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SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

Emerging Technology Summary

Demonstration of Ambersorb® 563 Adsorbent Technology

A field pilot study was conducted to demonstrate the technical feasibility and cost-effectiveness of Ambersorb® 563[1] carbonaceous adsorbent for remediating groundwater contaminated with volatile organic compounds (VOCs).

The Ambersorb adsorbent technology demonstration consisted of four service cycles, three steam regenerations, and one superloading. The study was conducted using a 1-gallon-per-minute (gpm) continuous pilot system that consisted of two adsorbent columns configured to operate in parallel or in series.

During the first service cycle, the columns were operated in parallel for direct comparison of the performance of virgin Ambersorb 563 adsorbent with that of virgin Filtrasorb® 400[1] granular activated carbon (GAC). While operating at five times the flow rate loading, Ambersorb 563 adsorbent was able to treat approximately two to five times the bed volumes (BVs) of water as did Filtrasorb 400 GAC before VOC breakthrough at the maximum contaminant level (MCL) was observed.

For the remaining cycles, two Ambersorb 563 adsorbent columns were operated in series to investigate the effect of multiple service cycles and steam regeneration on Ambersorb adsorbent performance. After each service cycle, steam regeneration of the Ambersorb adsorbent column was performed on-site. The regeneration process yielded a condensate consisting of a separable concentrated organic layer and a VOC-saturated aqueous phase. In addition, the principle of superloading was demonstrated by passing the aqueous phase from the third steam regeneration through an Ambersorb adsorbent superloading column.

This Emerging Technology Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the Superfund Innovative Technology Evaluation (SITE) Emerging Technology project that are fully documented in a separate report of the same title (see report ordering form in the back of this document).

[1] Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction

Roy F. Weston, Inc. (WESTON®) conducted a field demonstration study to evaluate (Rohm and Haas) Ambersorb 563 adsorbent technology for remediating VOC-contaminated groundwater. The Ambersorb 563 adsorbent technology is currently commercially available. The project was conducted under the Emerging Technology Program of the EPA SITE program at Site 32/36 at Pease Air Force Base in Newington, NH, over a 12-wk period during the spring/summer of 1994. A slip stream from the influent line to the two air strippers currently operating at Site 32/36 was used as the groundwater source for the pilot-scale demonstration. Site 32/36 was selected for the Ambersorb 563 adsorbent field trial because the groundwater in this area is contaminated with vinyl chloride (VC), 1,1-dichloroethene (1,1-DCE), cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), and trichloroethene (TCE). Contaminant concentrations in the groundwater ranged from parts per billion (ppb) to low parts per million (ppm) for TCE.

The objectives of the Ambersorb adsorbent technology demonstration project included:

- Demonstrate that Ambersorb adsorbents can offer a cost-effective alternative to GAC treatment, while maintaining effluent water quality that meets drinking water standards.
- Validate design parameters and system performance to be used for scale-up to full-plant scale, including evaluating different service cycles and establishing steam regeneration efficiency, superloading, and ease of phase separation.
- Evaluate the performance/cost characteristics of the Ambersorb 563 adsorbent groundwater remediation system.

Methodology

The Ambersorb adsorbent technology demonstration employed a 1-gpm continuous pilot system. The pilot unit included prefilters to remove suspended solids, two adsorbent columns that could be operated in parallel or series, one superloading column, and a steam regeneration system.

The steam regeneration system enabled the direct on-line regeneration of the Ambersorb adsorbent columns onsite and included a steam generator, condenser, collection/separation vessel, and vapor phase Ambersorb adsorbent trap for the condenser vent discharge. Steam was passed through the beds in a downflow to minimize condensate holdup in the vessels. To conduct a countercurrent regeneration, both adsorbent columns used an upflow, fixed bed configuration.

The testing program included:

- four service cycles
- three steam regenerations
- one superloading

Superloading refers to the process whereby the aqueous condensate from the steam regeneration of an Ambersorb 563 adsorbent service column is treated using a smaller column containing Ambersorb 563 adsorbent. Following superloading treatment, the aqueous condensate is discharged as part of the treated water stream. The superloading process is not typically used for GAC systems.

A breakthrough capacity computer model, developed by Rohm and Haas, predicted the service cycle times for the demonstration study based on the average historical contaminant concentrations measured in the site groundwater. In addition, it compared the predicted and measured performance of Ambersorb 563 adsorbent based on the average operating conditions and influent VOC concentrations measured during each service cycle.

In the first service cycle, the performance of Ambersorb 563 adsorbent and the performance of Filtrasorb 400 GAC were directly compared. The remaining service cycles evaluated two Ambersorb 563 adsorbent columns in series. Influent and effluent samples were collected and analyzed for VOCs during each cycle to establish breakthrough curves. Process parameters, including groundwater influent flowrate, temperature, and pressure, were also monitored at periodic intervals throughout the field trial.

Steam regenerations were conducted on the Ambersorb adsorbent column at the end of Cycle 1 and on the lead Ambersorb adsorbent columns at the end of Cycles 2 and 3 to evaluate the effect steam regeneration had on Ambersorb adsorbent performance. The steam regenerations were also conducted at various temperatures (307 °F, 293 °F, 280 °F) to evaluate the effect of regeneration temperature on contaminant recovery. The regeneration process yielded a condensate stream consisting of a distinct separable organic layer and an aqueous phase. Organic and aqueous phase samples and the vapor trap adsorbent were collected and analyzed for VOCs to assess regeneration recovery.

A superloading test to treat the aqueous condensate from a typical Ambersorb 563 adsorbent column steam regeneration process was also conducted during the field trial. To demonstrate the concept of a closed loop system in which the only discharge is the separable organic layer, a small dedicated superloading column treated the aqueous condensate from the third steam regeneration. The superloading column used Ambersorb adsorbent because of its high adsorption capacity and superior kinetics while operating at a high flow rate loading. Influent and effluent samples were collected and analyzed for VOCs to evaluate superloading performance.

Results and Discussion

Influent Groundwater

VC, cis-1,2-DCE, trans-1,2-DCE, and TCE were present in the influent groundwater at concentrations exceeding the MCL established in the National Revised Primary Drinking Water Regulations. TCE was the contaminant measured at the highest average concentration in the influent stream, ranging between 3,600 µg/L and 4,510 µg/L. Because of the high TCE concentrations in the influent stream, influent samples required at least a 10-fold dilution before analysis, thus increasing the minimum levels of detection for each VOC. As a result, VC and 1,1-DCE, present in the influent stream at low ppb levels (less than 5 µg/L), could not be accurately quantified for certain service cycles. Therefore, because of these analytical limitations, influent VC and/or 1,1-DCE concentrations were estimated for certain service cycles based on the amount of the contaminant subsequently recovered during regeneration.

Service Cycles

Virgin Ambersorb 563 adsorbent performance and virgin Filtrasorb 400 GAC performance are compared in Table 1. Ambersorb 563 adsorbent and Filtrasorb 400 GAC VC and TCE breakthrough curves are compared in Figure 1. Cycle 1 performance results show that both Ambersorb 563 adsorbent and Filtrasorb 400 GAC achieved water quality below the MCL for each VOC. Based on the number of BVs treated to the MCL, the results show that Ambersorb 563 adsorbent was able to treat approximately two to five times the BVs of water as Filtrasorb 400 GAC while operating at five times the flow rate loading [1/5 the empty bed contact time (EBCT)].

Performance results for the four service cycles are summarized in Table 2. A preload volume of 4,000 BVs was added to the total BVs treated to the MCL for Cycles 3 and 4 to account for the BVs of lead column leakage treated during the previous service cycles (i.e., when the column was in the lag position).

Table 1. Comparison of Ambersorb 563 Adsorbent and Filtrasorb 400 GAC Performance Results (Cycle 1)

Volatile Organic Compound	MCL* (µg/L)	BVs Treated to MCL: Ambersorb 563 Adsorbent	BVs Treated to MCL: Filtrasorb 400 GAC	Difference Factor†
Vinyl chloride	2	8,120	1,730	4.7
1,1-Dichloroethene	7	>13,700	>5,070	~2.7
cis-1,2-Dichloroethene	70	9,600	3,710	2.6
trans-1,2-Dicloroethene	100	>13,700	5,040	>2.7
Trichloroethene	5	8,190	4,850	1.7

* Maximum contaminant levels from National Revised Drinking Water Regulations, 40 CFR 141.61.
† Difference Factor=(BV Treated by Ambersorb 563 Adsorbent)/(BV Treated by Filtrasorb 400 GAC).

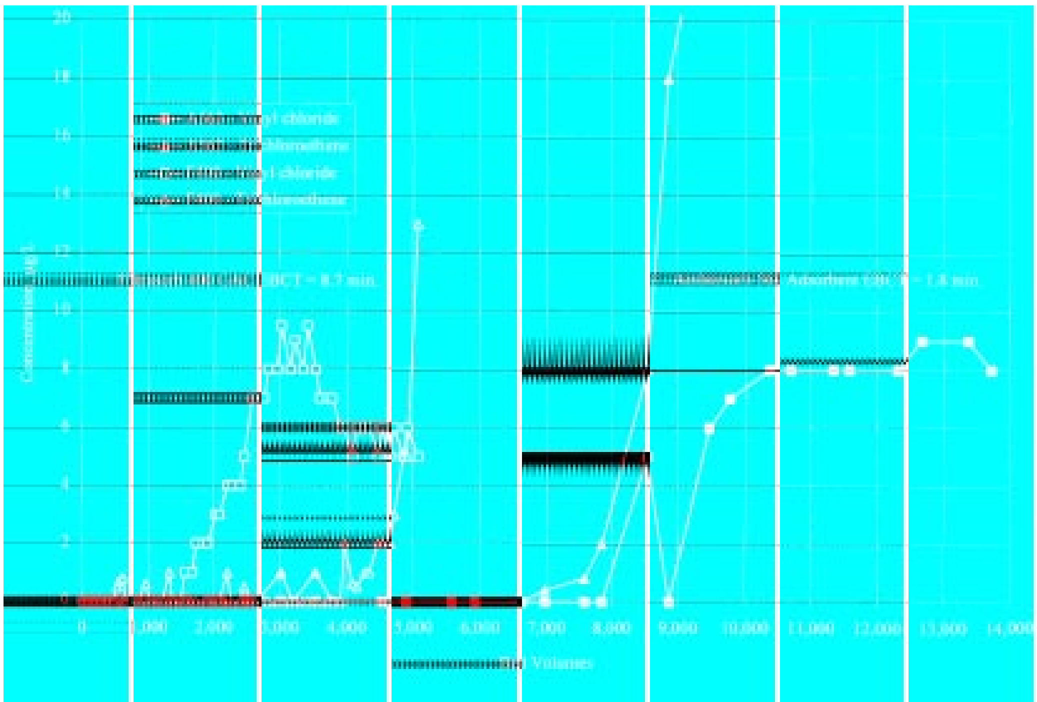

Figure 1. *Comparison of Ambersorb 563 Adsorbent and Filtrasorb 400 GAC VC and TCE breakthrough curves.*

Table 2. Summary of Ambersorb 563 Adsorbent Performance Results

	MCL* (µg/L)	BVs Treated to MCL: Cycle 1	BVs Treated to MCL: Cycle 3‡	Change† (%)	BVs Treated to MCL: Cycle 2	BVs Treated to MCL: Cycle 4‡	Change† (%)
Column I.D.		A563A	A563A-1		A563B	A563B-1	
Column Condition		Virgin	Regenerated		Virgin	Regenerated	
Volatile Organic Compound:							
Vinyl chloride	2	8,120	5,130	-37	8,320	5,010	-40
1,1-Dichloroethene	7	>13,700	>12,600	~-8	>12,700	16,600	>31
cis-1,2-Dichloroethene	70	9,690	8,810	-9	10,600	11,140	5
trans-1,2-Dichloroethene	100	.13,700	.12,600	~-8	>12,700	>16,800	~32
Trichloroethene	5	8,190	5,160	-37	9,400	7,350	-22
Influent VC conc., µg/L		3.4§	5.7		4.9	10.1#	

* Maximum contaminant levels from National Revised Drinking Water Regulations, 40 CFR 141.61.
† Change = (performance of virgin adsorbent - performance after first steam regeneration)/(performance of virgin adsorbent) * 100
‡ Includes BVs preloaded during previous cycle.
§ VC concentration estimated based on the mass recovery results for the first steam regeneration of column A563A.
\# VC concentration estimated based on reanalysis of selected influent samples at lower dilution.

Performance results show there was a 37% to 40% decrease in BVs treated to the VC MCL and a 22% to 37% decrease in BVs treated to the TCE MCL after steam regeneration of Ambersorb 563 adsorbent. For the remaining VOCs, however, there was no consistent decrease in the capacity of Ambersorb 563 adsorbent after steam regeneration, based on BVs treated to the MCL.

The reduction in BVs treated to the VC and TCE MCL is partially attributed to the increase in influent VC concentration during the study. Influent VC concentrations almost doubled between each steam regeneration cycle.

After the first regeneration, the adsorption capacity for most adsorbents, including GAC, will be reduced. Additional steam regenerations and service cycles are needed to determine the long-term effect of multiple steam regenerations on Ambersorb 563 adsorbent performance.

A comparison of the performance of Ambersorb 563 adsorbent measured during the field demonstration to that predicted by the Rohm and Haas breakthrough capacity model indicated that the model is a useful tool in predicting adsorbent capacities and service cycle times. The study showed the importance of having accurate analyses for VC, 1,1-DCE, and other less strongly adsorbed contaminants as input to the model.

Steam Regenerations

Total VOC mass recovery results for the steam regenerations are summarized in Table 3. The steam regeneration results show that a significant recovery of the VOC mass loaded onto the Ambersorb adsorbent columns during the service cycles, ranging from 73% to 87%, was achieved. The results also show that the bulk of the VOC mass recovery occurred within the first 3 BVs of steam as condensate. Furthermore, the results indicate that approximately 88% to 93% of the VOC mass recovered was associated with the easily separable organic phase.

The incomplete mass recovery of VOCs may be due to the following:

- Volatilization of VOCs during sampling of the condensate aqueous and organic phases.
- Inaccuracies during analysis of the steam regeneration samples.
- VOCs retained in the highest energy micropores of the Ambersorb adsorbent not being removed during steam regeneration.
- Dehydrohalogenation of the chlorinated organics.

Table 3. *Summary of Steam Regenerations Total VOC Mass Recovery Results*

Steam regeneration	Regeneration 1	Regeneration 2	Regeneration 3
Column temperature, ˚F	307	293	280
Total BVs generated	7.6	7.0	8.9
Total VOC mass recovery @ 3 BV, %	73.2	70.7	79.1
Total VOC mass recovery @ End, %	78.0	73.4	87.2
Total VOC fraction in organic phase @ End, %	89.5	92.5	88.4

Superloading

The results of the superloading test indicate that the aqueous condensate generated during steam regeneration was effectively treated to levels below the MCL. A total of 14 BVs of condensate, which averaged 700,000 µg/L VOCs (predominately TCE), were passed through the superloading column. TCE was the only VOC detected in the effluent stream and was first detected at a concentration of 2.5 µg/L after 14 BVs had been treated.

Scale-Up Parameters

The information developed during the demonstration study enhanced the existing database for the Ambersorb 563 adsorbent technology and helped validate process design parameters and system performance for scale-up to full-scale treatment systems. The key process operating parameters for the preliminary engineering design of an Ambersorb 563 adsorbent system are:

- process configuration
- EBCT or flow-rate loading
- vessel configuration
- steam regeneration conditions

A full and accurate characterization of the contaminants in the influent, as well as the effluent discharge limitations, is important input for the Ambersorb adsorbent system design especially for predicting service cycle time. The Emerging Technology Report discusses typical values for full-scale design parameters to be used for preliminary purposes only. Design parameters for a full-scale system must be specifically derived for each treatment application.

Conceptual Design and Preliminary Cost Estimate

The results of the Ambersorb adsorbent demonstration study were used to develop conceptual designs and cost estimates for full-scale treatment systems (average design flow of 100 gpm) using Ambersorb 563 adsorbent and GAC. Full-scale design parameters were based on the influent groundwater characteristics and adsorbent performance results measured during the first service cycle. The discharge criteria for the effluent from the treatment systems were assumed to be drinking water standards (i.e., MCL).

The Ambersorb 563 adsorbent system is designed as an up-flow, fixed-bed system, with two 660-lb adsorbent beds in series, each having a 1.5-min EBCT at 100 gpm. In addition, the Ambersorb 563 adsorbent system includes on-line steam regeneration and a condensate treatment superloading system. The lead Ambersorb adsorbent bed is regenerated approximately every 8 days or 8,000 BVs.

The GAC adsorbent system is designed with four 1,800-lb adsorbent beds (two parallel systems of two GAC beds in series). Each GAC bed has a 9.6-min EBCT at 50 gpm. In addition, the GAC system uses commercially available transportable GAC units that are replaced approximately every 11 days or 1,600 BVs.

Based on the results of the cost analysis, the installed costs (including engineering design costs) of the Ambersorb 563 adsorbent treatment system ($526,100) are significantly greater than the installed costs of the GAC treatment system ($336,800). The annual operating costs of the Ambersorb 563 adsorbent system (approximately $32,500/yr for the first 5 yr), however, were significantly lower than the GAC system (approximately $125,800/yr for the first 5 yr).

The total present worth cost analysis of the Ambersorb 563 adsorbent and GAC treatment systems indicates that, after approximately 2 yr, the total present worth cost of the Ambersorb 563 adsorbent treatment system is less than the GAC treatment system. The reduced costs over time result from the significantly lower operating costs for the Ambersorb 563 adsorbent system when compared with the GAC system.

Conclusions

Based on the results of the Ambersorb 563 adsorbent technology demonstration, the following conclusions were developed:

1. Ambersorb 563 adsorbent is an effective technology for the treatment of groundwater contaminated with chlorinated organics. The effluent groundwater from the Ambersorb 563 adsorbent system consistently met drinking water standards.
2. Direct comparison of the performance of Ambersorb 563 adsorbent with Filtrasorb 400 GAC, based on the number of BVs treated to the MCL, indicated that Ambersorb 563 adsorbent was able to treat approximately two to five times the BVs of water as did Filtrasorb 400 GAC while operating at five times the flow rate loading (1/5 the EBCT).
3. During the demonstration, on-site steam regeneration was successful and yielded an easily separable condensate consisting of a VOC-saturated aqueous stream (top layer) and a concentrated organic phase (bottom layer). The steam regenerations recovered approximately 73% to 87% of the total VOC mass adsorbed on the Ambersorb 563 adsorbent column during the service cycle. The organic phase contained approximately 88% to 93% of the total VOC mass recovered. The majority of VOC recovery occurred within 3 BVs of steam as condensate.
4. The principle of superloading was demonstrated as an effective treatment method for the aqueous condensate layer resulting from the steam regeneration of the Ambersorb adsorbent. A condensate stream containing 700,000 μg/L VOCs was treated to levels below the MCL using a superloading column containing Ambersorb 563 adsorbent.
5. Preliminary cost estimates of the installed costs for a 100-gpm treatment system using Ambersorb 563 adsorbent were significantly greater than those using GAC. The annual operating cost of the Ambersorb 563 adsorbent system, however, was significantly lower than the GAC system. The total present worth cost analysis showed that after approximately 2 yr, the Ambersorb 563 adsorbent system would be more economical because of its lower operating costs.
6. The demonstration study enhanced the existing database for the Ambersorb 563 adsorbent technology and helped validate process design parameters and system performance for scale-up to full-scale treatment systems. Information pertaining to key parameters of process configuration, EBCT or flow rate loading, vessel configuration, and steam regeneration conditions was developed or confirmed as part of the demonstration project.
7. Based on a comparison of the measured performance results obtained during the demonstration project and the performance results predicted by the breakthrough capacity model developed by Rohm and Haas, the breakthrough capacity model is a useful tool in predicting the adsorption capacity and service cycle times to support full-scale system design and cost analysis for the Ambersorb 563 adsorbent technology.
8. The accurate quantification of VC in the influent groundwater is critical in establishing the service cycle time for process operations of the Ambersorb adsorbent and GAC treatment systems. Based on the Rohm and Haas predictive model, ppb levels of VC in the groundwater result in significant decreases in adsorbent performance when compared with groundwater containing no VC. As measured in the study and predicted by the model, incremental increases in VC concentration result in decreases in adsorption capacity.
9. A decrease in the number of BVs treated to the MCL was observed for certain contaminants following one steam regeneration of the virgin Ambersorb 563 adsorbent. The reduction in BVs treated to the MCL may be the result of the increase in influent VC concentration during the study. Additional steam regenerations and service cycles are required to estimate the effect of steam regeneration on the long-term performance of Ambersorb 563 adsorbent.

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The complete report, entitled "Demonstration of Ambersorb® 563 Adsorbent Technology," (Order No. PB95-264164; Cost: $27.00, subject to change) will be available only from:
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