience exposure at the maximum levels.

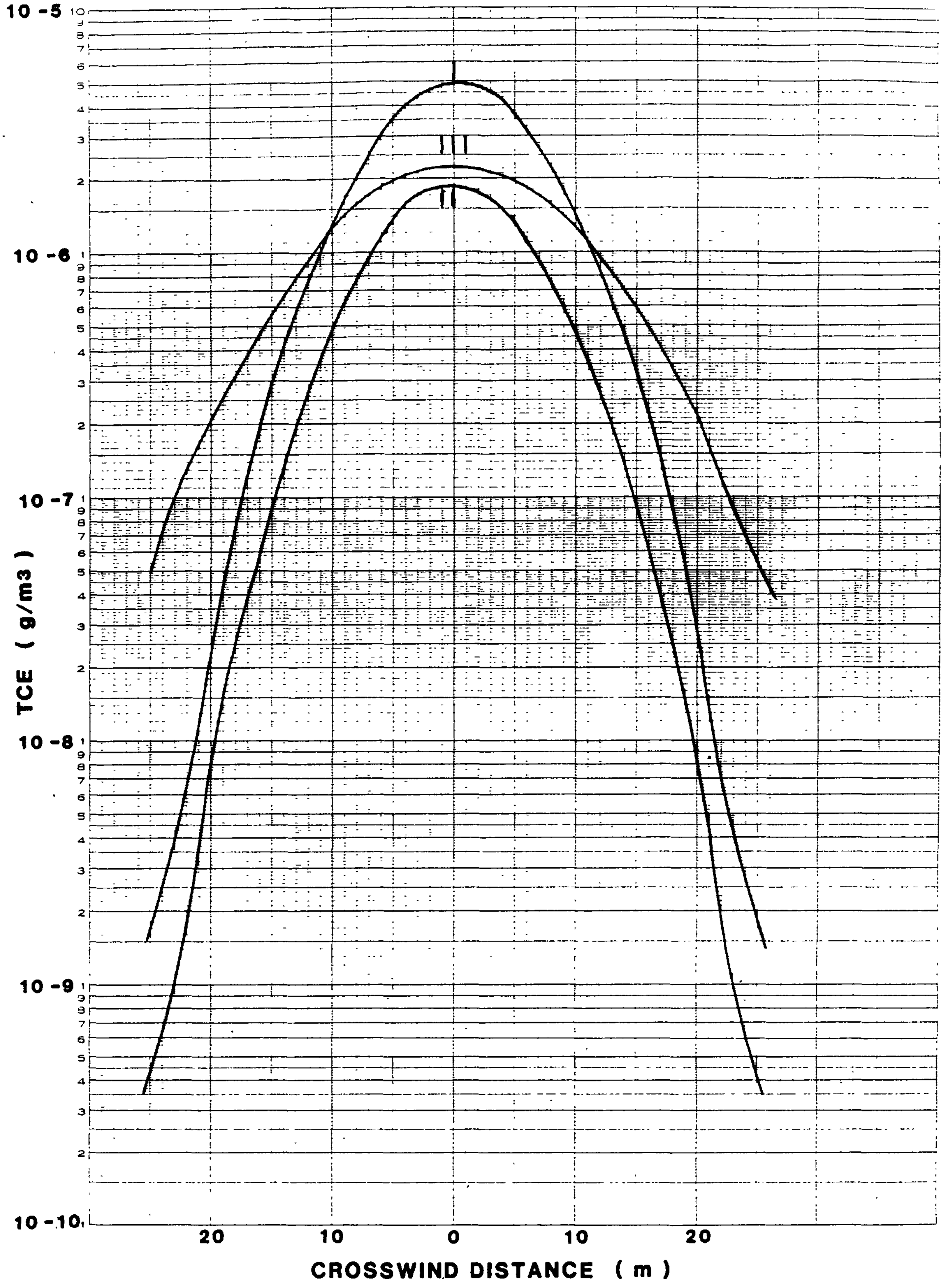
4.6 Summary and Conclusions

The estimates show that the ambient air groundlevel concentrations of trichlorethylene (TCE) and tetrachloroethylene (PCE) will be insignificant based upon existing standards for this chemical. The current OSHA standard for this chemical is an eight-hour time weighted average exposure of 100 ppm. Calculations were made for three atmospheric conditions: 1) the worst possible, 2) typical nighttime, and 3) typical daytime. It was assumed in all calculations that the



PSC Water Services, Inc.

FIGURE 4 - 1
TCE CONCENTRATIONS
VS.
DOWNWIND DISTANCE



PSC Water Services, Inc.

FIGURE 4 - 2
TCE CONCENTRATIONS
VS.
CROSSWIND DISTANCE
FROM POINT OF
MAXIMUM CONCENTRATION

MAXIMUM AMOUNT OF TCE (OR PCE) POSSIBLE WAS BEING EMITTED FROM THE TOWERS. IMPLICIT TO THIS ASSUMPTION WERE AQUEOUS LEVELS OF 100 UG/L, CONTINUOUS TREATMENT AT 300 GALLONS PER MINUTE, AND A 100% TRANSFER OF THE TCE FROM THE WATER TO THE AIR.

FOR THE WORST POSSIBLE CASE, AN INVERSION AT 30 METERS AND WINDS LESS THAN 5 MPH, A MAXIMUM GROUNDLEVEL CONTAMINATION OF LESS THAN 0.001 PPM WOULD OCCUR 160 METERS DOWNWIND OF THE TOWERS. UNDER NORMAL NIGHTTIME CONDITIONS, THE MAXIMUM GROUNDLEVEL CONCENTRATION WOULD BE LESS THAN 0.0004 PPM AT A DISTANCE 70 METERS DOWNWIND OF THE TOWER. DURING DAYTIME OPERATIONS A MAXIMUM CONCENTRATION OF LESS THAN 0.0005 PPM WOULD OCCUR 30-40 METERS DOWNWIND OF THE AERATORS.

GROUNDLEVEL CONCENTRATIONS WERE FOUND TO DIMINISH RAPIDLY WITH DISTANCE FROM THE POINT OF MAXIMUM CONCENTRATION. WITHIN 15 METERS CROSSWIND OF THE MAXIMA, CALCULATED LEVELS WERE TENFOLD LOWER.

THE ESTIMATES PROVIDED IN THIS REPORT INDICATE THAT USE OF PACKED TOWER AERATION TO REMOVE VOLATILE HALOGENATED ORGANICS AT WILLOW GROVE NAVAL AIR STATION WILL CREATE NO AIR POLLUTION HAZARD, EVEN UNDER THE MOST SEVERE OPERATIONAL AND METEOROLOGICAL CONDITIONS.

5.0 SUMMARY AND CONCLUSIONS

THE RESULTS OF THE FOREGOING ANALYSIS ON THE TREATABILITY OF THE POTABLE WATER SUPPLY AT THE WILLOW GROVE NAVAL AIR STATION TO REMOVE VOLATILE ORGANIC CONTAMINANTS SHOWS THAT PACKED TOWER AERATION IS THE PREFERRED TREATMENT METHOD FROM BOTH PERFORMANCE AND COST STANDPOINTS. SPECIFIC CONCLUSIONS FROM THIS PORTION OF THE STUDY ARE AS FOLLOWS:

1. MAJOR CONTAMINANTS FOUND IN THE WELLS ARE TRICHLOROETHENE (TCE) AND TETRACHLOROETHENE (PCE). LEVELS OF THESE CONTAMINANTS FOUND IN THE WELLS RANGE UP TO 100 PPB.

2. REVERSE OSMOSIS WAS NOT SELECTED AS A TREATMENT METHOD BECAUSE OF POOR PERFORMANCE, OPERATIONAL COMPLEXITY, AND HIGH COST.

3. GRANULAR ACTIVATED CARBON TREATMENT WAS NOT SELECTED DUE TO COST, PERFORMANCE WITH HIGHLY VOLATILE ORGANICS, AND POTENTIAL FOR CAUSING OTHER WATER QUALITY PROBLEMS.

4. PACKED TOWER AERATION IS THE RECOMMENDED TREATMENT ALTERNATIVE BECAUSE OF HIGH EFFICIENCY IN REMOVING VOLATILE ORGANICS, REASONABLE COST, AND INHERENT SIMPLICITY.

5. THE SUGGESTED LOCATION FOR A PACKED TOWER AERATION UNIT IS ATOP THE 500,000 GALLON RESERVOIR ADJACENT TO NAVY WELL NO. 2. IT WILL BE NECESSARY TO EVALUATE THE STRUCTURAL ADEQUACY OF THE RESERVOIR COVER PRIOR TO TOWER DESIGN.

6. THE RECOMMENDED AERATION TOWER DESIGN WOULD BE 300 GPM WITH COUNTER-CURRENT AERATION AND FLEXIRING PACKING. OVERALL DIMENSIONS OF THE TOWER WOULD BE 36 INCHES IN DIAMETER BY 16 FEET TALL.

7. AMBIENT AIR GROUNDLEVEL CONCENTRATIONS OF TCE AND PCE WILL BE INSIGNIFICANT BASED UPON EXISTING STANDARDS.

8. THE TOTAL ESTIMATED PROJECT COST FOR THE PACKED TOWER AERATION UNIT IS $66,200.

APPENDICES

APPENDIX A

WATER QUALITY CONSIDERATIONS

Water Quality Considerations - Willow Grove NAS

Th following discussions relate to water quality data included as Tables 9, 10 and 11 (p. 85, 89, and 90) of the Hydrogeologist's Report on "Potable Water Treatability Study - Willow Grove Naval Air Station" dated January, 1985. The discussions address organic and inorganic contamination individually.

-Inorganic Water Quality

In general the inorganic testing showed that all the wells produce a hard water of fairly consistent and potable quality. Only two (of over 30) inorganic parameters tabulated in Table 10 warrant consideration. The levels of barium and selenium are either near or in excess of their respective MCL's of 1.0 and 0.01 mg/L.

It is rare to find barium at concentrations in excess of 1 mg/L in groundwaters which contain sulfate. This is because barium sulfate is a highly insoluble percipitate which forms when the two elements are present in solution. The maximum level of dissolved barium expected in these samples would be less than 0.1 mg/L. This value was determined using the observed sulfate levels and the solubility product for barium sulfate. Thus, unless barite (barium sulfate) was used for a drilling mud, or extensive ion pair formation ($BaHCO_3^+$) is occurring the reported barium levels can be interpreted as an analytical artifact and should be disregarded.

The 1.0 mg/L MCL for barium was derived from air exposure data. It was determined that a concentration of 2 mg/L in drinking water would be safe for adults. To provide safety for more susceptible members of the population, a level of 1 mg/L was recommended. The limit set in the USSR is 4 mg/L. International and European standards do not list barium.

Selenium occurs naturally in various rock strata and can be found in water from both deep and shallow wells. The health effects of selenium are quite controversial and the EPA is currently considering dropping the MCL of 0.01 mg/L. The level was proposed in 1962 in response to animal studies that determined that selenium was carcinogenic. The current literature does not support this contention, nor is there **ANY** epidemiological evidence implicating a higher than normal daily intake of selenium.

The totality of evidence indicates that there is greater overall potential for selenium deficiency than for selenium toxicity given current intake levels. The maximum no-observed-adverse health effect for selenium in water is not less than 0.1 mg/L and appears to be as great as 0.5 mg/L. Selenium is relatively non-toxic and is an essential element in mammals. Therefore, treatment to remove or reduce selenium at Willow Grove is neither justifiabl nor warrented even though the observed selenium levels approach or xceed th curr nt MCL.

-Organic Water Quality

The impetus for the present study was the detection of volatile halogenated organics in the finished drinking water of the subject facility. The organics of primary concern are trichloroethylene (TCE) and tetrachloroethylene (PCE). Another chemical of possible concern which was isolated during the current study was 1,2-dichloroethene. The indication in the hydrogeologists report that the turbine pumps on both Navy Wells were leaking oil (p. 6) led to an additional evaluation for hydrocarbons. The results from this testing were negative, however, repair of the leaking pump seals sould be a high priority item.

The highest levels of PCE contamination were observed in samples taken from Navy Well #1. Of the chemicals present, PCE posed the most serious potential health hazard and efforts should be made to prevent migration of this contaminant towards the other producing wells. Risk assessment models predict that consumption of two liters of water per day for 70 years containing a PCE concentration of 0.8 ppb will induce one excess cancer in a population of 1 million (10-6 risk factor). The corresponding valu for TCE is 2.7 ppb.

The chemical 1,2-dichloroethene has been shown to be a biological degradation product of PCE and TCE. Thus, its presence in these samples is not surprising. This chemical does not currently have an RMCL. However, the isomer form, (detected at below 1 ppb) 1,1-dichloroethene does have an RMCL of zero. The relatively low concentrations of the isomer form indicates other than an anthropogenic source for 1,2-dichloroethene.

Bacteria selectively produce 1,2-dichloroethene from PCE and TCE. Degradation is accomplished by bacteria under anaerobic conditions (in the absence of oxygen) and has been shown to occur more rapidly in shallow soils near the surface. If these levels continue to increase over time, it may indicate that the contamination is at a relatively shallow depth. Declining levels may indicate that formation occurred while the contaminants migrated through the soil and the contamination is no longer at a shallow depth. Relatively stable levels may indicate a relatively steady-state of formation (or leaching) from a producing area. Continued bacterial degradation of PCE and TCE eventually produces vinyl chloride, a highly potent carcinogen. To date, vinyl chloride has not been detected in any of the samples taken at Willow Grove.

APPENDIX B

TREATMENT ALTERNATIVES

- EXECUTIVE SUMMARY -
TREATMENT ALLTERNATIVES FOR VOC CONTAMINATION
WILLOW GROVE NAVAL AIR STATION

This report presents three possible treatment alternatives for VOC removal from the potable water supply at the Willow Grove Naval Air Station. The three treatments evaluated are reverse osmosis, granular activated carbon (GAC) filtration and packed tower aeration. Packed tower aeration was determined to be the most efficient and effective for treatment of the VOC's encountered at Willow Grove.

Reverse osmosis was dismissed as a possible treatment alternative because of its demonstrated; 1) inability to remove VOC's, 2) complexity of operation, 3) high capital and operating costs.

Granular activated carbon is a viable treatment option for the subject facility. Annual replacement of carbon is estimated for a 15 minute empty bed contact time using TCE breakthrough as the design criteria. The GAC replacement and design criteria were based upon operating experiences at Philadelphia Suburban Water Company. Pilot testing of GAC at Willow Grove was not conducted. GAC was not selected as the optimum treatment alternative because of its; 1) cost, 2) potential for causing other water quality problems, and, 3) poor performance for highly volatile organics (e.g. carbon tetrachloride and vinyl chloride) which have been detected or may be encountered in this supply at a future time.

Packed tower aeration was selected as the method of choice for treatment to remove the volatile halogenated organics present in the potable water supply at Willow Grove Naval Air Station. Aeration was selected because of its; 1) inherent simplicity, 2) high efficiency, and 3) cost effectiveness.

The suggested design configuration for Willow Grove would require only one tower that would treat water as it pumped from either Navy Well #1 or Navy Well #2. The location of choice is directly over the 500,000 gallon clearwell located between the two production wells. A structural evaluation will be required to assure the reservoir cover has sufficient bearing capacity for the tower. In the proposed configuration, piping modifications would be required to relocate the point of chlorine application to the tower effluent. Preliminary cost estimates for this facility are in the range of $60,000 to $70,000.

Initial Treatment Design Considerations - Willow Grove NAS

This report considers three possible treatment alternatives for removal of volatile halogenated organics present in groundwater at the subject facility. The three treatments considered are reverse osmosis, granular activated carbon (GAC) and packed tower aeration.

-Membrane Processes - Reverse Osmosis

The three major membrane processes used for water treatment are electrodialysis, reverse osmosis and ultrafiltration. Electrodialysis is a proven process for desalting applications. Conversely, ultrafiltration does not remove salts but is useful for separating large molecules (such as humic material and color bodies) from water. The principal use of reverse osmosis is for purification of brackish water (up to 10,000 ppm total dossolved solids). None of the membrane processes are effective for removal of small non-polar volatile organics such as TCE and PCE. Thus, a membrane process would be of little benefit for removal of the contamination present at the Willow Grove Naval Air Station.

Reverse osmosis has been found to be effective for removal of proteins, sugars, bacteria and viruses. These substances are probably removed because of their relatively large molecular size. However, low molecular weight, water soluble organic molecules are poorly removed.

Reverse osmosis is capital intensive, complicated and expensive to operate. Reverse osmosis facilities normally require chemical pretreatment and chemical posttreatment. Capital costs for plants of similar capacity to Willow Grove have ranqed from $500,,000 to $5,000,000 (1982 dollars). Major problems encountered at operational facilities include deterioration of sulfuric acid feed systems, membrane fouling and declining treatment rates over time.

-Granular Activated Carbon (GAC)

Granular activated carbon has been used successfully to remove volatile halogenated organics from water. The effective life of a GAC contactor or the amount of contamination removed by a given volume of carbon is dependent primarily upon the concentration of the contaminant and the relative affinity of the GAC for that contaminant.

Normally, isotherm evaluations are conducted to screen different GAC's and determine their ability to remove the contamination of concern. From the isotherm data, design criteria is generated for pilot scale evaluations. Pilot studies with GAC are conducted to estimate operational

GAC capacities and develop specific system design data.

The bed lives, conceptual designs and cost estimates presented in this section are based upon assumed adsorption capacities obtained from the literature and PSWCo experiences with GAC for removing these chemicals. The estimates of expected bed life for the contaminants at Willow Grove are given based primarily upon experience with similar waters. These estimates are used to generate conceptual design criteria. These design criteria are then used to estimate costs for implementation of GAC at the Willow Grove Naval Air Station.

TABLE 1: ESTIMATED GAC BED LIFE - WILLOW GROVE NAS

	Contact Time (min)	
Criteria	5	15
Time to breakthrough levels in days		
Trichloroethene (TCE) @ 50 ppb		
Initial Breakthrough	80	200
20% Breakthrough	140	350
Tetrachloroethene (PCE) @ 100 ppb		
Initial Breakthrough	160	350
20% Breakthrough	200	450
1,2-Dichloroethene @ 5 ppb		
Initial Breakthrough	100	250
20% Breakthrough	160	375
1,1,1-Trichloroethane @ 2 ppb		
Initial Breakthrough	60	150
20% Breakthrough	80	200

GAC DESIGN PARAMETERS

Table 1 predicts that GAC is a viable treatment alternative at Willow Grove. Conceptual designs were developed for pressure GAC contactors. Empty bed contact times of 5 and 15 minutes were evaluated for each contactor type using an hydraulic loading rate of 5 gpm/ft. Preliminary design calculations are included as an Appendix.

Pressure Contactors

Pressure contactors costs are based upon pressurized downflow operation using cylindrical ASME code pressure vessels with a design working pressure of 50 psi. Each contactor is designed to treat 0.432 MGD and has a 9 foot diameter with bed depths of 4 and 10 feet for the respective EBCT's of 5 and 15 minutes. The corresponding overall heights are 19 and 23 feet. The carbon contactors would include a nozzle style underdrain and would be designed for rapid removal of spent carbon and recharge.

Two pressure contactors would be required, 1 on-line, and 1 backup unit to be used during backwash and recharge events. Figure 1 shows a typical pressure filter installation.

TABLE 2: SUGGESTED GAC DESIGN CONFIGURATION

-Pumping Capacity	0.432 MGD
-Design Capacity	0.864 MGD
-Type of Treatment	Pressure Vessel, Downflow Post-Chlorination
-Empty Bed Contact Time	15 minutes
-Number of Vessels	2
-Vessel Diameter	9.0 feet
-GAC Bed Depth	10 feet
-Overall Vessel Height	23 feet
-Required area, Filtration	120 sq. feet
-Regeneration	None - GAC Replacement
-GAC Storage Facilities	None - Standby Filter
-Required Area, Storage	NA
-Total Area Requirement (if totally enclosed)	1,200 sq. ft.

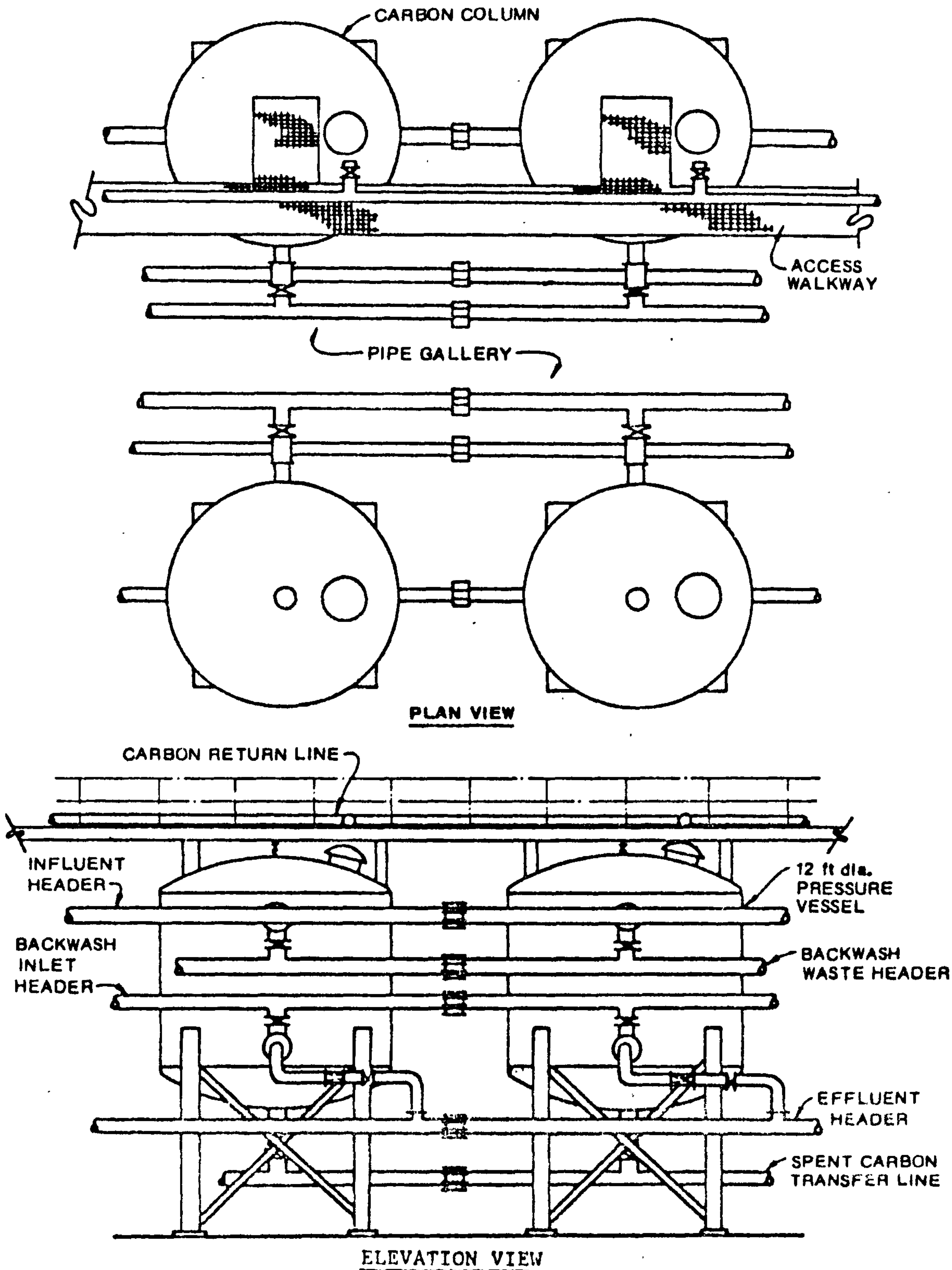


Figure 1 Typical activated carbon column installation.

Table 2 provides the suggested conceptual design for implementation of GAC treatment at the Willow Grove Naval Air Station. The 15 minute empty bed contact time should allow operation of approximately 1 year before carbon replacement is required. Each contactor is designed to allow treatment of the maximum pumpage observed at Willow Grove (300 gpm). The second contactor would be put on-line while the first is being maintained, recharged or if an emergency develops and two production wells are required at one time. Some important water quality considerations must be addressed if GAC treatment is the method chosen for VOC removal at Willow Grove.

- **Treatment Considerations for GAC Contactors**

Granular activated carbon is highly efficient in removing chlorine from water. Thus, the point of chlorination at Willow Grove must be relocated to the effluent side of the GAC columns.

The point of chlorination must be relocated, not only to save chlorine but also, because GAC so effectively removes chlorine that bacterial regrowth within the GAC beds is a distinct possibility. Application of chlorine after GAC filtration will assure disinfection. Placing the GAC filters on the influent side of the covered storage reservoir at Willow Grove will provide sufficient contact time for adequate disinfection prior to consumption.

The numerous halogenated volatile organics present in the groundwater indicate that competitive adsorption may adversely affect adsorption. Chemicals can be selectively desorbed from GAC due to displacement by preferentially adsorbed organics. This phenomena can create effluent concentrations which exceed influent concentrations for the displaced organics. Our research at Philadelphia Suburban Water has shown the chlorinated alkenes preferentially displace chlorinated alkanes. Thus, after a period of operation we would expect to see compounds such as 1,1,1-trichloroethane, 1,1-dichloroethane and carbon tetrachloride having concentrations coming off the GAC which exceed those going onto the GAC.

The small volumes of GAC required at Willow Grove negate any advantage of conducting regeneration of GAC on-site. Since on-site regeneration of GAC is not practical, prudence dictates replacement of spent GAC with virgin material. If material is sent off-site for regeneration, there would be no control over the returned product (e.g. a GAC used to treat hazardous wastes could be mixed with or returned instead of the potable water carbon).

- Cost Estimates - GAC

Capital cost estimates are provided for carbon contactors and the initial carbon fill. Other major cost items such as pumping station and hydraulic system modifications are not included. Table 3 identifies major cost factors associated with a GAC treatment facility.

TABLE 3: GAC ECONOMIC FACTORS

CAPITAL

1. Carbon Contactors
2. Initial Carbon Fill
3. Backwash System
*4. Regeneration Facility
*5. Additional Property Aquisition
*6. Pumping Station Additions & Modifications
*7. Hydraulic Modifications
*8. Engineering

OPERATION AND MAINTENANCE

1. Personnel
2. Power
3. Materials
4. Replacement or Make-up GAC
*5. Analytical Support

***FINANCING COSTS**

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*Costs not determined in this evaluation.

Cost estimates are based primarily upon the "Current Costs of Processing Equipment" from the April 5, 1982 issue of Chemical Engineering and "Estimating Water Treatment Costs, Volume 2" USEPA publication 600/2-79-162b. All costs are updated to 1985 dollars using the March 21, 1985 Engineering News-Record Construction Cost Index (CCI) of 389 (1967 - 100). The cost data provided are factored estimates only (i.e. no vendor quotations were obtained).

Table 4 provides line item cost estimates for GAC pressure contactors at Willow Grove having an EBCT of 15 minutes. Included on the table are first year O &M estimates. These estimates assume electrical costs of $0.056 per Kwh. A more detailed breakdown of specific design calculations is provided in the Appendix.

TABLE 4: GAC PRESSURE FILTER COSTS

	Contact Time (min) 5	Contact Time (min) 15
I. Capital Cost Items		
A. Contactors	$155,000	$170,000
B. Clearwell	Use Existing Facility	
C. Initial Carbon Fill	Included in O&M	
D. Backwash System	Included in A	
E. Regeneration Facility	Not Applicable	
F. GAC Unloading Facility	Not Applicable	
G. Carbon Storage	Contactor Storage	
H. Relocate Chlorination	7,500	7,500
Preliminary Capital	**$162,500**	**$177,500**
II. First Year O&M Costs		
A. Labor	$ 1,500	$ 500
B. Power	1,000	1,000
C. GAC	13,500	11,000
D. Maintenance Materials	1,500	1,500
Preliminary O&M	**$ 17,500**	**$ 14,000**

- Summary GAC Treatment at Willow Grove

GAC is a possible treatment alternative for removal of VOC's (specifically TCE and PCE) from the potable water supply at the Willow Grove Naval Air Station. The increased capital cost of a 15 minute contact time versus a 5 minute contact time would be recovered by the reduced operating costs associated with the larger system.

The capital cost associated with the suggested GAC configuration is approximately $0.06/1000 gallons assuming a 20 year life for the facility. Operating costs are estimated at $0.09/1000 gallons. The performance of GAC for certain volatiles is questionable and close monitoring of these other organics would be required.

- **Packed Tower Aeration**

Air stripping of volatile organics from water can be accomplished by a number of methods. Diffused aeration, tray towers and packed towers have all been applied for removal of volatiles from water. The efficiency of a particular system is dependent primarily upon its ability to provide intimate contact of the water with air. Packed towers have become the method of choice for air stripping because of their high efficiency and low costs. As of November 1984, there were approximately three dozen installations using packed tower aeration to produce potable water from contaminated groundwater supplies.

Figure 2 provides a sketch of a packed tower aerator filled with a packing material to provide a large surface area for air and water to contact each other. Contaminated water is introduced at the top of the column and trickles down through the packed bed. Fresh air enters the bottom of the tower and is passed up through the bed. The volatile contaminants in the water are transferred to the air and the clean water exits the bottom of the column.

Removal of volatile organic chemicals by aeration has been found to closely follow Henry's Law. Henry's Law states: "In a dilute solution, the vapor pressure of the solute (contaminant) is approximately proportional to its mole fraction". Thus, the partitioning of an organic from th water to the air can be considered to represent the relative tendency for a compound to partition between a gas and a liquid phase. Based upon Henry's Law constants, all of the volatile halogenated organics of concern at Willow Grove are amenable to treatment by air stripping.

The degree of removal of volatile organic compounds from water by aeration is dependent upon several factors, the most important of which include:

1. Contaminant concentration
2. air to water ration
3. effective contact area between air and water
4. water temperature
5. physical and chemical properties of the contaminant.

Table 5 provides physical properties for the contaminants isolated from water samples taken at Willow Grove. The table indicates that 1,2-dichloroethene will be the most difficult chemical to remove by air stripping and design criteria should verify effective removal for this compound. If designs provide for effective removal of this chemical then effective removal of the other volatile organics present will be assured (including carbon tetrachloride and vinyl chloride).

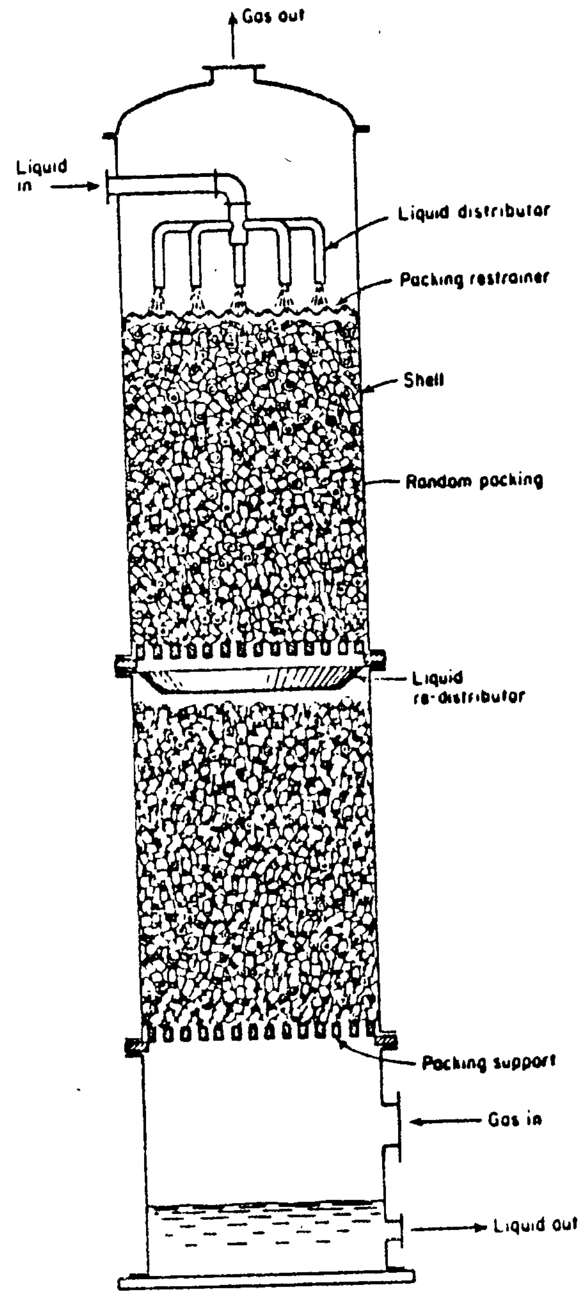


Figure 2. Packed Tower Aerator

Table 6 includes the preliminary design criteria necessary to remove these chemicals by packed tower aeration. Table 7 shows the results of initial screening tests conducted at Willow Grove to select the optimum packing material and air to water ratio for operation of a packed tower aerator. The results from these continuing evaluations will be used to provide optimized packed tower aerator design recommendations for the Willow Grove facility. Table 8 provides preliminary cost estimates for packed tower aeration at Willow Grove.

TABLE 5: PHYSICAL PROPERTIES OF VOLATILE ORGANICS FOUND AT WILLOW GROVE NAVAL AIR STATION

CHEMICAL	MOL. WEIGHT	DENSITY (g/cc)	B.P. (C)	SOL. (ppm)	HENRY'S K*
Trichloroethene (TCE)	131.4	1.466	87.2	1,100	0.5
Tetrachloroethene(PCE)	165.9	1.623	120.8	140	1.1
1,2-Dichloroethene	97.0			3,500	0.2
1,1,1-Trichloroethane	133.4	1.339	74.1	720	1.5

*Antoine correlation from solubility and vapor pressure

TABLE 6: Packed Tower Aerator Design Criteria
Willow Grove Naval Air Station

HYDRAULIC DESIGN	
-Treatment Rate	300 gpm
- Water Temperature	13 C.
-Air to Water Ratio	20-30:1
-Tower Diameter	36 inches
-Liquid Mass Rate	21,238.5 lb/hr ft
-Air Mass Rate	526 - 700 lb/hr ft (800-1,100 cfm)
-Surface Loading	42.4 gpm/ft
MASS TRANSFER DESIGN	
- Efficiency	95+% reduction of 1,2-Dichloroethene
-Required Packing Material	Under Evaluation
-Number of Transfer Units	Under Evaluation
-Height of Transfer Units	Under Evaluation
-Overall Packing Depth	Under Evaluation Estimated at 20 feet for Conceptual Design.

TABLE 7: Preliminary Aeration Study - Willow Grove
Navy Well #2 - 2/13/85

	% Removed		
Sample	TCE	PCE	1,1,1-TCE
Untreated (ppb)	13.4	25.8	0.96
Packing A			
3' bed depth	73%	76%	55%
4' bed depth	84.5%	86%	62%
Packing B			
3' bed depth	63%	66%	53%
4' bed depth	67%	70%	52%

TABLE 8: Preliminary Cost Estimates - Packed Tower Aeration
Willow Grove Naval Air Station

Engineering and Design	
-Structural Analysis	$ 3,500
-Drafting	4,800
-Electrical Engineering	1,000
-Permits	1,500
Fabrication and Installation	
-Tower Shell	$ 15,000
-Liquid Distributor, Redistributors	1,500
-Packing Support Tray	500
-Packing	3,000
-Demister	1,000
-Blower	2,000
-Piping	5,000
-Electrical	1,500
-Erection	5,000
-Sheet Metal Work	1,000
-Site Preparation	1,000
Subtotal	$ 47,300
Contingency @ 15%	7,100
Profit & Overhead (@ 20-30%)	9,500 - 14,200
Estimated Costs	$64,000 - 68,600

Summary - Packed Tower Aeration at Willow Grove

Packed tower aeration is the most practical treatment alternative for removal of volatile halogenated organics at the Willow Grove Naval Air Station. Optimal implementation of this process should utilize the existing lift capacity of current production wells. The tower discharge could then be directed to the existing storage reservoir. This configuration would negate the need for additional pumping facilities. A detailed report providing specific design recommendations will be prepared following the completion of aeration pilot testing and review and approval of the conclusions arrived at in this report.

APPENDIX: GAC DESIGN CALCULATIONS

I. Required Surface Area (5gal/min/sq.ft. loading):

$$\left(\frac{432{,}000 \text{ gals}}{\text{day}}\right)\left(\frac{\text{day}}{1{,}400 \text{ min}}\right)\left(\frac{\text{ft}^2}{5 \text{ gal/min}}\right) = 60 \text{ ft}^2$$

= 9 ft. diameter per contactor

II. Required Bed Volume:

A) 5 minute contact time

$$\left(\frac{432{,}000 \text{ gals}}{\text{day}}\right)\left(\frac{\text{day}}{1{,}440 \text{ min}}\right)\left(\frac{\text{ft}^3}{7.481 \text{ gal}}\right)\left(\frac{5 \text{ min}}{1}\right) = 200 \text{ ft}^3$$

B) 15 minute contact time = 600^3ft

III. Required Bed Depths:

A) 5 minute contact time = 3.3 ft.

B) 15 minute contact time = 10 ft.

IV. Initial Carbon Fill Cost:
(assumes; bulk density of 26#/ft^3, $0.70/#)

A) 5 minute contact time = $ 4,500

B) 15 minute contact time = $11,000

V. Pressure Contactor Cost Estimates
-Designed as Contactor Pairs of 0.864 MGD capacity
(after reference 5 p. 300-302)

A) 5 minute EBCT

-Excavation & Sitework	$ 770
-Manufactured Equipment	71,600
-Concrete	3,200
-Steel	1,650
-Labor	12,400
-Pipe & Valves	22,300
-Electrical & Instrumentation	22,800
SUBTOTAL	**$134,720**
-Miscellaneous & Contingency (15%)	$ 20,280
TOTAL	**$155,000**

Cost per Contactor = $77,500 x 2 contactors = $155,000

B) 15 minute EBCT

-Excavation & Sitework	$ 770
-Manufactured Equipment	81,000
-Concrete	3,200
-Steel	1,650
-Labor	13,100
-Pipe & Valves	24,500
-Electrical & Instrumentation	22,900
SUBTOTAL	$147,120
-Miscellaneous & Contingency (15%)	$ 22,880
TOTAL	$170,000

Cost per Contactor = $85,000 x 2 contactors= $170,000

APPENDIX C

INTERIM TREATMENT RECOMMENDATIONS

INTERIM TREATMENT RECOMMENDATIONS
-WILLOW GROVE NAVAL AIR STATION-

The following interim procedures are recommended to assure a safe potable water supply at the subject facility. These procedures should be followed until a permanent solution for groundwater contamination is implemented.

1. Use **ONLY** Air Force Well #3 for potable water supply.
2. Pump Navy Well #1 to waste to protect Air Force Well #3 and Navy Well #2 from PCE contamination.
3. Repair/replace oil seals of turbine pumps in Navy Wells #1 and #2.
4. Continue existing monitoring program and expand to include 1,2-dichloroethene and vinyl chloride.

Justification for Recommendations:

The USEPA has established drinking water recommended maximum contaminant levels (RMCL's) of zero for the primary contaminants (TCE and PCE) identified in the subject water supplies. Although RMCL's are unenforceable health goals, the levels observed in Navy Well #1 will most likely exceed the soon to be promulgated MCL's for public drinking water supplies. The EPA has indicated that the MCL's to be proposed this Spring will be in the range of 5 to 50 parts per billion for each of seven contaminants.

The Air Force Well consistently shows the lowest levels of contamination and should be used for water supply whenever possible. In all likelihood, the levels observed in the Air Force Well will not exceed the MCL's to be promulgated by EPA this Spring.

In order to assure that the levels of contamination in the Air Force Well do not increase it is recommended that continuous pumping of Navy Well #1 be practiced. Based upon the referenced hydrogeologists report, a pumping rate of at least gpm should be maintained. This should contain the PCE and some of the TCE contamination in the local area of Navy Well #1 and prevent contaminant migration towards the Air Force Well. The untreated wastage from Navy Well #1 could be used for landscaping, firefighting, or other purposes.

The Navy should be advised that when selecting a well for service the levels of both PCE and TCE should be considered. From a health effects viewpoint, PCE is considered to be more detrimental than TCE. The higher levels of PCE in samples taken from the Navy Wells indicate concern is warranted.

APPENDIX D

ALTERNATE SOURCE OF SUPPLY

ALTERNATE SOURCE OF SUPPLY

In the event that the existing contaminated wells in the Naval Air Station cannot be economically rehabilitated, other avenues must be pursued to secure a safe water supply. Options available for the Base fall into two categories:

1. Internal supply development through siting new wells; and
2. External interconnection with a neighboring municipal supply.

Internal Supply Development: The potential for finding additional suitable sites for drilling wells within the Base compound was discussed in the "Hydrogeologist's Report". Therein it was noted that based on the characteristics of the underlying aquifer additional wells with suitable yields could be installed.

A well drilling program carries with it an element of risk. It is not known with certainty an exact location for situating a new well. At the Naval Air Station, the risk is increased because of the widespread zone of groundwater contamination. Without more investigations, a new well may yield contaminated water initially or become contaminated from the same sources affecting the existing wells.

Before embarking on a well siting program, investigations along the lines presented in Conclusion No. 6 by the Hydrogeologist should be performed. The major points are:

1. Locate sources of contamination; and
2. Define level of soil and ground-water contamination.

Without this knowledge, a drilling project would be highly speculative and not recommended.

It is assumed, based on the previous study, that suitable high yield wells can be located on the property. Furthermore, if it can be taken that the extent of contamination will be defined and contained, primary consideration falls on the cost inherent in developing new wells versus other available options.

Capital costs have been developed from actual bids received for projects of a similar nature. The costs include the following items:

1. Well exploration: drilling test wells at selected locations based on hydrogeologic investigations.

2. Well development: enlarging, casing, screening and test pumping one or more test wells for production wells.

3. Well house: structure including pumps, controls, chlorination equipment.

In 1985 dollars, the estimate cost for well exploration and well development is $35,000; a typical well house is estimated to cost $106,000. This yields a total construction cost of about $141,000 to bring a new production well on-line.

The above costs are subject to variation due to site specific considerations. They do not include expenses incurred in locating and containing sources of contamination; this element of the Hydrogeologist's recommendations should be performed no matter which option is selected. Operating costs should be roughly similar to present expenses.

External Supply Development: The Naval Air Station is located in the water service area of the Horsham Township Authority. The Authority provides water to much of the Township surrounding the base. Municipal water service is being provided to several buildings on the southwestern side of the Air Station from a 12-inch main along Horsham Road.

Horsham's system consists of 11 in-service pump and well stations, 4 storage tanks totalling 2,450,000 gallons of storge plus an extensive distribution system. The overflow elevation on the storage tanks is 454.20 feet. The entire Horsham system is served by gravity. Interconnections exist between Horsham and the systems serving Warminster and Hatboro.

From existing data, it is estimated that the average daily water requirements at the base are 160,000 gpd. Based on discussions with the Horsham Township Authority's Engineer, there is sufficient capabilities within the Horsham system to meet this demand plus provide for fire service needs. Seven of Horsham's well stations are equipped with emergency electrical generators to assure continued system operation in the event of power outages.

It is not feasible to extend the existing base service off Horsham Road to serve the rest of the Air Station. The internal distribution system is comprised of 4 to 6 inch lines. These are inadequate to handle all the water the base uses and, hence, would have to be up-sized. Furthermore, economical installation to reach the main base compound would entail crossing the runways.

The best approach for the Air Station to access Horsham's system would be an extension of an existing 10-inch main in Maple Avenue along the southern base boundary. This main presently ends about 800 feet along Maple Avenue from the intersection with Horsham Road.

The extension would consist of additional 10-inch water main along Maple Avenue paralleling the base boundary to the intersection with U.S. Route 611. At this point, the line would be routed north into the Air Station along Avenue A. The interconnection with the base water system would be at the existing 10-inch line in the vicinity of Buildings 21 and 43.

Project costs for the connection with Horsham's water system are presented in Table 1. Component costs for engineering, legal/administration, the meter, valve and backflow preventor were obtained from the Authority's Engineer. Construction costs total $117,700 and total project costs $156,500.

With this alternative, the Naval Air Station would pay service charges to the Horsham Township Authority. The Authority presently charges a flat $1.12 per thousand gallons for water use. Based on the estimated demand at the Air Station, the annual cost for water service would be about $65,400.

TABLE 1

ESTIMATED PROJECT COSTS
CONNECTION OF WILLOW GROVE NAVAL AIR STATION
WATER SYSTEM WITH HORSHAM TOWNSHIP SYSTEM

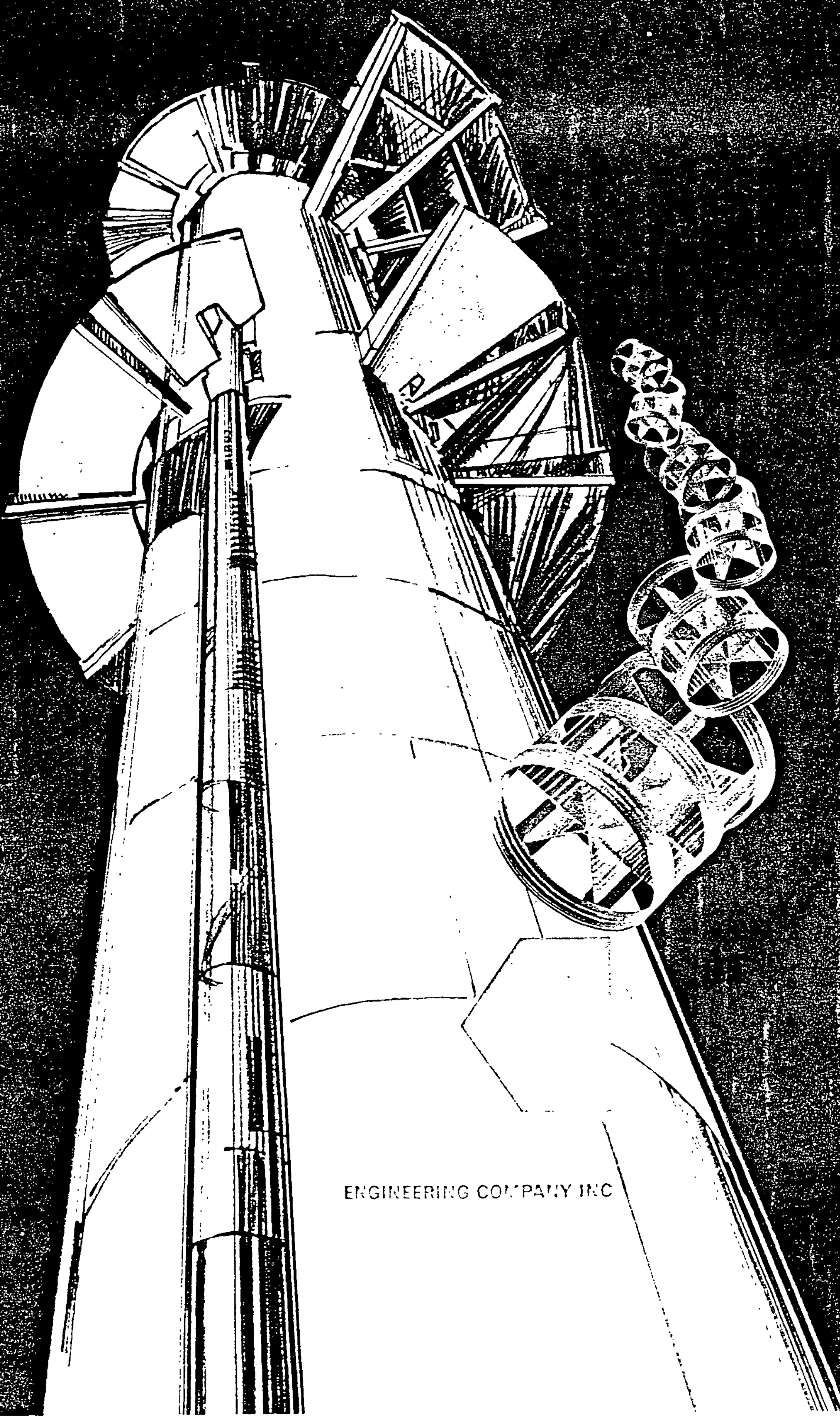
Item	Estimated Cost
Constructon Costs	
3100 ft. 10" D.I.P. Water Main	$ 89,900
FMCT Water Meter	13,800
Backflow Preventor	8,200
10" Tapping Sleeve and Valve	3,500
Meter Pit	2,300
Total Construction Cost	117,700
Contingency (10%)	11,800
Legal and Administrative (3%)	3,500
Engineering (20%)	23,500
Total Project Cost	$156,500

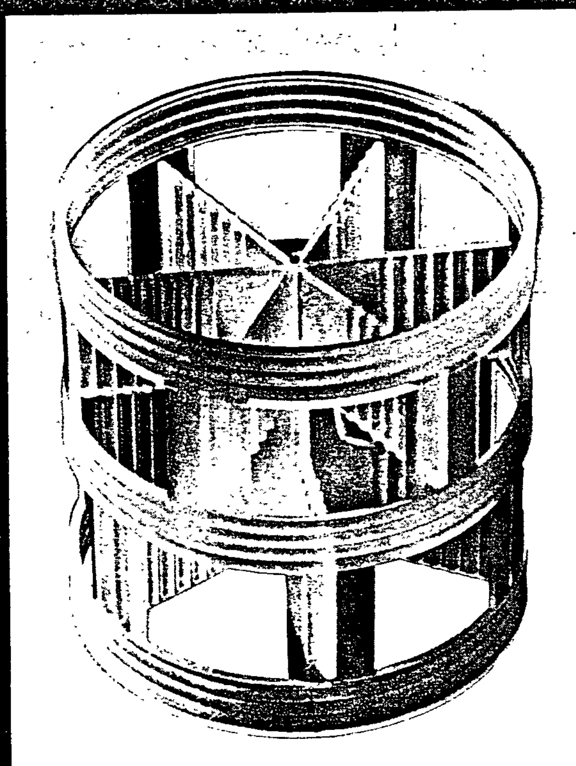
APPENDIX E

INFORMATION ON FLEXIRING PACKING

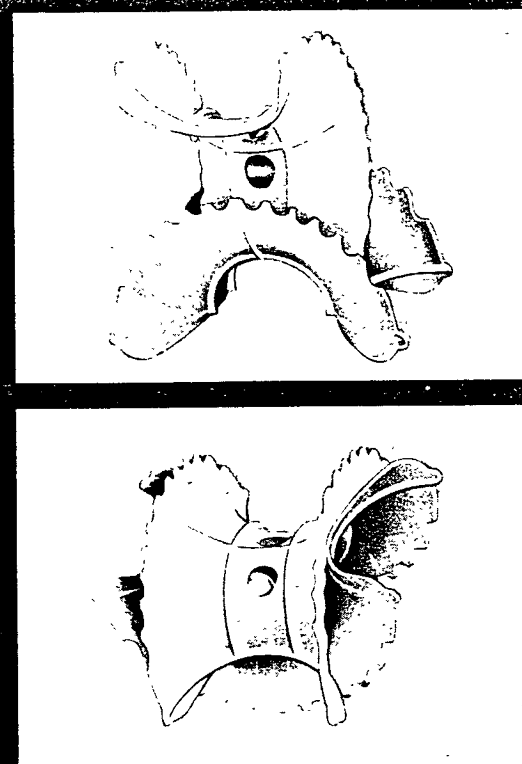
Bulletin PFR-1

PLASTIC FLEXIRINGS®





KOCH PLASTIC FLEXIRING



"NESTING" INTALOX SADDLES

COMPARATIVE EMBRITTLEMENT RESISTANCE

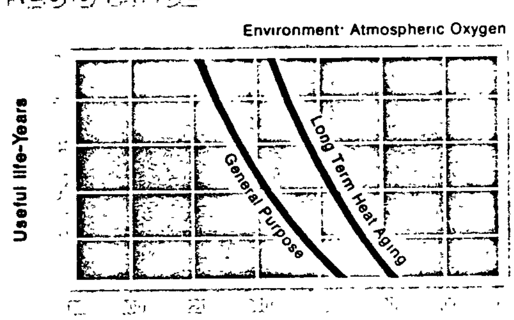


FIGURE 1

COMPARATIVE EXTRACTION STABILITY

RESIN IDENTIFICATION	NO. OF COMPLETED CYCLES
Koch LTHA Grade	[illegible]
Competitive Grade	[illegible]
Other Grades—A	[illegible]
B	[illegible]
C	[illegible]
D	[illegible]
E	[illegible]

TABLE 1

Plastic FLEXIRINGS of LTHA Polypropylene or Glass Fiber Reinforced (G.F.R.) LTHA Polypropylene offer the most economical choice of media for packed tower construction.

With allowable operating temperatures as high as 290°F in twenty (20) foot bed depths, LTHA Polypropylene FLEXIRINGS and G.F.R. LTHA Polypropylene FLEXIRINGS are being successfully used in these environments where polypropylene resin grades previously used were not satisfactory:

Acid Gas Absorbers and Strippers at temperatures as high as 275° F.

Sweetening of aliphatics containing aromatics.

Condensation sections (direct contact heat transfer).

The cylindrical shape of FLEXIRINGS prevents "nesting" that occurs with the half-moon form of Intalox® Saddles or the rosette configuration of Tellerettes® Further, the FLEXIRING shape gives much greater resistance to thermal distortion. With plastic FLEXIRINGS *continued* high performance in service is guaranteed where other packings of the same plastic show a falling-off in capacity and efficiency after short service periods.

Polypropylene

LTHA RESIN: This polyolefin resin has become an important material because of its lightness, chemical resistance and low cost. But the term "polypropylene" covers substances with widely varying service characteristics.

Koch polypropylene FLEXIRINGS are manufactured of virgin unfilled LONG TERM HEAT AGING (LTHA) resin—the resin being chemically stabilized to provide maximum resistance to embrittlement at elevated temperature. Figure 1 and Table 1 demonstrate why KOCH LTHA polypropylene FLEXIRINGS last *at least twice* as long as other polypropylene tower packing.

EMBRITTLEMENT RESISTANCE: Figure 1 describes the results of hot air aging of LTHA and general purpose polypropylene resins. Note that even at 250°F. and 260°F, the LTHA resin shows more than *two times* the useful life of the general purpose resin.

Since polypropylene FLEXIRINGS are employed extensively in hot alkaline acid gas treating, an accelerated test has been devised to compare performance in this type of environment. Polypropylene FLEXIRINGS are boiled for one week in a 25% water solution of potassium carbonate (atmospheric pressure) and then hot air oven-aged at 285°F for one week. The two operations lasting a total of 2 weeks constitute one cycle.

Table 1 gives the results of 3 duplicate programs in which the best resins of a number of polypropylene manufacturers were exposed to this test. Again the Koch LTHA polypropylene scored highest, proving that KOCH LTHA polypropylene FLEXIRINGS will last twice as long as competitive polypropylene packing.

"Intalox"® is a registered trademark of Norton Co.

"Tellerettes"® is a registered trade name of the Ceilcote Co.

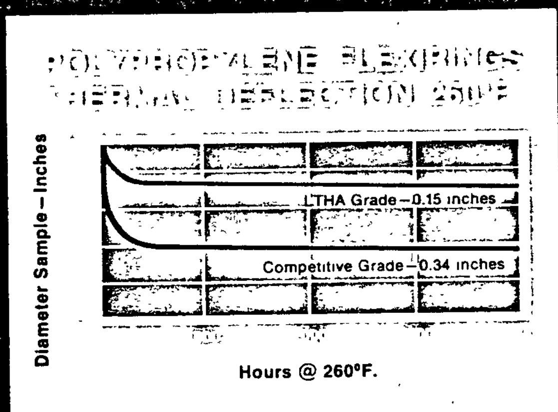


FIGURE 2

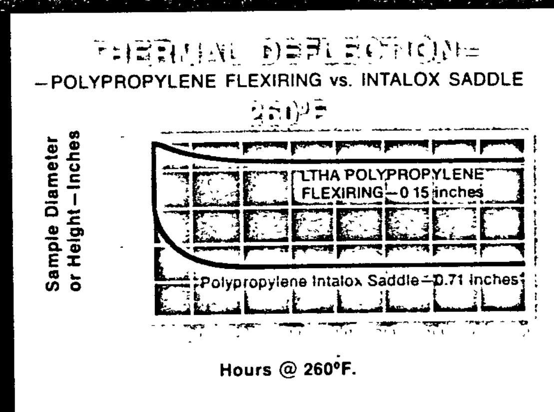


FIGURE 3

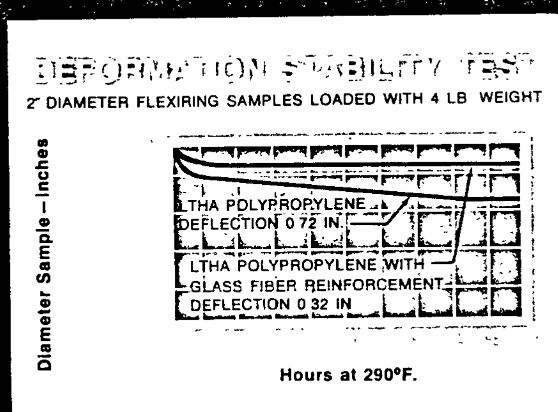


FIGURE 4

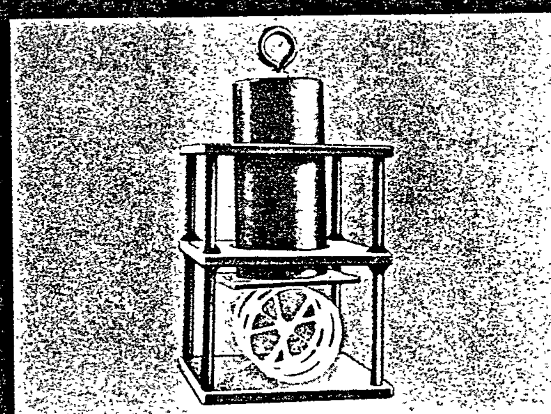


FIGURE 5

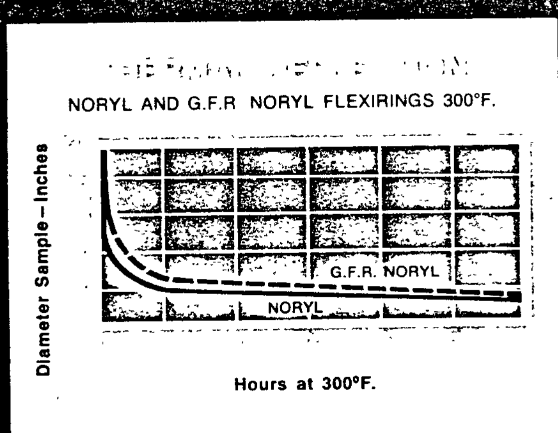


FIGURE 6

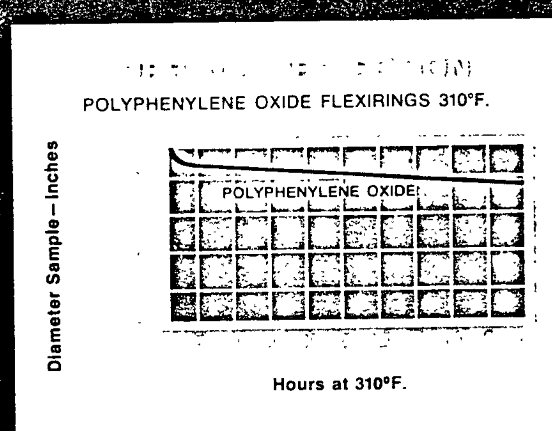


FIGURE 7

THERMAL DEFORMATION: Koch LTHA Polypropylene FLEXIRINGS will withstand more compressive stress at elevated temperature. Practically, this means that deeper beds at higher temperature are permitted with Koch FLEXIRINGS while maintaining low pressure drop, high capacity and maximum efficiency.

To prove the outstanding superiority of LTHA polypropylene FLEXIRINGS in resistance to deformation, a two (2) inch FLEXIRING on its side, was loaded with a four (4) pound weight to simulate the load on the bottom rings in a 20 foot bed depth. (Fig. 5) The ring was exposed to hot air at 260°F. Figure 2 shows that Koch LTHA polypropylene FLEXIRINGS undergo *half* the distortion compared to competitive rings.

Polypropylene Saddle packing was subjected to the same deformation test. Figure 3 indicates the rapid distortion of the saddle—more than 4 times the deflection experienced by the FLEXIRING.

When there is no solvent effect, as in most aqueous systems, Koch LTHA polypropylene FLEXIRINGS are recommended up to 260°F under continuous service.

GLASS FIBER REINFORCED (G.F.R.) POLYPROPYLENE FLEXIRINGS: Combining LTHA polypropylene resin with glass fibers creates a more heat-resistant product. The addition of chemical coupling agents insures that each glass fiber is totally surrounded by polypropylene resin. As a result, glass fiber *reinforced* (G.F.R.) Polypropylene FLEXIRINGS will resist the action of alkalis to the same degree as straight polypropylene rings. The glass fibers, totally surrounded by polypropylene, are not exposed to the corrosive environment.

Filled polypropylene packing—a mechanical blend of glass fibers (or other material) and polypropylene resin—should not be confused with *reinforced* material. One difference is the brittleness of a filled resin in comparison to a reinforced resin. *Filled resin is never used to manufacture Koch FLEXIRINGS.*

Figure 4 shows that at 290°F, G.F.R. LTHA polypropylene FLEXIRINGS will show less than half the distortion experienced by straight polypropylene rings.

G.F.R. rings are recommended in continuous service (non-solvating environments) up to 290°F.

Other Plastics

Polypropylene has excellent chemical properties but is limited to continuous service at a temperature of 290°F (glass fiber reinforced). Koch Engineering Company produces FLEXIRINGS of other materials that can withstand higher temperature. Noryl, PPO, Kynar and glass fiber reinforced versions of the latter are examples. (Figs. 6-7)

Applications

Plastic packings—especially the relatively inexpensive polypropylene and reinforced polypropylene—have largely replaced ceramic and metal in many absorption, distillation, extraction and direct contact heat transfer operations. The following are just a few examples:

EFFICIENCY AS A FACTOR OF GAS RATE

SYSTEM: CO_2 – Dilute NAOH
LIQUID RATE: 20GPM per sq. ft.
PACKING: LTHA POLYPROPYLENE FLEXIRINGS

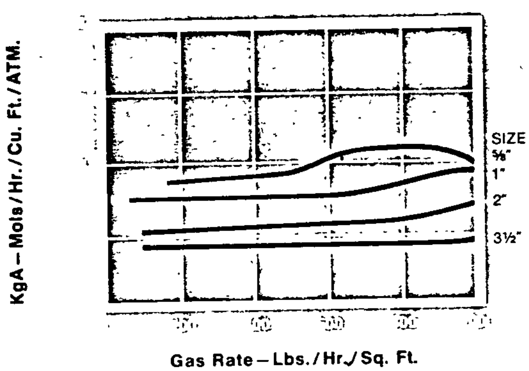


EXHIBIT A

CAPACITY – PRESSURE DROP LTHA POLYPROPYLENE FLEXIRINGS

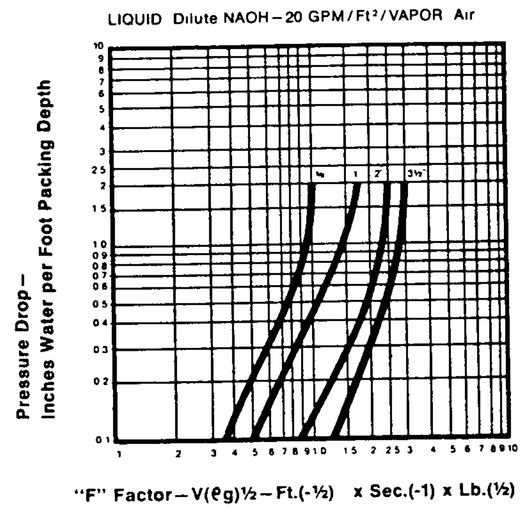
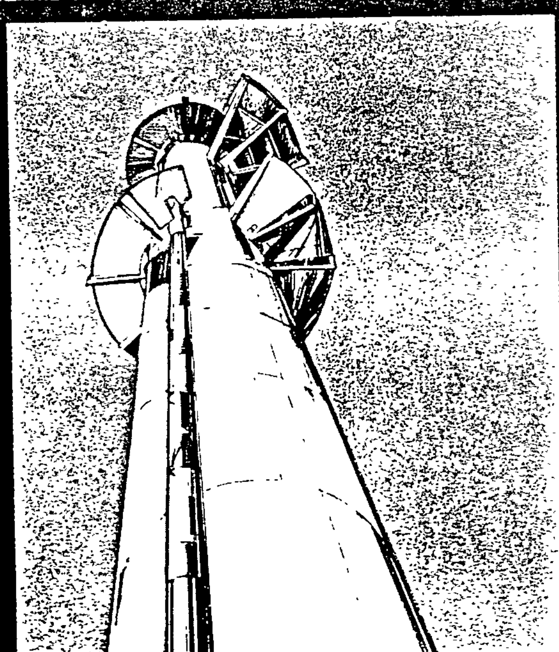


EXHIBIT B



DATA ON POLYPROPYLENE FLEXIRINGS

NOM SIZE INCHES	GEOMETRIC SURFACE SQ. FT./FT.³	FREE SPACE %	PACKING[1] FACTOR (AVERAGE)	BULK DENSITY – LBS./FT.³	
				LTHA Polypropylene	G.F.R. LTHA Polypropylene
5/8	105	92	78[2]	7½	9½
1	65	94	45[2]	6½	8¼
1½	40	96	28[2]	4¾	6
2	35	96	22[2]	4	5¼
3½	28	97	18[3]	4	5

1. Suitable for Plastic or Metal Rings.
2. Used in the hydraulics correlation. Figure should be reduced 10% for distillation under vacuum. Figure should be increased 10% for operation at liquid rates between 10 and 30 GPM per Sq. Ft. Increased by 15% at liquid rates 30 to 80 GPM/ft.²
3. Figure is to be used at all liquid rates up to 100 GPM/ft.²

EXHIBIT C

a. Installations for Alkanolamine Absorption and Stripping of acid gases use Koch LTHA polypropylene FLEXIRINGS. In many cases, the Koch FLEXIRINGS have replaced existing porcelain saddles and rings. The LTHA polypropylene FLEXIRINGS are used in bed depths exceeding 20-ft., and at temperatures of 250-260°F.

b. In promoted and straight hot potassium carbonate Absorbers and Strippers, LTHA polypropylene FLEXIRINGS have become the specified packing. In the case of pressurized Strippers, where temperature exceeds 260°F and is below 290°F, G.F.R. LTHA polypropylene FLEXIRINGS have proved satisfactory. The unreinforced LTHA polypropylene rings, again, have replaced ceramic and steel packing in many of these towers and are operating successfully up to temperatures of 255°F. In some cases, this packing has already been in service for longer periods than the ceramic packing replaced.

c. Liquid extraction of sulfur compounds from C_3's, C_4's, C_5's, etc., even containing aromatics, has been successfully effected with caustic and alkanolamines using Koch LTHA polypropylene FLEXIRINGS and G.F.R. LTHA polypropylene FLEXIRINGS. It is true that aromatics do tend to soften polypropylene. The LTHA rings, however, will float in the continuous aqueous phase, thereby removing all stress from the ring. The slight softening, therefore, does not preclude use of the LTHA polypropylene. Where more compressive stress will be put on the ring we recommend our G.F.R. LTHA polypropylene, in the presence of aromatics. It is, of course, valuable to test resin behavior if the particular system is one with which Koch Engineering does not have experience.

There are other obvious applications, but we have enumerated some of the severe ones—temperature-wise, especially—with which Koch has now had long-term experience. Potential users are encouraged to consult Koch with their particular problems.

Koch Plastic Flexirings Have Other Advantages:

a. Installation of this packing does not require the extreme care that must be observed with ceramic packings: no water is required, no provision need be made to prevent collision of the packing pieces as they fill the tower. Customers have reported to Koch that it takes only *one-tenth* the time and cost to install plastic FLEXIRINGS, compared to porcelain saddles; only *one-third* the time compared to heavier metal packings, which are shipped in smaller containers.

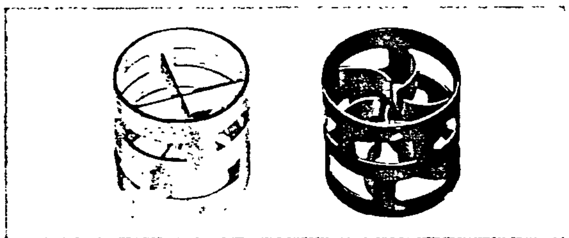
b. The smooth surface of polypropylene FLEXIRINGS discourages solids disposition but occasionally this will occur. Koch LTHA FLEXIRINGS can be easily cleaned *in situ*: the tower may be filled with water, for example, and the floating rings agitated with steam, air, inert gas or any other appropriate vapor.

c. Troublesome breakage, ceramic sludge or metal corrosion products are a thing of the past when Koch plastic packing is used. Thus pressure drops are maintained low and towers can operate at peak capacity and efficiency.

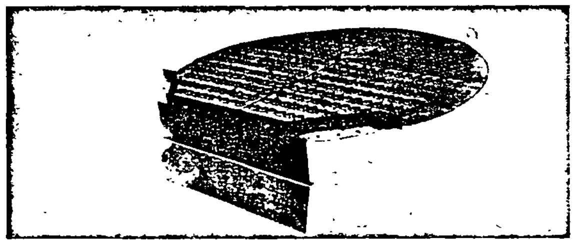
Koch offers you a full line of process separations equipment developed in 40 years of experience.

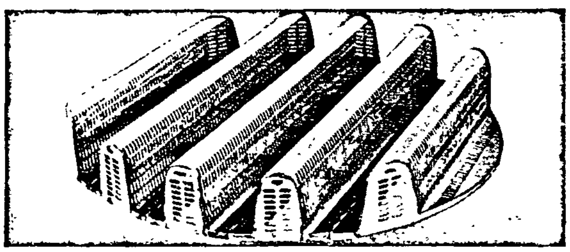
These product bulletins now available...

KOCH METAL AND PLASTIC FLEXIRINGS – BULLETIN KF-3
Build smaller packed columns with higher operating efficiency. Get the lowest pressure drop per unit of mass or heat transfer. No breakage – no sludge – maintain high processing efficiency and capacity.



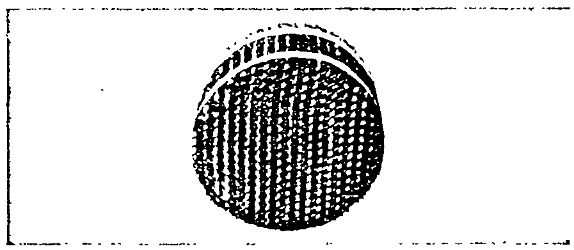
KOCH FLEXITRAYS® – BULLETIN KT-5
Proved after thousands of installations –
a. lowest first cost
b. highest capacity with maintained efficiency (Best "turn-down" characteristics)
c. freedom from fouling





KOCH PACKING SUPPORT PLATES, DISTRIBUTORS, RE-DISTRIBUTORS – BULLETIN KI-3
Proved designs for maximum packing performance. Prevent excessive restrictions at the supports. Provide and maintain equal irrigation densities and concentrations across column diameters. Avoid bottlenecks and poorly distributed liquids.

AIR POLLUTION CONTROL – BULLETIN KPC-1
Complete systems for particulate matter removal in submicron range to meet the most stringent government codes.



KOCH SULZER PACKING – BULLETIN KS-1
For the very difficult vacuum fractionations.

TRICKLING FILTER FOR B.O.D. REMOVAL – BULLETIN TRF-1
A unique application of Koch Engineering mass transfer technology to provide rapid degradation of biologically active wastes.

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