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AquaDetox Stripping System for Groundwater Remediation

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Introduction

Enormous quantities of water are contained relatively near the surface of the ground in the United States. It has been estimated that within one-half mile of the surface, there are between 33 and 100 quadrillion (10^{15}) gallons of water. The volume of groundwater within this zone is estimated to be 4 times that of the volume of water in the Great Lakes. (1)

Approximately 25% of all of the water used in the United States comes from this resource--and it is the source of 50% of the drinking water in the U.S. Groundwater supplies up to 90-95% of the needs of rural America. Approximately 35% of our cities depend--at least in part--on groundwater for their supply. (2)

Our "thirst" for water is growing faster than our population. In 1950, 151 million Americans consumed 35 billion gallons per day of water; in 1980, our population had grown by 50% to 227 million, but our use of water had increased by nearly 160% to 90 billion gallons per day. (3)

Incidents of groundwater contamination have occurred in all 50 states. The industrial revolution, which began creating significant amounts of contamination nearly 100 years ago, has multiplied manyfold since World War II. An important factor in this development has been the use of an ever growing number of chemicals--including some which can have a detrimental impact on the environment.

During the past 10-15 years, we have seen the emergence of ever more accurate and sensitive methods for detecting substances in water at exceedingly low levels--parts per billion, parts per trillion, and even lower. Fortunately, at the same time, there has been the development of a number of technologies that can be utilized to restore water to "drinking water" quality.

Technologies that are in practice for the remediation of groundwater and contaminated soil include:

- Removal to hazardous landfill
- Incineration
- Wet air oxidation
- Solidification
- Soil air purging
- Carbon bed adsorption
- Membrane separation
- Ion exchange
- Stripping

Each of these technologies have their advantages and disadvantages. The nature of the remediation, public acceptance of a given approach, experience of the responsible parties, and economics dictate the direction that is taken at any given site.

AquaDetox Aqueous Purification Process--An Overview

In this paper, stripping is defined as a process to remove dissolved, volatile compounds from water. A carrier gas, such as air or steam, is purged through the contaminated water with the volatile components being stripped from the water into the gas phase. While the physical principles involved are straightforward, the practice of the stripping has undergone very considerable development since the early 70's.

The effort has focused on:

1. Development of the proper theoretical relationships that allow a sound understanding of what is occurring.
2. Application of these relationships, along with the correct hardware, to attain extremely high levels of contaminant removal.
3. Development of the proper scale-up parameters to go from pilot units handling <1 gpm to production units handling over 3000 gpm.
4. Recognition that under the proper conditions, compounds with very high boiling points (e.g., 200 C) can be stripped from water.
5. Compilation of a vapor-liquid equilibrium data base with special emphasis on EPA priority pollutants.

The effort necessary to address these criteria has been carried out by the Separations Section of the Applied Science and Technology Department of The Dow Chemical Company. The research and development has been under the direction of Dr. Lanny Robbins.

By the early 80's, the result of this effort was the AquaDetox process, an integrated technology for the high efficiency stripping of organic contaminants from water.

AquaDetox is capable of removing 92 of the 110 volatile compounds listed in CFR 40, July 1, 1986, by the EPA. Further, such systems have

the demonstrated capability to remove these compounds to the very low ppb range. This represents remediation that goes several orders of magnitude beyond that of conventional stripping systems. The ability of AquaDetox to attain such low levels of contaminant in the effluent represents a major breakthrough. Since conventional strippers will normally achieve only 80-95% removal of the contamination, their water effluent quality is unacceptable. Typically, carbon beds are added to attain final water effluent levels in the ppb range that are required by current environmental standards. With AquaDetox, carbon beds are not required.

Another major concern raised regarding conventional stripping systems is that they simply remove contaminants from the water, but discharge them into the air. The AquaDetox technology solves the air emission problem as well.

A Case Study

A typical groundwater remediation situation was selected to allow a comparison of the technical and economic merits of the various types of AquaDetox processes to the more traditional remediation methods..

The basis of the studies was:

Component	Concentration (PPB)	
	Inlet	Outlet
Toluene	20000	4
Benzene	150	1
Trichloroethylene (TCE)	1000	5
Perchloroethylene (PCE)	5000	5

The cases selected for comparison were:

Case 1:

Removal of the entire contaminant load with carbon beds. The carbon would be recycled to supplier for regeneration. See Figure 1.

Case 2:

Removal of 95% of the contaminant load with a "conventional" stripping column. Since this would not attain the desired outlet requirements, carbon beds on both the liquid and vapor streams would also be needed. See Figure 2.

Case 3:

Removal of the contaminants to the required water outlet level using air AquaDetox technology. Carbon beds are needed only on the vapor outlet, to prevent air contamination. See Figure 3.

Case 4:

Removal of the contaminants to the required water outlet level using AquaDetox operating under moderate vacuum conditions. With this approach, the need for carbon beds, even on the vapor outlet, is eliminated. All of the organic contaminants are condensed in the overhead recovery system. See Figure 4.

Case 5:

Removal of the contaminants to the required water outlet level using AquaDetox operating under deep vacuum conditions. Again the need for carbon beds, on either the vapor or the liquid outlet, is eliminated. See Figure 5.

The material balance data for each of the cases is summarized in Table 1.

The economic data used to compare the cases is summarized in Table 2.

A general schematic overview of each of the cases is shown in Figures 1-5.

An Economic Model

The data representing the operating costs and the capital costs for each of the alternatives was organized into an economic model on a Lotus 1-2-3* spreadsheet. As such, it was possible to consider a wide range of economic parameters, and to quickly assess their impact on the overall yearly cost for the remediation. The data selected for comparative purposes is summarized in Table 2. The model permits additional comparisons to be done very rapidly for different economic inputs.

Results

No such thing as the "normal" groundwater remediation scenario exists. Each set of circumstances has their own unique characteristics. Certainly one of the most speculative parameters in a remediation is the length of time that will be required to satisfactorily remove the contaminants. With this in

mind we decided to look at the economics for two different time periods:

- o 3-year project life
- o 10-year project life

The results, expressed as the TOTAL COST (\$) TO REMEDIATE 1000 GALLONS OF GROUNDWATER, are summarized in Table 3 and Figure 6.

For a project with a 3-year duration, a conventional air stripper (Case 2) would be expected to cost 55% of what it would cost to carry out the cleanup using only carbon beds (Case 1).

On the other hand, using the AquaDetox technology approach (Cases 3-5), again for a 3-year project life, would result in a cost that would be only 28-35% of the cost for relying on carbon beds (Case 1). The variation in total cost reflects the different types of AquaDetox processes that could be used.

If the project were to have a 10-year life, the economics are even more favorable toward the AquaDetox alternatives. In this instance, AquaDetox would cost between 16 and 26% of a carbon bed system, again depending on the exact method chosen.

When the AquaDetox alternatives are compared only to the conventional stripper with carbon beds on both the liquid and vapor outlet streams, the economics continue to remain very favorable for AquaDetox. Table 3 reveals that for a 3-year life, AquaDetox will run approximately 50 to 60% of the cost of the conventional stripper with carbon beds. Over a 10-year life, AquaDetox is approximately 35 to 60% of the cost of the conventional stripper with carbon beds. The range in cost for AquaDetox is due to the 3 different alternatives available.

Figure 7 presents the initial capital that would be required for each of the alternatives. The carbon bed alternative clearly requires less initial capital. The other alternatives are roughly equivalent, with the air AquaDetox technology having a small advantage.

However, as we have seen, when one considers *operating costs* as well as *capital costs*, it is clear that the *most expensive* alternative is *Case 1 - carbon beds only*, while the *least expensive* alternative is *Case 5 - the deep vacuum AquaDetox*.

Summary

Over the past several years, an effort has been underway to gain a better understanding of how air stripping can be made more efficient for the removal of contaminants from groundwater. This work has led to the development of AquaDetox technology for stripping, which far surpasses more conventional approaches to stripping. In most cases, AquaDetox can remove contaminants from groundwater down to near "drinking water quality," and thereby entirely eliminate the need for carbon beds on the liquid phase. Moderate vacuum and deep vacuum AquaDetox goes even further, allowing the near total recovery of contaminants from the vapor phase - without the use of carbon.

These results are attained without sacrificing costs. Indeed the total cost for a unit using AquaDetox technology will, in most cases, be substantially less than for either carbon beds alone, or a conventional air stripper followed by carbon beds.

AquaDetox technology can be used to remove a wide variety of volatile compounds, and can even be used to remove compounds that are normally considered "non-strippable," e.g., those with boiling points in excess of 200 C.

The application of AquaDetox for the removal of compounds greater than 200 C, as well as the use of vacuum, are technologies that are patented by The Dow Chemical Company.

References

1. "Groundwater: Examining a Resource at Risk," EPRI Journal, October, 1985, p. 7-8.
2. "Groundwater: Saving the Unseen Resource," National Groundwater Policy Forum, Conservation Foundation in cooperation with the National Governors' Association, November, 1985, p. 5.
3. "Protecting the Nation's Groundwater from Contamination," U.S. Congress, Office of Technology Assessment, OTA-0-276, October, 1984, p. 5.

*A trademark of Lotus Development Corporation

TABLE 1

REMEDIALATION ALTERNATIVES - OVERALL MATERIAL BALANCES

BASIS			
FLOW: 1000 gpm			
COMPONENT	FEED ppb	OUTFALL ppb	AIR
Toluene	20000	4	LESS THAN 10 LB/DAY TOTAL EMISSION
Benzene	150	1	
TCE	1000	5	
PCE	5000	5	

***** OVERALL MATERIAL BALANCES *****

CASE 1 - CARBON BEDS ON WATER

COMPONENT	Stripper		Liquid Carbon Bed		Vapor Carbon Bed		AIR EMISSIONS lb/day
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Toluene	NONE REQUIRED		20000	4	NONE REQUIRED		NONE
Benzene			150	1			
TCE			1000	5			
PCE			5000	5			

CASE 2 - CONVENTIONAL STRIPPER WITH CARBON BEDS ON AIR AND WATER

Stripper Removal: 0.95
Vapor Carbon Bed Removal: 0.97

COMPONENT	Stripper		Liquid Carbon Bed		Vapor Carbon Bed		AIR EMISSIONS lb/day
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Toluene	20000	1000	1000	4	19000	570	6.8
Benzene	150	7.5	7.5	1	142.5	4.275	0.1
TCE	1000	50	50	5	950	28.5	0.3
PCE	5000	250	250	5	4750	142.5	1.7
Total:							8.9

CASE 3 - AQUADETOX AIR STRIPPER WITH CARBON BED ON AIR

Stripper Removal: water outfall quality
Vapor Carbon Bed Removal: 0.95

COMPONENT	Stripper		Liquid Carbon Bed		Vapor Carbon Bed		AIR EMISSIONS
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	lb/day
Toluene	20000	4	NONE REQUIRED		19996	599.88	7.2
Benzene	150	1			149	4.47	0.1
TCE	1000	5			995	29.85	0.4
PCE	5000	5			4995	149.85	1.8
Total:							9.5

CASE 4 - AQUADETOX AT MODERATE VACUUM

Stripper Removal: water outfall quality

COMPONENT	Stripper		Liquid Carbon Bed		Vapor Carbon Bed		AIR EMISSIONS lb/day
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Toluene	20000	4	NONE REQUIRED		NONE REQUIRED		NONE
Benzene	150	1					
TCE	1000	5					
PCE	5000	5					

CASE 5 - AQUADETOX AT DEEP VACUUM

Stripper Removal: water outfall quality

COMPONENT	Stripper		Liquid Carbon Bed		Vapor Carbon Bed		AIR EMISSIONS lb/day
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Toluene	20000	4	NONE REQUIRED		NONE REQUIRED		NONE
Benzene	150	1					
TCE	1000	5					
PCE	5000	5					

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TABLE 2
Economic Analysis

Basis:

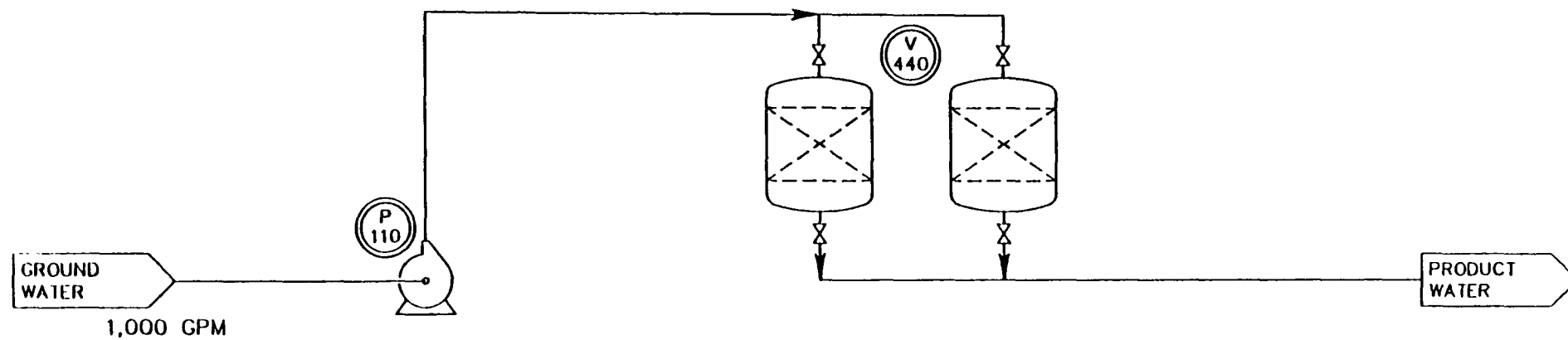
Capital recovery costs are based on straight line depreciation.

Project life:	10 years	Dep. rate 10% per yr.
	3 years	Dep. rate 33% per yr.
Power cost:	0.08 \$ per kwh	
Steam cost	6.00 \$ per 1000 lbs.	
Taxes and insurance;	3.00 % of capital cost	
Maintenace	4.00 % of capital cost	
Miscellaneous	2.00 % of capital cost	
Operational	8000 hours per year	

TABLE 3
Cost Comparison for Remediation Alternatives

	<u>\$/Kgal</u>	<u>% of</u> <u>Case 1</u>	<u>% of</u> <u>Case 2</u>
3-YEAR LIFE			
CASE 1	4.951	100	181
CASE 2	2.735	55	100
CASE 3	1.735	35	63
CASE 4	1.589	32	58
CASE 5	1.381	28	50
10-YEAR LIFE			
CASE 1	4.723	100	219
CASE 2	2.152	46	100
CASE 3	1.249	26	58
CASE 4	0.957	20	44
CASE 5	0.749	16	35

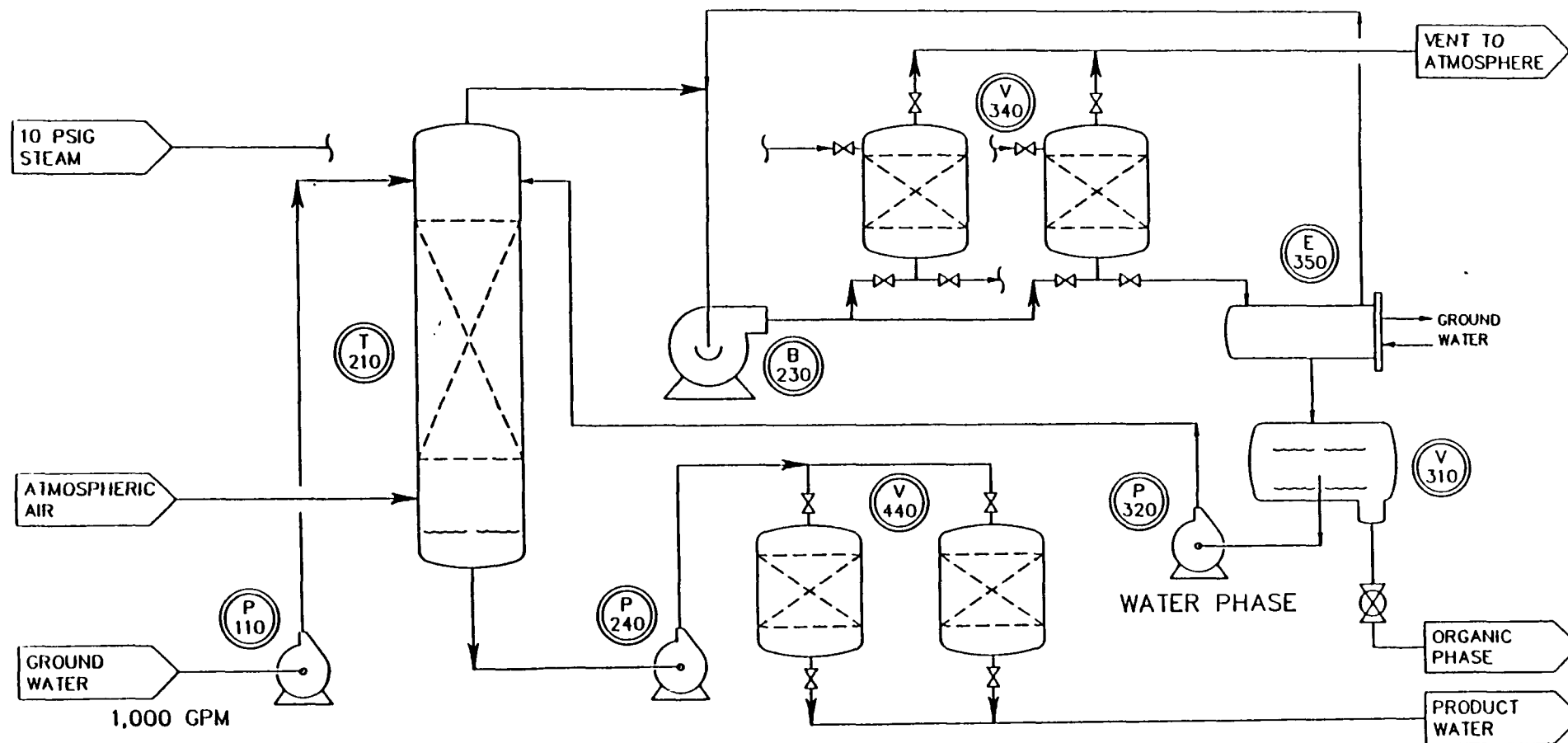
CASE 1: Entire removal with carbon beds on liquid.
CASE 2: Conventional air stripper. Carbon beds on liquid & vapor.
CASE 3: Air AquaDetox with carbon bed on vapor.
CASE 4: Moderate vacuum AquaDetox, no carbon beds.
CASE 5: Deep vacuum AquaDetox, no carbon beds.



CASE 1 Carbon Bed, removal from the liquid phase

Figure 1

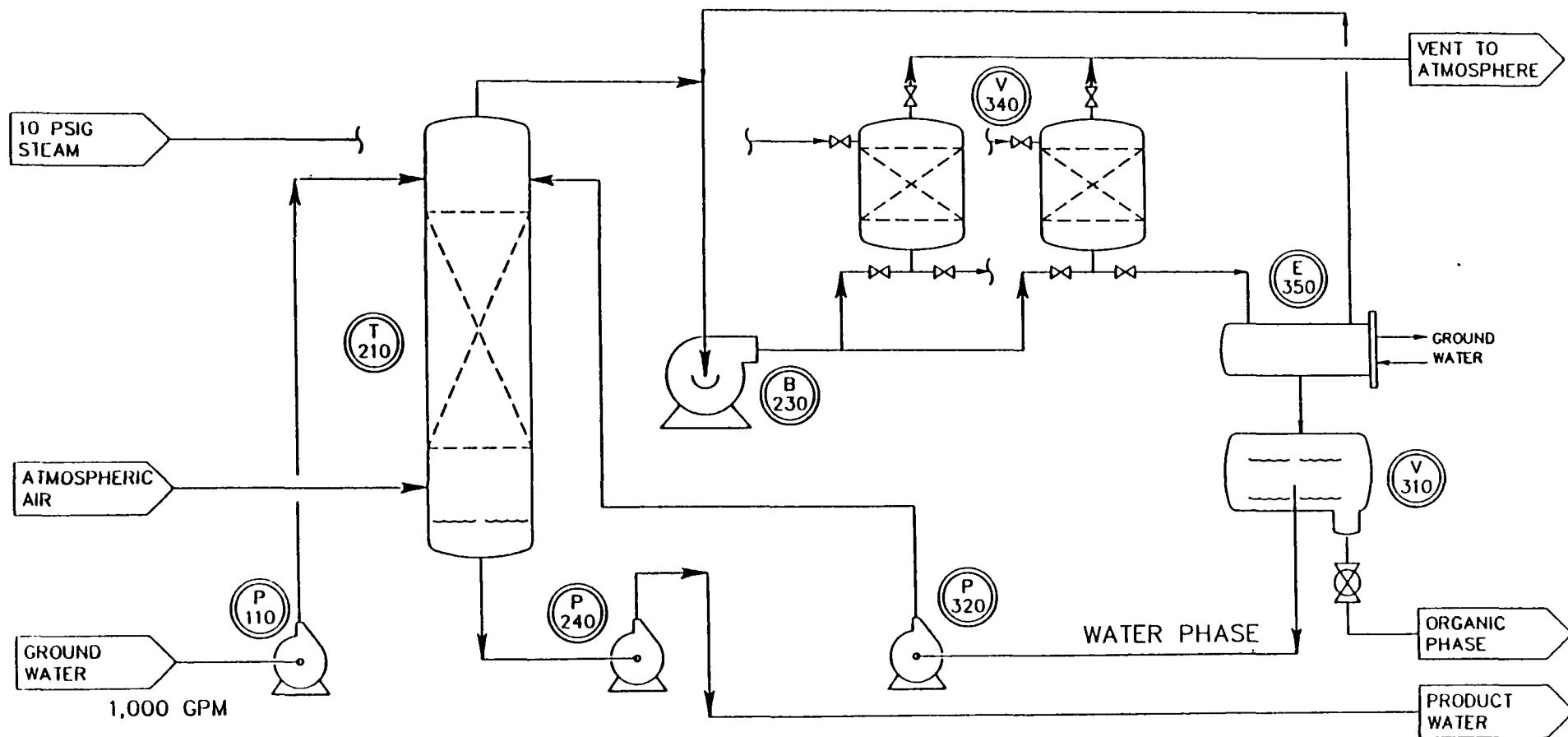
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CASE 2 Air Stripping with Carbon Bed clean-up of both liquid and vapor.

Figure 2

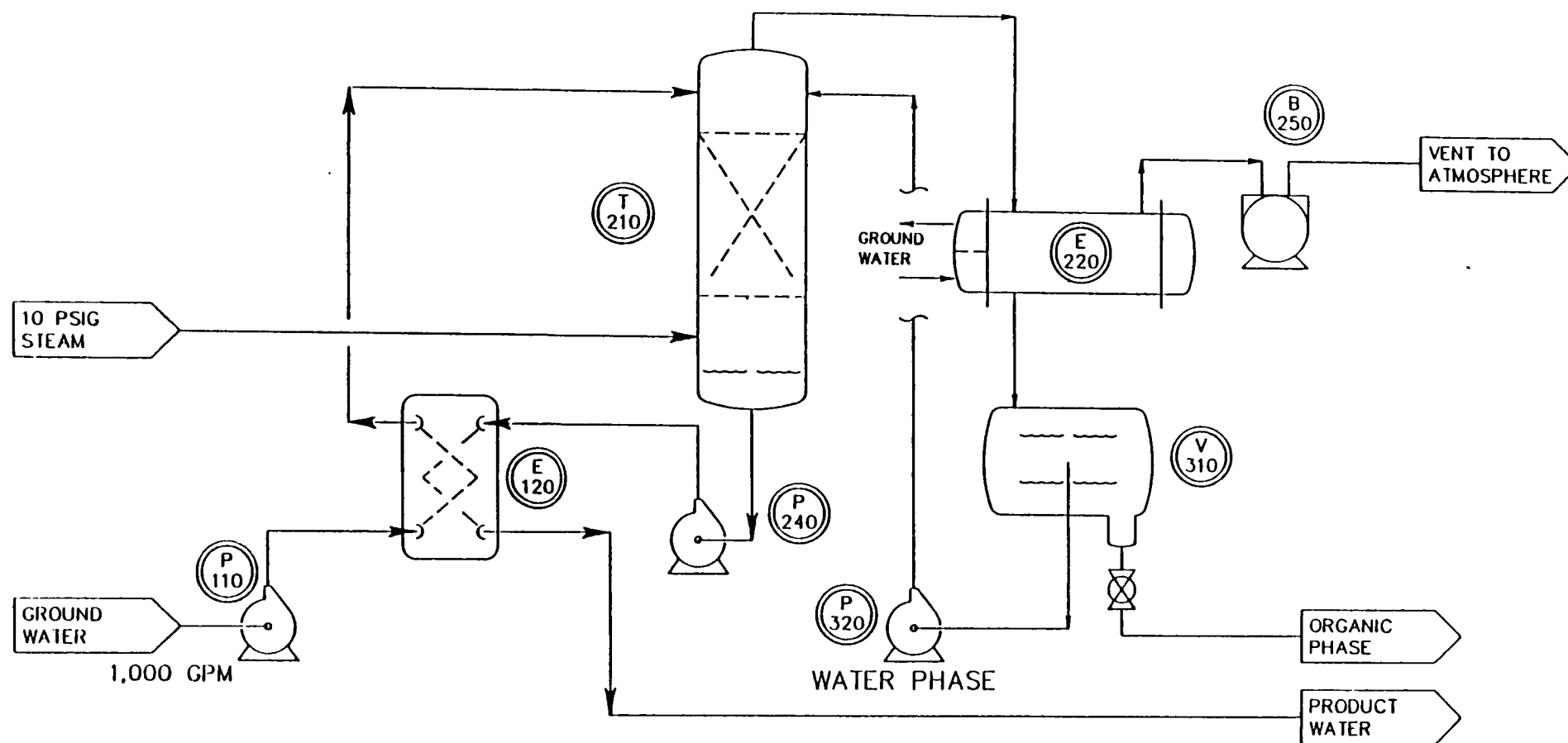
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CASE 3 Air AquaDetox System with
Carbon Bed clean-up on vapor

Figure 3

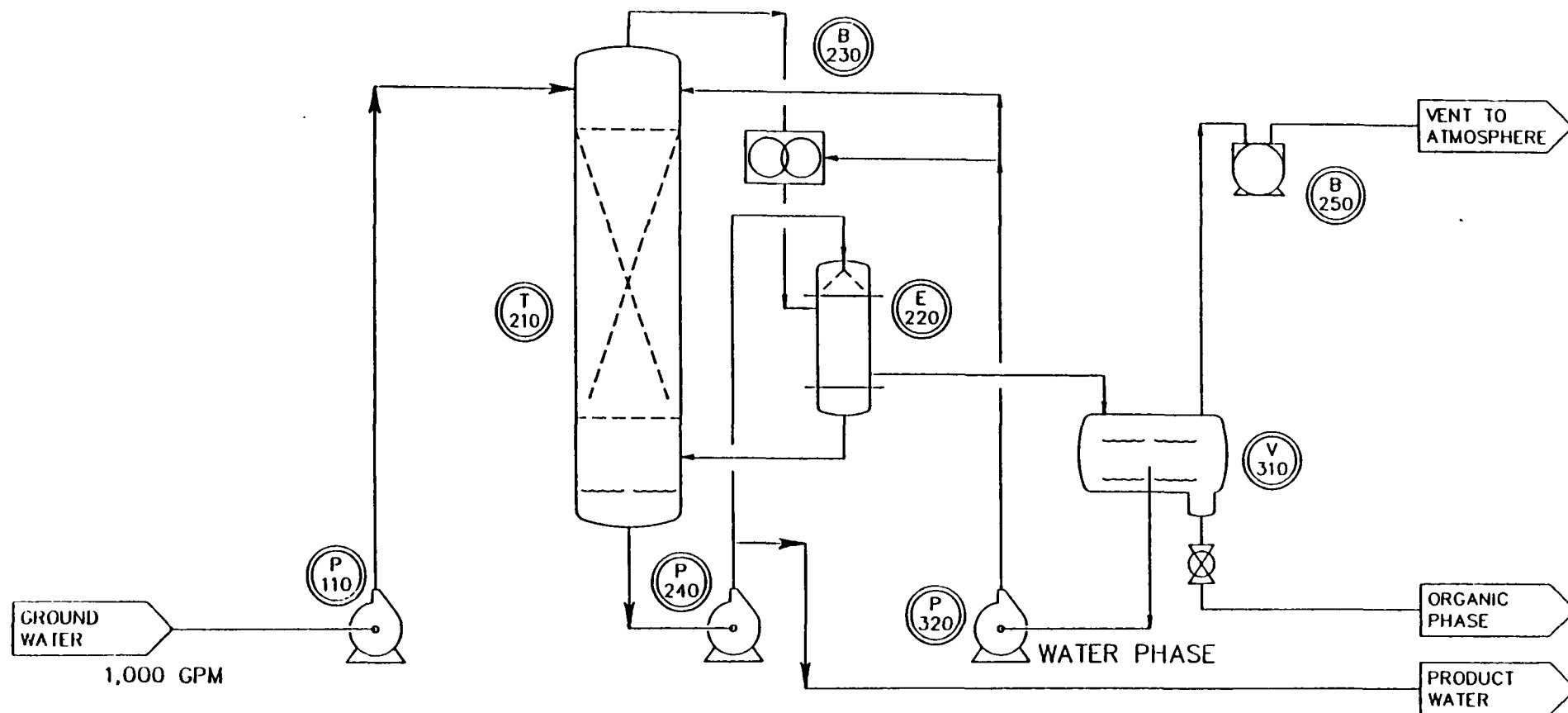
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CASE 4 AquaDetox System with moderate vacuum

Figure 4

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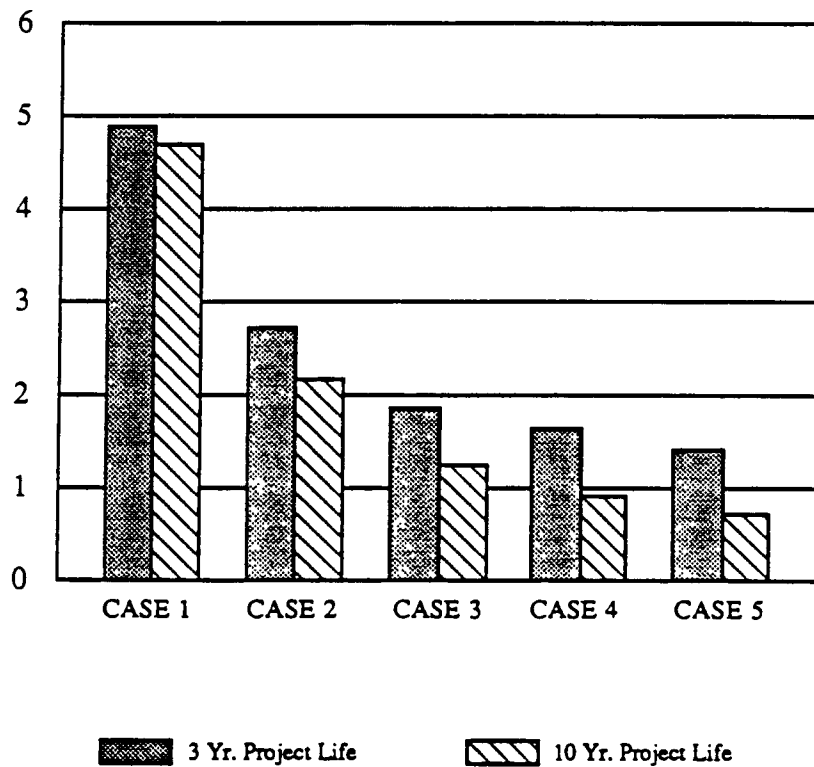


CASE 5 AquaDetox System with deep vacuum

Figure 5

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FIGURE 6
Total Cost per 1000 Gallons Treated



Case 1: Entire removal with carbon beds on liquid.

Case 2: Conventional air stripper, carbon on liquid & vapor.

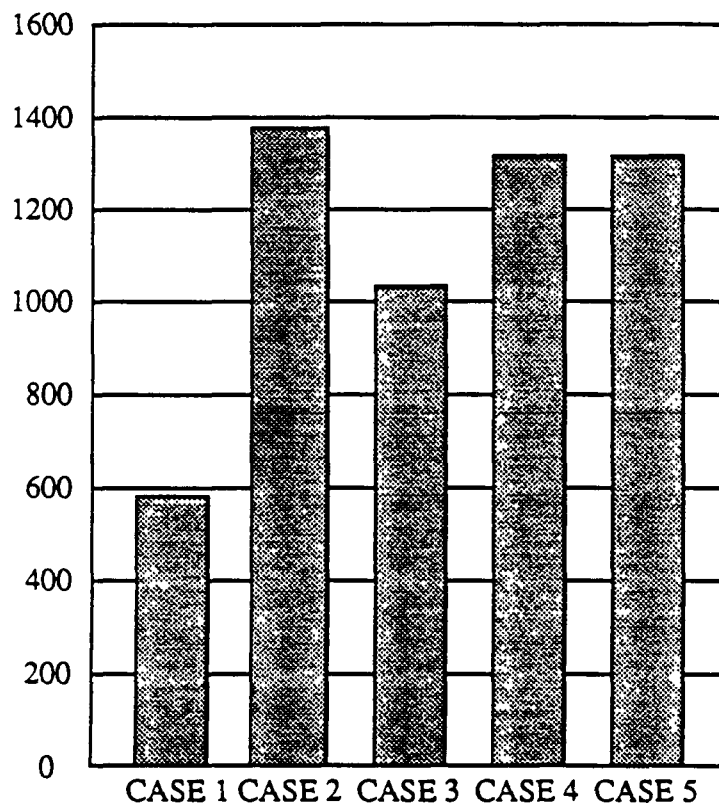
Case 3: Air AquaDetox system with carbon bed on vapor.

Case 4: Moderate vacuum AquaDetox system, no carbon beds.

Case 5: Deep vacuum AquaDetox system, no carbon beds.

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FIGURE 7
Capital Comparison



Case 1: Entire removal with carbon beds on liquid.

Case 2: Conventional air stripper, carbon on liquid & vapor.

Case 3: Air AquaDetox system with carbon bed on vapor.

Case 4: Moderate vacuum AquaDetox system, no carbon beds.

Case 5: Deep vacuum AquaDetox system, no carbon beds.

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