DESIGN OF THE CIRCULATING AIR BARRIER FOR COLD TESTS AT HANFORD*

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ABSTRACT

Numerous activities focusing on the final disposition of wastes from Hanford's single-shell tanks (SSTs) have been initiated; these tanks are well beyond design life and are perceived as being in danger of failure. Characterization of contaminated sediments resulting from past tank leaks, continued safe operations of SSTs, total confinement of leaking materials, secondary waste minimization, and final closure of SSTs are five of the many facets of the SST issue at Hanford and elsewhere in the nation.

K&M Engineering and Consulting Corporation (K&M), supported by BDM Federal, Inc. (BDM), completed a study in June, 1993, for DOE's Morgantown Energy Technology Center (METC) of alternative drilling technologies and subsurface confinement barriers for application at Hanford, Washington, specifically targeting the C tank farm in the 200 East area. The technologies were evaluated for their ability to permit direct sampling and monitoring under the tanks and/or injection of barrier materials to prevent contaminant plume movement. Two of the subsurface barrier technologies developed and evaluated in that study were selected for further development, the Circulating Air Barrier and Subsurface Cone Grouting. The current task (1993-1994) is design of the Circulating Air Barrier (CAB) system for demonstration at Hanford.

The CAB system is a desiccant-type barrier designed to prevent the movement of liquid contaminants toward the groundwater, using a gas circulation and processing system to lower the water saturation in a targeted subsurface zone below the saturation required for liquid flow through that zone. The demonstration test design development of this concept encompasses the following: model development and sensitivity analysis; site characterization; barrier performance predictions; surface processing systems design, both injection and production; analysis of the drilling and completion systems; demonstration test plan; and detailed cost estimate. This effort is scheduled for completion in mid-1994.

BACKGROUND

The 1991-1993 K&M/BDM study** included evaluation of alternative drilling technologies and subsurface barriers for application at DOE's Hanford Site. The drilling assessment focused on the ability to drill in unconsolidated soils, provide good horizontal and vertical position control, facilitate subsurface characterization and monitoring, and permit installation of subsurface barriers beneath waste storage tanks. The study explored the possibility of cross-deployment of commercially available technologies found in the oil and gas industries to accomplish these objectives.

Another facet of the study included investigation and concept development of barrier systems which could be installed beneath and around the tank farms with a minimum of excavation. The barrier concepts include existing, commercially available technologies which have to be suitable for the variety of soil conditions found beneath the Hanford tank farms. The barriers were also investigated for their ability to withstand chemical attack and seismic deformations, and for their ability to have the barrier integrity verified remotely.

The study culminated in the development of seven integrated subsurface barrier systems which were evaluated and ranked in qualitative terms for their suitability to the Hanford Site, their ability to meet environmental health and safety constraints and leak response capability, and in quantitative terms of installation/ excavation requirements and estimated deployment times and costs.

As a result of the study, two barrier systems were targeted for demonstration testing at a cold site at Hanford:

- The Circulating Air Barrier (desiccant-type barrier)
- Subsurface Cone Grouting (physical barrier)

Implementation plans were developed for each of these two barrier systems, identifying near- and long-term activities required for eventual application of the technologies at a live site, including the demonstration test design development. Demonstration test design development of the Circulating Air Barrier system is the current focus.

INTRODUCTION

The study focus is the 200-E area, particularly the C tank farm and the high heat-generating tank 106-C. One of the contingency plans associated with this tank, which still contains 48,000 gal drainable liquid***, includes creation of a confinement barrier system should the tank suddenly develop a leak. This barrier would be designed to prevent the downward movement of the contaminant plume, preventing the liquid contaminants from reaching the groundwater. In addition, several tanks in the C tank farm have already been identified as leakers, and the tanks contain a total of 169,000 gallons of drainable liquid.

** Overview "Analysis of Alternative Drilling Technologies and Subsurface Confinement Barriers for Single Shell Tanks at Hanford", Wentzel et al, WM93 proceedings.
*** Tank Farm Surveillance and Waste Status Summary Report, September 1993, WHC-EP-0182-66.

The site is semi-arid; water contained in the soil matrix is low, averaging less than 20%. The geology is complex; sediments vary rapidly, both vertically and horizontally. Average porosity is relatively high, about 40%. The ground water table is found approximately 244 feet below the surface of the C tank farm area. This type of environment is well suited for application of the CAB technology.

The CAB concept involves the circulation of air (or another gas) through a subsurface interval in order to lower and then maintain the water saturation below the saturation required for liquids to flow. The barrier can be installed using either vertical or horizontal wells, establishing a pattern of air injection and production so that the injected air moves from the injection wells through the ground formation to the production wells; a schematic of the CAB system utilizing horizontal wells is shown in Fig. 1. The moving air vaporizes water in the zone and carriers the water vapor to the production (extraction) wells. The production stream is then processed in a surface facility to remove the water and any contaminants or particulates. In time, the circulating air reduces the water saturation in the swept interval, and continues to remove, by evaporation, liquids that move into the zone such as a leak plume. No liquids can flow through this interval until a critical saturation is achieved, a saturation level that is well above the initial saturation. In the event that a leak occurs, the CAB system serves as a tool for early leak detection and provides a means to withdraw volatile contaminants for surface treatment.

The inherent design of the CAB system, a desiccant barrier, provides the following distinct advantages:

- non-physical confinement technology;
- active monitoring and leak detection system;
- based on proven, commercially available oil and gas technologies and equipment;
- emergency response and rapid deployment capability; and
- high potential for integration with other remediation technologies.

While the CAB offers these advantages for application at Hanford and elsewhere, the concept needs to be demonstrated to develop data needed for scale-up and regulatory acceptance. This project addresses the following issues for the CAB demonstration design development:

- modeling, including development, validation and sensitivity analysis;
- cold test design, test plan and cost estimate development; and
- surface effluent control design.

MODIFICATION OF THE BOAST MODEL AND RESULTS OVERVIEW

Using BOAST, a black oil reservoir simulator, CAB performance assessments were conducted for two separate sites for the Hanford project: a cold test site and the C tank farm area. The simulator was used to predict and optimize the performance of the CAB process in containing "leaks" of varying sizes and properties. Subsurface fluid and formation properties were analyzed in order to represent the geologic strata for both sites.

BOAST is a validated, commercially available black oil reservoir simulator modified to meet requirements of application of the CAB technology at Hanford. BOAST was selected to model the CAB process due to the following attributes:

- three-dimensional, three-phase flow model;
- finite-difference, implicit pressure/explicit saturation solution;

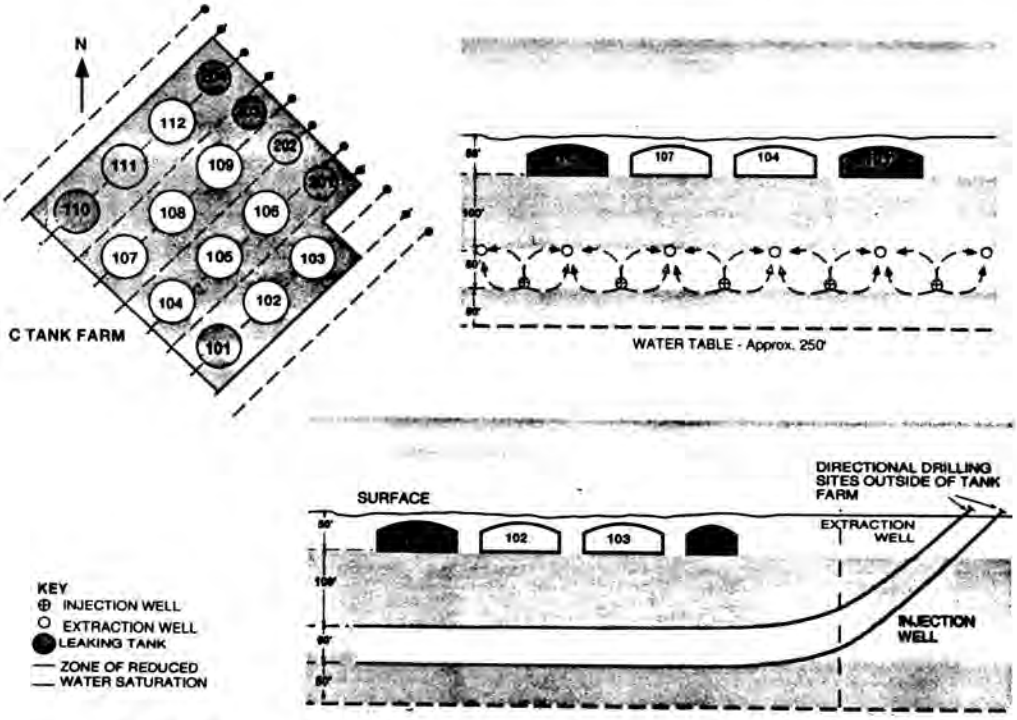


Fig. 1. The circulating air barrier can be installed using horizontal wells.

- isothermal Darcy flow simulation;
- flexibility for application at other sites;
- PC capability; and
- vapor phase transport simulation.

BOAST is a proven predictive model meeting petroleum industry standards, as shown in the comparison of solutions by BOAST and four industry simulators in Fig. 2. In addition, BOAST has been verified in industry, successfully predicting liquid and gas movement through soil.

For prediction of CAB performance at Hanford, the complex geology had to be characterized and converted to 22-layer BOAST grid format. In the C tank farm, studies of four RCRA wells drilled since 1989 reveal that there are 10 easily grouped soil units of relatively consistent grain size and appearance. These beds are grouped into three stratigraphic units: the upper, middle, and lower Hanford Formation, based on correlation with wells drilled for the ERA-VOC project in the 200 West area, which were cored and extensively sampled and studied. These highly variable geologic characteristics, summarized below, were used to define the 22-layer model input to predict performance of the CAB system:

- materials range from fine sand and clay to gravel;
- thickness of the various subsurface layers ranges from 2 to 85 feet;
- porosity ranges from 20 to 55%;
- vertical and horizontal permeabilities range from 24 to 9785 millidarcies; and
- initial water saturation ranges from 6 to 10% of pore volume.

Additional model input requirements include: geometry of the simulated zone including well spacing and orientation; capillary pressure and pressure-volume-temperature data; fluid density and viscosity for each phase; vapor pressure data, etc. The crucial model output is the length of time and volumetric air flow rate required to dry and maintain the CAB zone, and the air flow rates and pressures required to confine any simulated leak. These volumetric air flow rates become the critical parameters for design of the injection and production stream processing facilities.

The simulator predicts performance for each of the three modes of the CAB process operation:

- initial drying: creation of the CAB zone of reduced water saturation;
- leak confinement mode: CAB response required to contain a "leak"; and
- monitoring: minimum flow rates required to maintain the CAB barrier for leak detection.

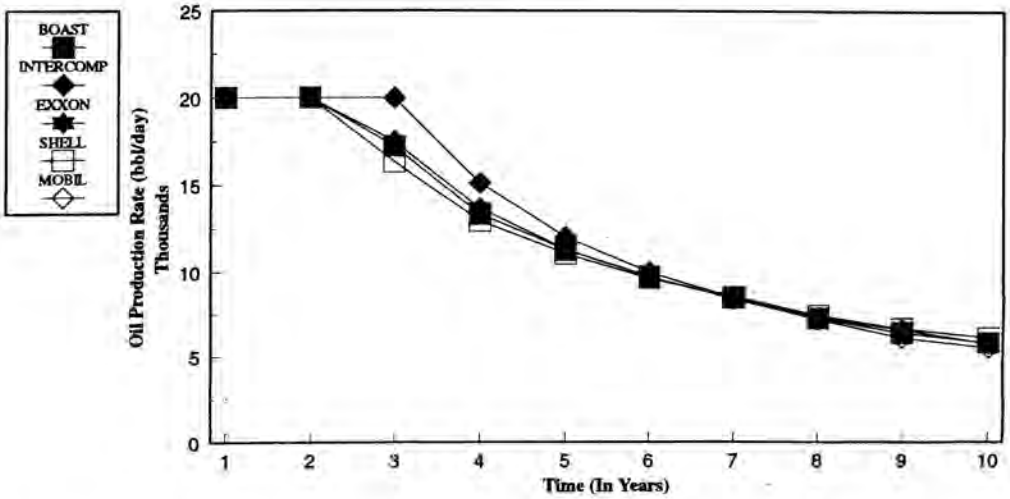
A sensitivity analysis of parameters critical to CAB design and performance for each mode of operation was conducted. A cross-sectional area at demonstration scale (25'x10'x60') was simulated to test the effect of the various site-specific and process-specific parameters on CAB performance. These parameters were systematically varied between upper and lower bounds, and model output for each case was evaluated.

The sensitivity study was performed using a wide range of horizontal permeability values ranging from a low of 2000 md to a high of 8000 md, with vertical permeabilities ranging from one-third to one-half the horizontal permeabilities.

The initial drying process (drying mode) was simulated to reduce the water saturation in the CAB zone from 8% to 4%. The "leak" (confinement mode) was simulated as a 20 day leak at a constant rate. Sample results of this analysis are summarized in Table I.

During the simulation of the drying mode when using a distance of 20 feet between the injection and production wells, it was required to inject air at a rate of 300 mcfd for a period of 80 days in order to reduce the water saturation in the CAB zone from 8% to 4% of total pore space. Increasing the distance between wells to 25 feet increased the required drying time to 120 days.

When simulating the leak confinement mode, variable leak rates were simulated, ranging from as low as 0.357 bbl/day



Source: Odeh, A.S., "Comparison of solutions to a Three-Dimensional Black-Oil Reservoir Simulation Problem," Journal of Petroleum Technology, V.33, pp. 13-25, January 1981.

Fig. 2. BOAST is a proven predictive model meeting petroleum industry standards.

TABLE I
Sample Results of Sensitivity Analysis of the CAB Process

Case Number	Horizontal Permeability md	Vertical Permeability md	Distance bt. wells ft	Viscosity cp	Leak Volume bbl/day	Injection Rate During Leak Mode, mcfd	Leak Confined? Yes/No
1a	8000	4000	20	32	1.000	850	No
1b				32	0.500	850	No
1c				32	0.357	850	No
2a	6000	2000	25	32	0.500	540	No
2b				32	0.357	540	No
3a			20	32	1.000	576	Yes
3b				15	1.000	576	Yes
3c				10	1.000	576	Yes
3d				5	1.000	576	No
3e				5	0.500	576	No
3f				5	0.357	576	No
4a	4000	2000	20	32	0.500	418	Yes
4b				15	0.500	418	Yes
4c				10	0.500	418	No
4d				5	0.500	418	No
4e				32	1.000	418	No
4f				15	1.000	418	No
5a	2000	1000	20	32	1.000	216	Yes
5b				15	1.000	216	Yes
5c				10	1.000	216	Yes
5d				5	1.000	216	Yes
5e				1	1.000	205	Yes
6a			25	15	1.000	205	Yes
6b				10	1.000	205	Yes
6c				5	1.000	205	No
6d				1	1.000	205	No

(15.0 gal/day) to as high as 1.0 bbl/day (42 gal/day), for a period of 20 days (the rates represent equivalent tank farm "leak" rates, shown below). At the same time, air was being injected at a pressure of 45 psia and produced at a pressure of 10 psia. The air injection rate required to contain the "leak" is a function of the vertical and horizontal permeabilities and injection pressure. At low permeabilities, the maximum air injection rate is less than that at higher permeabilities when using the same injection pressure. The injection pressure cannot exceed a level that could potentially damage the single shell tanks.

Simulated Leak Volume <u>**Demo Site**</u>	**Equivalent Leak Volume** <u>**Tank Farm**</u>
1 bbl/day	134,000 gal
0.5 bbl/day	67,000 gal
0.357 bbl/day	48,000 gal

During the simulation of the monitoring mode, the air was injected at a constant rate of 400 mcfd in order to maintain the CAB for leak detection and monitoring.

Results have indicated that the best performance of the CAB zone is at low range of horizontal and vertical permeabilities (1000 to 2000 md). At such low permeabilities the CAB can confine the leak fluid for a wide range of fluid viscosities. Leak viscosities as low as 1 cp (water as the leak fluid) were confined and produced, preventing groundwater contamination in the simulation runs.

Furthermore, it was determined that the distance between injection and producing wells is very critical to the performance of the CAB process. For cold demonstration in relatively homogenous sands, a 20 ft distance was ideal for the CAB process for the given porosity and permeabilities. A leak fluid with viscosities from 1 to 32 cp can be confined in soils with horizontal permeabilities up to 6000 md when the CAB zone is 15 feet thick, the air injection rate is 576 mcfd and injection pressure is 45 psia.

SURFACE PROCESSING EQUIPMENT DESIGN

After using the model to conduct the sensitivity analysis, subsurface design parameters were optimized and model output was used to design the air (gas) stream processing system for the surface facilities, including injection and production components. A key design objective is to ensure compliance with all applicable regulatory/environmental health and safety requirements. Another design objective is to provide sufficient system flexibility to accommodate the range of operating conditions (initial drying, leak confinement, and monitoring modes) and scale of operation (cold demo, hot demo, and full-scale application). The detailed design and test plan preparation will also facilitate the cost estimate development.

The interrelated design constraints imposed by the different operating modes and scale factors for the CAB design include:

- CAB zone dimensions;
- total liquid volume removed from the zone during initial drying;

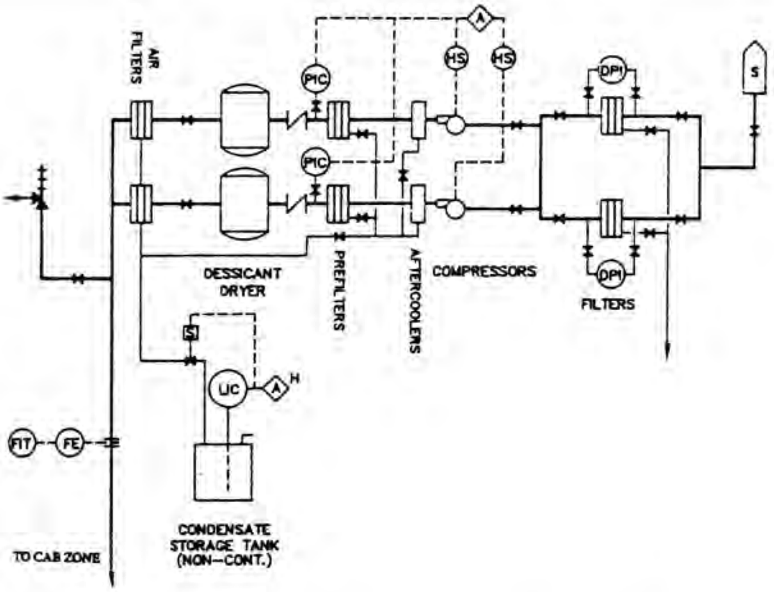


Fig. 3. CAB surface processing system: injection.

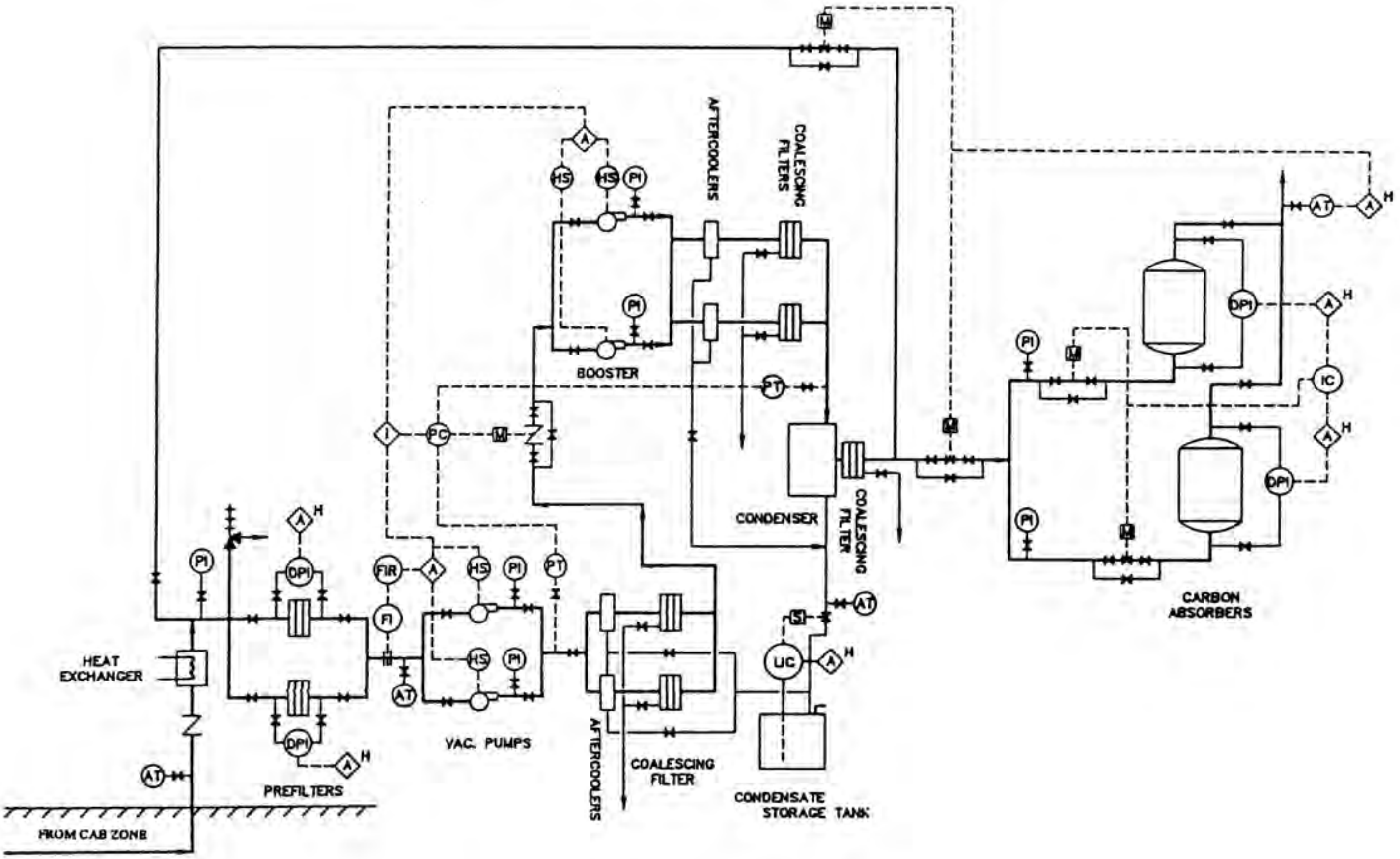


Fig. 4. CAB surface processing system: production.

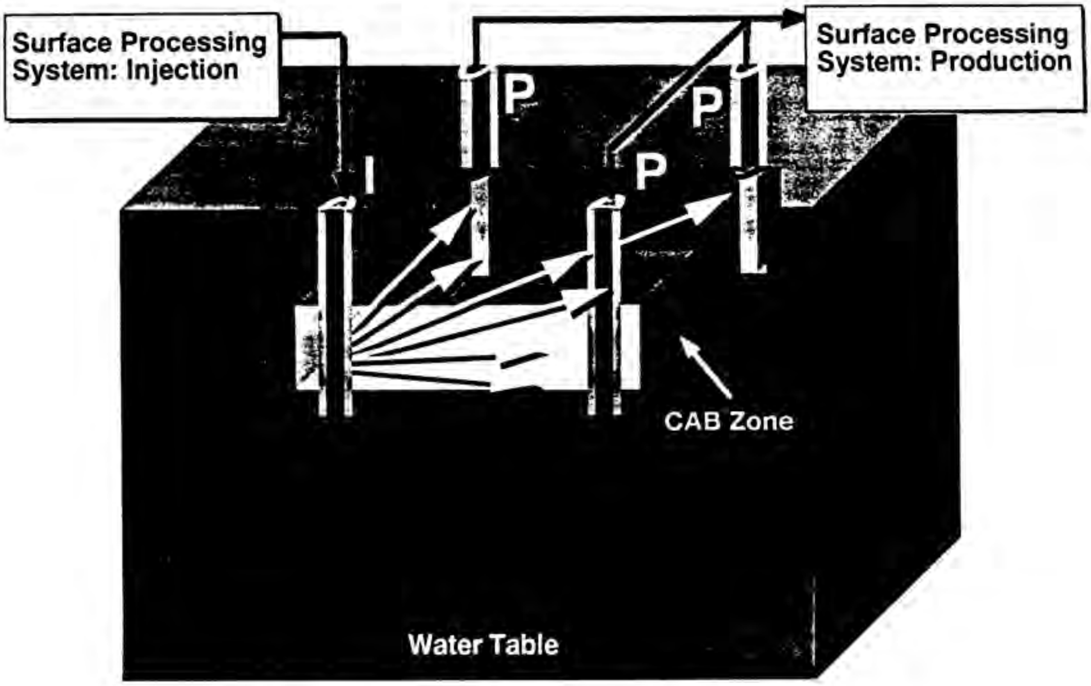


Fig. 5. CAB demonstration design concept.

- required air flow rates to create/maintain the CAB zone; and
- anticipated contaminant plume movement.

These factors are used to establish upper and lower boundaries on processing facility operating conditions. For design purposes, all of the air exiting the production wells will require processing (as if contaminated) before being exhausted to the atmosphere. Effluent disposal must meet regulatory requirements.

The surface processing design consists of two systems, air injection to the CAB zone and air/water vapor/contaminant production from the zone. The injection system includes the following processing stages:

- compression;
- aftercooling;
- desiccant drying; and
- filtration.

The compressed, very dry air will be injected into the CAB zone at formation temperature (55 F avg.). After passing through the CAB zone, the moist, particulate- and contaminant-laden air will be processed through the following stages:

- radiation/contaminant monitoring;
- heat exchange;
- vacuum blowing;
- boosting;
- drying;
- aftercooling; and
- filtering
  - high efficiency particulate arresters (HEPA)
  - activated carbon.

Effluent disposal will include produced wastewater and filter disposal/regeneration. These systems are shown for a preliminary design option on Figs. 3 and 4.

Specific components are selected based on operating constraints/requirements, secondary waste minimization, commercial availability and cost.

DEMONSTRATION TEST PROGRAM

The modeling and design efforts culminate in the development of a detailed demonstration test program targeted for a cold site at Hanford. Objectives of the demonstration test program include:

- demonstrate concept at a cold site with soil characteristics similar to those at the Hanford C tank farm;
- validate and update the BOAST model
  - compare field performance with model-predicted performance of demonstration design;
- provide data for detailed cost estimates;
- provide inputs to scale-up to hot demonstration; and
- demonstrate compliance with environmental, health and safety requirements.

A schematic of the demonstration concept, in which four vertical wells are used (one injection, 3 production) is shown on Fig 5.

The on-site cold test program encompasses the following steps:

- finalize site-specific demonstration design;
- install initial vertical well and complete characterization;
- verify simulator and condition site for CAB test;
- drill remaining wells to complete the CAB process test pattern;

- establish the desiccated zone;
- conduct "leak" tests and verify CAB process; and
- restore site.

Activities remaining under the current task (through mid-1994) include analysis of the drilling and completion systems, finalization of the demonstration design, and completion of the detailed cost estimate.

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