MULTIPHASE EXTRACTION (BIOSLURPING) OF JP-4 IMPACTED SOIL AND GROUNWATER, YOKOTA, JAPAN

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Abstract

Brewer Environmental Services (BES) successfully completed a site investigation and initiated remediation of a JP-4 release at an aircraft fueling ramp in Yokota, Japan. This project was unique due to the location, redmedial approach selected and depth at which MPX (bioslurping was applied)

A pilot study was not funded so the remedial approach chosen had to allow for a variety of possible field conditions. The design criteria for the system was to remove the JP-4 layer floating on top of and dissolved in the shallow aquifer groundwater: remove the vapor phase JP-4 compounds in the vadose zone; provide a cleanup system with the most flexibility, easiest maintenance, and least impact to facility operations

BES selected and with CARBTROL, Inc., designed a containerized Multiphase Extraction (MPX) system. The MPX system is designed to recover jet fuel in liquid, vapor and dissolved (in groundwater) phases via vacuum-pumping which utilizes a high vacuum liquid ring pump. Currently, JP-4 constituents are recovered from a depth of 50 feet in the nine wells using MPX.

BES designed an innovative MPX wellhead which consists of multiple valving, multiple sampling ports, an extraction tube and a unique gasketed coupler. The wellhead design allows for the extraction tube to be adjusted to any length in the field to extract any combination of phases. A system for dynamic determination of water level was also developed.

The containerized MPX approach allows the system to be shippable and modified to any set of phases that hydrocarbon contamination can be found, thereby reducing the impact by passing a pilot study phase.

Simplicity of the single pump design means that all maintenance equipment are in the system – not downhole. A telemetry unit allows automatic maintenance callups and vital system functions to be monitored from anywhere in the world.

Introduction

Brewer Environmental Services (BES) completed a site investigation and initiated remediation of a JP-4 release at an aircraft fueling ramp in Yokota Air Base, Japan. This paper will focus on the remediation portion of the project. Due to several factors described below, the selected technology of Multiphase Extraction (Bioslurping) was key to a successful initiation of remediation at the site. To the authors knowledge, this was the first application of the technology in the Far East and one of the few times that it has been applied to groundwater depths approaching 15 meters (50 ft.).

Background

Yokota Air Base is approximately 40 km (25 miles) inland of the Pacific coastline and is located west-northwest of the Tokyo metropolitan area on the main island of Honshu, Japan. The Air Base facilities include command and administrative offices, maintenance shops, aircraft runways, taxiways, hangers and aircraft refueling systems. The aircraft refueling system consists of fuel storage tanks, pumphouses, underground piping, lateral hydrant control pits, and aircraft hardstands. A leaking underground lateral hydrant control pit was considered the source of the subsurface JP-4 contamination encountered beneath this portion of the airfield.

The site is elevated 125 meters (415 ft) above msl on a relatively flat upland alluvial plain composed of unconsolidated volcano-clastic sediments originating from the central highlands. These unconsolidated sediments are composed of sand and gravel with occasional cobbles and discontinuous silt and clay lenses.

Most of the sediments are suspected to be saturated with exploitable quantities of groundwater. Groundwater beneath the site consists of a deep production aquifer at about 60-85 m (200-280 ft) above msl and a perched

Note: Underlining is by CARBTROL

aquifer which is at approximately 112 m (367 ft) above msl at the site. This corresponds to a depth of approximately 14 m (46 ft) below ground surface at the site.

JP-4 is a jet fuel that is very similar to gasoline and is composed of organic hydrocarbon compounds that fall in the range of C6 to C14. These compounds fall into two classes: the aromatics and the Aliphatics which are divided into three families; the alkanes; the alkenes; and the alkynes. Alkanes represent 95% of the vapor and aromatics make up 2% of the vapors (USEPA, 1992). JP-4 is no longer used as a fuel by the Air Force.

Three previous investigations of the fuel leak had been conducted at the site prior to the author's involvement. These investigations produced five 50 mm (2") groundwater monitoring wells set at a general depth of 15 meter (49 ft) and a vapor well which extend to a depth of 13 meters (42 ft). The five wells were screened in the interval from 11 to 15 m (36 to 49 ft) while the vapor well was screened from 8 to 13 m (26 to 42.6 ft). During the investigation phase of the project, the authors also installed five additional 50 mm (2") wells to a depth of 15 m (49 ft). These wells had screened minimum intervals of 4.5 m (15 ft). Generally they are screened from a depth of 15 meter (49 ft) to 10.5 meter (35 ft). Wells were screened with larger intervals where contaminants were encountered higher in the vadose zone.

Soil boring data indicated a volatile contamination in the vadose zone ranging from a depth of 5 m (16 ft) to 14 m (46 ft) with the zone of maximum contamination generally at 12 m (39 ft). However, as expected the vadose zone contamination was encountered at shallower depths closer to the reported spill site and only in the capillary zone at points distant from the spill.

Previous investigations reported a light non-aqueous phase liquid (LNAPL) of up to 100 mm (4") thick, however, by the time the authors conducted the project, the maximum apparent LNAPL thickness was observed to be 9 mm (.36") thick.

Remedial Technology Section

Previous investigations had detected hydrocarbon contaminant in all the four main phases: 1) in the vapor phase; 2) in the soil matrix (either sorbed to the soil, in soil pore space, or dissolved in soil moisture); 3) as a LNAPL or free product layer on the phreatic surface; and 4) as a dissolved phase in the groundwater. A complete remedial approach would address all of the four main phases in which the contaminant had been found. Previous consultants had suggested vapor extraction coupled with a dual pump LNAPL removal system.

The client also indicated that the design must be an in-situ remedial technology with time and economy playing a major selection role. Due to community pressures to begin cleanup, no intermediate pilot study phase was funded. Therefore, the selected remedial approach must have the flexibility to be modified in the field.

Due to the proven success rates of remediation using SVE technology (Johnston, 1990), the authors pursue SVE as a likely candidate for remediation. However, studies conducted at sites where the remediation system depended solely on vapor extraction was found to "weather" the contaminant – that is it will preferentially remove the volatile components leaving behind the less volatile compounds (Pedersen, 1991). The authors considered that a complete remedial approach would likely include in-situ bioremediation either naturally or enhanced in order to remediate the remaining less volatile compounds. Thus, the authors decided that bioventing which uses lower extraction rates, thereby limiting the weathering effects, should be an integral component of the design.

Specific project remedial objectives were:

- Remove the LNAPL layer floating on top of the shallow aquifer;
- Remove and/or destroy the residual JP-4 fuel compounds in the vadose zone;
- Complete the action in the most cost-effective manner, in the least time;
- Utilize a system that provides the most flexibility, easiest maintenance, and least impact to base operations.

The MPX Approach

The Multiphase Extraction (MPX) or bioslurp concept is a relatively new, innovative approach to site remediation at petroleum release sites that have LNAPL contamination. The MPX system is designed to recover free-phase LNAPL via vacuum-enhanced pumping, while simultaneously removing volatiles and initiating vadose zone remediation via bioventing.

MPX has been used with success at Fallon Naval Air Station where more than 8,100 gallons of JP-5 had been removed in 14 months (Kittel et. Al., 1994). Currently the Air Force has 34 sites which have or plan to have bioslurping systems in operation (Battelle, 1995).

The MPX system utilizes a high vacuum liquid ring pump connected by PVC piping to an extraction tube placed in each well. The extraction tube is inserted into a 50 mm (2”) well and by means of adjustment, can extract (1) only vapors, (2) vapors with entrained liquid, or (3) only liquid. The differential enhancement of product thickness can be accomplished by pressure differentiation either through drawdown or upwelling.

The MPX overcomes many of the drawbacks of more traditional skimmer and dual pump systems. Some of the significant features of the MPX are that it:

- Enhances LNAPL recovery via vacuum-enhanced pumping;
- Utilizes existing 50 mm (2”) wells;
- Requires only one pump to extract from multiple wells, reducing capital and maintenance costs;
- Simultaneously treats the vadose zone via bioventing;
- Could be optimized to significantly reduce the ratio of groundwater extracted per gallon of fuel recovered, compared to conventional dual-pump recovery systems;
- Can be designed to simulate vacuum-enhanced recovery (to achieve an increase of hydraulic gradient through negative pressure);
- Provides suction lift greater than the theoretical maximum due to liquid entrainment;
- Can be converted easily to a conventional bioventing or vapor extraction system when free product removal activities are completed.
- The system does not have a high cost for equipment because it does not rely on additional pumps and sensors as do the traditional pump and treat systems.

Our approach was to initially remove low-weight volatiles as quickly as possible and then convert the system to a bioventing emphasis while simultaneously removing LNAPL from the aquifer. Hydraulic control by vacuum enhancement was considered a secondary feature of the system, however, hydraulic control could not be established until a plume has been completely defined.

MPX (Bioslurp) System Design

Our MPX remedial system design maximized safety, flexibility, capability, mobility, modularity, expandability, low maintenance and active alarming. The MPX pump is connected to a collection system which distributes the vacuum to nine wells and collects the mixture of vapors, liquid and groundwater from those nine wells. Each well has a MPX wellhead which consists of valving and an extraction tube. The collected multiphase contaminant is then separated into vapor, water and LNAPL for disposal.

The MPX system consists of four major elements. These are the:

- Containerized MPX treatment center;
- Collection piping system;
- Effluent disposal systems;
- MPX wellheads.

Containerized MPX Treatment Center

The MPX treatment center was built into a 6.1 m (20 ft) ocean going container which was purchased and refurbished to permanently house the system. Building the treatment system into a standard cargo container allowed it to be factory pre-tested and then shippable anywhere in the world. The MPX treatment center was built by CARBTROL in Westport, Connecticut, shipped by rail to Portland, Oregon where it was loaded onto a ship bound for Tokyo Harbor. Once it cleared customs in Tokyo, the treatment center was trucked to the site and placed on pre-formed footings.

The system features two main compartments with separate entry for each. The explosion-proof (XP) compartment houses all the pumps, storage and treatment equipment. It is accessed by two cargo doors in the front of the container. All fluid and vapor hookups are on this side. The other compartment is the control room. It contains the control panel, breaker box and telemetry unit and is accessed by a side personnel door. All electrical and telephone connections are made to this side. The two sides are separated by a two hour fire wall and intrinsically safe (ISC) circuit breakers. Details on the system schematic and layout are presented in Figures 1 and 2.

The MPX treatment center consisted of the following major components:

1. 7.2 hp liquid ring pump capable of drawing a vacuum of up to 25” Hg with a rated capacity of 15 gpm of liquid, or 100 SCFM vapors;
2. Air/Water separator and seal water system;
3. Oil/Water separator;
4. 946.25 I (250 gal) product storage tank;
5. Transfer pump with pump sump;
6. Bag filter;
7. Dual inline 90 kg (200 lbs) liquid phase granular activated carbon (GAC) units;
8. Dual inline 90 kg (200 lbs) vapor phase granular activated carbon (GAC) units;
9. A NEMA 4 Control Panel with 7 alarm lights, 2 switches (one for each of the two pumps) and a reset button;
10. Sensaphone Telemetry system with autodialer;
11. Various valves, sensors, flow meters, pressure gauges and sampling valves;
12. Heating, lighting and ventilation.

Note: Underlining is by CARBTROL

Collection Piping System

The collection piping system is composed of a trunkline and smaller individual run lines. The trunkline is connected to the MPX treatment center and forms the backbone of the collection system. It is approximately 110 m (360 ft) long and constructed of 100 mm (4”) schedule 40 PVC piping. The run lines join individual wellheads to the trunkline with reducing tees. These are of various lengths and constructed of 50 mm (2”) schedule 40 PVC piping. The position of wells, MPX treatment center and collection systems are presented in Figure 3.

Effluent Disposal System

Access to the base wastewater system was not feasible from the site location within the airfield. Therefore the treated MPX system effluent water was discharged into a subsurface Effluent Evapotranspiration Field (EEF). The EEF was designed to maximize evapotranspiration of the effluent water. Vapor effluent is discharged to the atmosphere after carbon treatment via a 75 mm (3”) vent pipe. JP-4 is collected in the fuel tank. The collected fuel is disposed of at an on-base fuel recycling facility.

MPX Well-head Design

The well head design is illustrated in two different views in Figures 4 and 5. The well head is constructed in a 600 mm (24”) traffic rated manhole with removal steel plate cover. The manhole box is open on the bottom and lined with gravel to allow for drainage of rainwater and runoff. The well head is connected to the collection system manifold by PVC piping, valves, and a clear flexible hose joined to the PBC pipe by cam-locks. The design incorporates two ball valves, one to act as a dilution intake for the 50 mm (2”) well, the other to control the flow from the MPX well head into the manifold system which them flows into the MPX extractor (Figure 4).

The extraction tube is a 25 mm (1”) flush-threaded PVC pipe held in place by a rubber-gasketed PVC compression fitting. The PVC pipe is in 1.5 m (5 ft) and 3 m (10 ft) sections with the final section cut to the depth of the groundwater.. When adjustment is needed, the compression fitting is simply unscrewed and the tube is adjusted. The tube has calibration marks in inches and has a total range of 150 mm (6”) adjustment without modification. Figure 5 illustrates the extraction tube position relative to the groundwater when the system is set for extraction of vapors with entrained liquids (slupring). In this case the dynamic water level is raised in relation to surrounding water level due to a vacuum enhanced pressure gadient.

There are two quick disconnect sampling ports in each well head which can be used to sample either vapors (concentration in ppm) or pressure (vacuum in inches of H_20). The lower one is at the top of the well casing and measures or samples the air diluti.on. The higher one is at the top of the extraction tube and measures or samples the extraction vacuum or vapors.

System turn on and baseline performance

Installation consisted of connecting all piping, electrical and phone lines. In addition a seal water makeup line was added to provide a constant supply of sealwater to the liquid ring pump. Repairs were also made to items that had minor shipping damage.

After an initial break-in period the liquid ring pump influent and dilution valves were adjusted to begin vapor and liquid recovery. This test was conducted by first closing all the well head valves except for the one at the test well which received maximum system vacuum (>100” H_20). Then vacuum readings were collected at that well to determine the maximum vacuum that a particular well could develop. Each well was tested in turn. The results of this test are presented in Table 1.

TABLE 1
Initial Vacuum Developed at Each Well

Well I.D.	Wellhead Vacuum (“H_20)	Casing Vacuum (“H_20)
VE-1	2.8	NA
MW-1	>100	>100
MW-2	82	68
MW-3	>100	90
MW-5	20	5
MW-7	24	12
MW-8	>100	>100
MW-9	20	3.2
MW-10	34	20

For this test the bioslurp tube was modified by disconnecting all the vertical length of tube within the well except for a five foot section of slurptube which was left attached to the well head compression fitting to assure a seal. Vacuum readings were collected via a magnehelic gauge attached to the upper (well head vacuum) and lower (casing vacuum) sampling ports respectively. This test configuration assured that slurp tube was above the top of the water table and as such not affected by water entering the tube.

These baseline readings indicated the individual well permeabilitiy characteristics and guided the use of the dilution valve at each well. Wells with >100" H_20 were determined to require opening of the dilution valve to aid in slurping at lower vacuum pressures. The more permeable wells had the dilution valves shut completely.

Dynamic Water Level Determination

The authors developed a method for dynamically determining the correct water level without removing the tubes or disrupting the vacuum. The method requires the use of a triple range magnehelic gauge setup with quick disconnect couplings to measure the vacuum at the upper and lower monitoring ports of the well head.

The method first requires a measurement of the vacuum at the top sample port. If the well is properly slurping, the gauge should fluctuate around a range. A typical value would fluctuate plus or minus 5" H_20 at approximately 10" H_20. Then the magnahelic gauges are connected to the lower sample port. This reading must be lower than the upper port, typically it will be 4" H_20. If the well is properly slurping, this vacuum should also be fluctuating.

By going from upper to lower ports, one can determine if the slurp tubes are at the correct level. If the lower port is very low and steady, and the upper port is high and steady, the slurp tube is in the water. If the upper port is low and steady and the lower port is high and steady, the slurp tubes are set too high and the well is bioventing. By keeping an eye on the magnahelic gauges and moving the tube up and down, one can maximize fluctuation. The highest fluctuation is the dynamic water level and the correct bioslurp level.

Balancing the system

After the slurp tubes were set to the correct water level the well head vacuum valves at each well were opened starting with the well farthest from the system. The well head valve was gradually opened until slurping droplets were observed in the clear section of one inch vacuum hose. This process continued until all the well head valves were open at which point slurping was not evident in any of the wells. Vacuum readings were then taken at the well head and casing. These readings indicated that the maximum available vacuum the MPX system was able to develop with all the wells open was 11" H_20. This available vacuum was below the minimum required to effectively slurp from the one inch diameter slurptubes installed in the wells. Therefore, the system was balanced to slurp from certain wells by selectively reducing the vacuum available to poor performing wells and directing the additional vacuum to proven slurp wells.

The best bioslurp results were observed when only three to four wells were in operation at one time. Approximately 30-40 inches H_20 was the optimal vacuum pressure needed to maintain active slurping using existing slurp tubes and current depth to groundwater. The obvious water and vapor recovery was dubbed "macroslurp" by the field crew due to the readily observable water trickling through the clear vacuum tube installed at each well. Macroslurp could further be identified by the sound of running water flowing through the vacuum hose.

As the available vacuum was divided among all the wells in the recovery system, the vacuum pressure at each well head was reduced accordingly. As a result macroslurp dropped off and was replaced by small droplets of water being entrained in the vacuum stream. This mode of water and vapor recovery was dubbed "microslurp" due to the small size of the droplets. The observation of microslurp was much more dependent on the proper tube position in relation to the water table than macroslurp. For microslurp to take place the droptube had to be placed within approximately 12.5 mm (.5") of the water table as determined by the dynamic water level determination method. The configuration of vacuum settings for the well field and the resultant mode of operation for each well when the system was turned over is presented in Table 2.

TABLE 2

Vacuum Distribution

Well I.D.	Wellhead Vacuum Inches of H_20	Casing Vacuum inches of H_20	Resultant Recovery
VE-1	0.1	NA	Biovent
MW-1	8	0.5	Bioslurp
MW-2	1	0.8	Biovent
MW-3	14	1	Biovent
MW-5	12	0.3	Bioslurp
MW-7	10	1.2	Bioslurp
MW-8	14	0.8	Biovent
MW-9	10	0.3	Bioslurp
MW-10	12	2	Bioslup

Operations and Maintenance

The MPX system requires very little in the way of maintenance other than scheduled cleaning of the strainers, bag filter, and oil water separator. A training seminar was conducted by the authors to train base personnel in the operation and maintenance of the system and as a byproduct instill in them a pride of ownership. The half-day classroom session was followed by a hands-on demonstration at the site. The authors developed an operations manual which was handed out during the training.

A telemetry unit was installed in the control room portion of the container. This unit will call out when a fault condition occurs or will accept incoming calls to verify status. This has proven invaluable as the unit dials out to O&M personnel whenever the system is down. During the first three months of operation, the telemetry unit called the onsite maintenance personnel for problems relating to low seal water and base power outage (telemetry unit operating on back up battery). This coupled with the training has insured continuous operation.

Performance

The system became operational on October 4, 1995 and was turned over to the user on October 11, 1995. A process monitoring program (PMP) was initiated to monitor the system performance. A PMP form was kept at the treatment center and utilized to track system run times, flowrates and concentrations.

Initial vapor concentrations were much higher than anticipated during the design phase. System vapor measurements indicated a LEL of over 350%. A LEL of 100% for JP-4 is equivalent to 13,000 ppm (Baker, 1984). Therefore the initial concentration going into the system was over 45,500 ppm. Our 400 lbs. Of carbon was saturated in about 2 hrs. Calculations based on this level of concentration indicated that a different method of off-gas treatment would have to be utilized. After 1454 hours of operation, the authors went back out to the site and measured the LEL at 225% (29,250 ppm).

During the investigation and well installation phase of the project, much lower levels of LNAPL were discovered than anticipated in the original design. Due to power considerations and the very high vapor concentrations, the authors balanced the system to operate primarily in biovent mode. As of 1/16/96 only 1,465 gallons of wastewater and 5 gallons of product was recovered and processed by the system. Table 3 summarizes cleanup to date.

TABLE 3
Remediation to Date

Dates	Run Time (hrs)	Vapor Phase (lbs.)	Vapor Phase JP-4 Equiv. (gal)	Water Flow (gal)	Est. Dissolved JP-4 removed To date (gal)	Free Product (gal)	Total JP-4
10/4/95 to 11/6/95	598	10593.5	1694.96	1060	.21	.05	1695.22
11/7/95 to 1/16/96	1216	20401	3264.16	405	.08	5	3269.24
Cum	1814	30994.5	4959.12	1465	.29	5.05	4964.46

Lessons Learned

Field tests indicate that the system does not currently have sufficient power to run all the wells in bioslurp mode. Although the system is rated at 100 SCFM we are averaging 65 CFM overall. When allocated among nine wells, that amounts to 7.22 CFM per well. With the current slurp tube diameter of 25 mm (1”), our tube velocity is calculated to be 1303 ft/min. Approximately 2000 ft/min tube velocity is required for good bioslurping. During the next phase of activity, the authors plan to reduce the slurp tubes to 19 mm (3/4”) diameter thereby increasing the tube velocity to 2375 ft/min.

An additional problem encountered was the build up of condensate in the air effluent line. A small valved bypass was installed to drain the air effluent pipe and redirect the water into the influent trunk line, to be processed by the system.

The telemetry unit and training have proven to be more effective than expected. The unit was programmed to call out to base personnel in the event of a fault condition. Base personnel have been prompt in responding to alarms and due to the training course were able to restart the unit and perform necessary corrections.

The system operating in microslurp mode was not supplying enough recovered water to provide an adequate and constant amount of seal water to the liquid ring pump, therefore additional water had to be added to the system. In the future a water line should be hard piped to the system.

Conclusions

Extremely high vapor levels still exist at the site and based on performance, they are expected for sometime. Once the vapor concentration is reduced, the authors plan to increase the bioslurping of groundwater and the thin layer of LNAPL that exists.

Although the site was not and still is not fully characterized, the nature of the problem required the authors to initiate remediation immediately. In this case, the system design provided a very flexible capability that allowed for initiation of remediation tailored to the mix of phases encountered. For example, petroleum thickness was reported to be approximately 100 mm (4”), however, when the authors arrived on site, maximum thickness was measured at approximately 9 mm (.36”). If the authors had designated any other method of LNAPL removal, it would not have been applicable to the conditions encountered onsite.

The authors feel that the MPX also provides a solid base to expand the system. Once, the plume is fully defined, a set of remediation wells will be installed in a fashion that can address the entire plume. If the determination is made that more power is needed, the authors will replace the liquid ring pump with one that has increased capacity. Currently 200 and 300 SCFM models are available. Off-gas treatment will also be modified to accommodate the high vapor concentrations.

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