Enhanced Fluid Recovery
August 1, 1995
Preliminary Technical Guidance
Overview, Design, Strengths, and Limitations

Summary

Positives: Enhanced fluid recovery (EFR) is being used to reduce free phase hydrocarbon and dissolved contamination to levels that allow low cost alternative solutions, such as monitoring only, risk based site assessment, or natural attenuation. It has also been used to remove free product in an emergency response situation. The technique uses existing site wells, a single commercial vacuum truck, and PVC manifold and well stingers that are built from off-the-shelf materials. There is no permanent installation, no capital cost, and the financial risk of application is primarily the one day rental cost of a vacuum truck and disposal of fluids (primarily groundwater in the vacuum truck tank).

The technique is likely to be successful in the same situations in which a combination SVE/pump-and-treat system is likely be successful. An analysis of available data indicate EFR has worked where hydraulic conductivities have averaged 10^{-4} to 10^{-3} cm/sec and the depth to the water table has generally been greater than 10 ft. In most cases, thickness of product has initially been less than one foot in the extraction monitoring wells and the average recovery of hydrocarbon per visit was 40 gal (one case of 310 gal/visit is not included). Thus, hydrocarbon recoveries have been generally good.

Caveats: The measured water table cone of depression is very steep and the calculated radius of influence from the volumes of water recovered is not great. Thus, there is a real concern that the technique is not very effective at remediating dissolved phase contamination very far from the wellbore. Additionally, the radial area of recovery of residual product trapped below the water table may not be as great as expected because drawdown does not extend very far. There have been two recent failures which were in situations in which a standard SVE/P&T system would also have been unsuccessful and would not have been attempted. No method is currently available for choosing an optimum schedule for the periodic visits and no data is currently available on the long term effectiveness of the technique (does rebound occur?).

Recommendations: Since the cost of piloting the EFR technique is likely less than $2000 per visit (more than one visit may be needed), it is recommended that the technique be attempted. The issue is not whether the technique will recover hydrocarbon (the data indicates it will in good geology), but rather will it achieve the reductions necessary to allow alternate solutions. This may be significantly influenced by state regulations. Because of strategy questions, scheduling of treatments, lack of long term data, and lack of experience in difficult geology, it is requested that a member of the TA&D section be involved in the planning and long term monitoring of the application of the technique.

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Introduction

EFR (Enhanced Fluid Recovery) has evolved from a number of different but successful applications of vacuum technology to soil and groundwater remediation and a desire to eliminate capital expenditures. Vacuum dewatering has long been used in the construction industry and vacuum well point systems have been used to control water table gradients at many sites. Baker and Gates (1990) showed that vacuum enhanced recovery techniques could be successfully applied at hydrocarbon contaminated sites to facilitate increased recovery of fluids, control groundwater gradient, and recover vapor and residual hydrocarbons. EFR uses a vacuum truck that applies a strong vacuum to existing wells inducing air and liquid flow (vapor, water, and/or free phase hydrocarbon-FPH) to the wells. One of the original purposes was to remediate contamination in abandoned Underground Storage Tank (UST) basins filled with permeable backfill placed in native soil. This creates a bathtub effect that tends to retain contamination. Since then it has proven to be effective in native soil but is dependent upon the type of soil, the vacuum applied, the hydrocarbon type, and geologic parameters such as stratification and depth to groundwater.

Theoretically, EFR carries out remediation by several mechanisms. It will directly extract free phase hydrocarbons (FPH); and the equipment can be adjusted to maximize product recovery versus water recovery. EFR can induce air flow in the subsurface that will remediate contaminated soils above the water table, similar to an SVE (soil vapor extraction) system, and volatilize "smeared product" and exposed residual hydrocarbons within the cone of depression. Concurrently, fresh air is drawn into the contaminated soil area. The increased oxygen content enhances aerobic biodegradation. Most of the hydrocarbons recovered from the ground, including FPH, are volatilized by the air flow and are emitted through the exhaust of the vacuum truck. Liquids, primarily water, are collected in the tank of the vacuum truck. A single treatment is typically scheduled to last one day (six to ten hours) and multiple treatments are generally scheduled at monthly intervals.

The purpose of this document is to recommend geologic conditions under which EFR is likely to be successful. Success is defined as reducing FPH and dissolved contamination to levels that allow the implementation of low cost alternatives such as risk based closure, monitoring only, and natural attenuation. This will likely be dependent upon state regulations. This document will also review a compilation of data obtained from ten sites and two cases that were not successful. Equipment design, field operations, and a pilot testing procedure are also presented.

Geologic and Hydrocarbon Characteristics for Application

Rate of recovery and efficiency of operation are dependent on site specific conditions such as depth to water, hydraulic conductivity of the soil, stratification, and type of hydrocarbon.

EFR is best applied in aquifers up to approximately 50 feet in depth. However, if the depth to water is in excess of 25 feet, primarily vapor with little or no water will be recovered because of the limits of atmospheric pressure (which is approximately 33 feet of water or 30 inches of mercury). Some fluids may be recovered from depths exceeding 25 feet if the fluids are lighter than water or if air is entrained (forms bubbles decreasing the specific gravity) in the water column.

If the water table is too shallow, within three feet of ground level for example, there may be substantial loss of vacuum to surface bypass. The critical depth will vary according to site conditions such as soil type and the integrity of cover or pavement over an area. EFR has been used successfully with depth to water less than five feet below ground level in a paved area. This shallow-depth limitation is best judged on a site by site basis.

Permeability is required for vapor and liquid flow. The construction industry frequently uses vacuum techniques rather than water pumps to dewater low permeability sites. Some operators have indicated that EFR can operate with a minimum hydraulic conductivity of 10^{-6} cm/sec (or approximately 0.1 gpd/ft^2 - a fine silt). There are insufficient data to confirm this at this time. Soil conductivity greater than 10^{-4} cm/sec is desirable because it yields a larger radius of influence for a given well, but conductivity that is too high can yield too much water and will fill the vacuum truck too quickly.

Stratification (horizontal layering) of the soil tends to cause a reduction of vertical permeability. In some cases this is beneficial because it forces lateral flow to the extraction well, rather than vertical bypass. However, if the variation in permeability is high, for example a clay layer overlying a sand, then flow may be channeled exclusively through the high permeability zone, yielding little or no remedial benefits in the tight zone.

A similar problem may occur in fractured bedrock and in clay soils with cracks, peds or fractures. However, peds or cracks in soil may also serve to increase EFR's radius of influence and increase the volume of soil matrix affected, which is beneficial. In some cases, EFR operations may induce fracture-like flow in low permeability formations and yield the same benefits as soil peds or desiccation fractures.

EFR is most effective in treating volatile hydrocarbons such as gasoline or condensates (specific gravity less than 0.80 or API gravity over 45) that are susceptible to volatilization. Middle distillates, such as kerosene and diesel, are affected by EFR through oxygen enhanced biodegradation, but this process occurs over a longer time frame than is usually practical for EFR.

Equipment Design and Field Operation

<u>Equipment</u> This technique is implemented by connecting a commercial vacuum truck to groundwater monitoring wells via a PVC manifold, monitoring well couplings, and stingers. Up to four wells can be connected directly to the manifold at one time (each port on the manifold may be altered to accommodate more wells). Vacuums in excess of 20 inches of mercury (272 inches of water) with flow rates in the range of 350 to 700 cubic feet per minute (CFM) should be anticipated for optimal removal using EFR. Construction materials for manifolds and stingers consist of standard PVC components typically used in well construction. This standardization has provided tolerances and snugness of fit adequate for EFR vacuum operations.

The EFR manifold (Figure 1) is constructed of two and four inch schedule 40 PVC with quick connect aluminum fittings. The basic manifold has four entry ports for input from multiple monitoring wells. Each entry port on the manifold has a ball valve to control flow from wells that may produce too much fluid. On the monitoring well side of the ball valve, a sight-glass of clear PVC is installed to visually monitor fluid flow. The EFR operator has the ability to control flow of fluids from each well with the ball valves on the manifold. The manifold ports are connected to the wells via a two inch diameter vacuum hose with quick connect fittings and well stingers (Figure 2) that are inserted into the monitoring wells. The outlet of the manifold is connected by quick-connect fittings to the vacuum trucks four inch vacuum hose that runs directly to the truck tank. The tank is kept at a vacuum by the truck's vacuum pump. Fluids, mostly water, collect in the tank, and vapors, mostly air and hydrocarbons, are emitted from the stack. Every effort should be made to keep the lines short to reduce pressure drop (loss of vacuum).

Stingers are individually assembled from five foot (or shorter) lengths of one inch diameter hand-slotted PVC tubing for two inch monitoring wells, and one and one-half inch diameter tubing for four inch and six inch monitoring wells. Stinger lengths are joined by threaded fittings. The stingers extend from the top of casing to the product/water interface, or lower depending on the desired cone of depression. The stingers are connected at the top of the monitoring well with a PVC overshot or slipover coupling. The slipover couplings consist of the same PVC joints that are generally used to glue same-size pieces of PVC together end-to-end. They are designed to fit snugly over the monitoring well stick-ups without the necessity of any clamps or expandable fittings. Obviously, different size couplings are required for two, four, or six inch diameter wells. Stingers are generally slotted their entire length to allow air entrainment to provide additional fluid lift if necessary. (Note: Although the stinger may be slotted along the entire length, it resides inside the monitoring well. Therefore, vacuum from the monitoring wells extends into the surrounding soil from the screened interval of the well itself, which is usually a limited interval with screen a few feet above and below the water table.) Additionally, each stinger assembly may have a sealable surface slot that can be partially or fully opened to reduce vacuum on a given well without reducing vacuum for the manifold system.

It is recommended that capabilities of the vacuum truck (air flow rate, and vacuum) be obtained prior to performing EFR at a site. The vacuum truck must be capable of maintaining a constant vacuum and the curve of airflow rate versus vacuum is needed to judge the vacuum pump performance.

Operations The manifold and stingers should be assembled off site prior to the EFR event to ensure that all parts are present and all fittings are the correct size and are in good working order. The assemblies can then be disassembled and transported to the site. If the size of fit of the stinger slipover couplings are in question, these parts should be checked on the actual observation wells prior to the time they will be used. If monitoring wells are constructed of standard materials, there should be no problem with the fit.

Wells that will be used for EFR should be checked for mechanical integrity and quality of construction. Well risers and stick-ups should be checked for cracks or flaws, and the surface seal or grout should be inspected. Cracked grout should be sealed. On flush mounted monitoring wells, the size of the man-hole or key-box should be checked or measured to ensure the stinger assembly and slipover coupling will fit into the key-box and over the well stick-up. The stick-up must extend high enough out of the ground (one or two inches) for the slip-over coupling to be installed.

Prior to the EFR operation, vacuum truck operators should be advised to have sufficient vacuum hose (four inch and two inch with quick connect couplings) to reach the wells and the manifold. These hoses are standard equipment on most trucks. However, one should never assume the truck will have enough. Try and keep the length of hose short to avoid loss of vacuum.

Before beginning vacuum operations, each monitoring well on-site should be gauged with an oil water interface probe to determine depth to water or depth to product and product thickness. The TA & D section has water level data loggers that can be used to determine the drawdown at other well locations. Additionally, if any supplemental vacuum monitoring points are to be used, such as hand driven soil monitoring probes, they should be installed prior to the arrival of the vacuum truck to minimize stand-by charges.

The manifold and stingers can be assembled and installed on site while the truck is building vacuum. All fittings should be snug. The truck should build a vacuum of at least 20 inches of mercury (shown on tank gauge). At this time, and prior to opening the truck valve and the valves on the manifold, the EFR operator should take a vapor reading (ppm of hydrocarbon) from the exhaust stack of the vacuum tank to provide a baseline for future measurements.

After the baseline reading is taken, the valves on the truck and the manifold may be opened to apply vacuum to the selected wells. The EFR operator may want to open the valve on each well individually while monitoring the sight glass to note the apparent volume and type of recovery (clean water, water with product, water with vapor, etc.).

The exhaust stack from the vacuum tank should be monitored every fifteen minutes during the first hour of operation, and hourly thereafter. Monitoring should include a measure of hydrocarbons vapor in parts per million (ppm) leaving the stack, and air flow in CFM. Air flow may be calculated by measuring the velocity of air in the stack with an anemometer, and multiplying this value in feet per minute times the cross sectional area of the stack in square feet. Emissions of hydrocarbons should be measured with a Bacharach TLV Sniffer with dilution probe (capable of measuring hydrocarbon vapors to 100,000 ppm).

These readings can be input into a formula used by the South Coast Air Quality Management District (SCAQMD) for calculating the removal rate of gasoline from soil using vapor extraction:

$$\frac{\text{ppmV (60 min/hr)(SCFM)(86lb/lb-mole)}}{\text{(1,000,000) 379 cubic feet/lb-mole}}$$

Where: ppmV = concentration in parts per million by volume TPH as gasoline

SCFM = flow rate corrected to standard conditions

86 lb/lb-mole = average molecular weight of gasoline

379 cubic feet/lb-mole = ideal gas constant

VHg = Vacuum in inches of mercury

Note: To calculate other compound removal rates, use appropriate concentrations and molecular weights as determined from field and laboratory data.

Figure 3 is an example of the data collection sheet used for EFR events. At the completion of a EFR event the operator can determine the approximate volume of hydrocarbon vapors that has been removed from the site.

Examples of Applications

Emergency Response EFR has been used to mitigate the movement of free-phase hydrocarbons at service stations, terminals, and refineries in a variety of locations around the country. An EFR team can be mobilized to a site in a manner of hours and can begin cleanup of the release soon afterward. An EFR team was mobilized to a terminal in South Dakota to remove free-phase hydrocarbons that were being released to the environment at an unknown rate. When a release occurs the free-phase hydrocarbons migrate downward due to gravity and capillary attraction. The hydrocarbons then collect in the capillary fringe and begin to migrate laterally.

Ecova, a former subsidiary of Amoco, initiated activities at the site in South Dakota on September 15, 1994. Utilizing a single vacuum truck, at multiple wells, Ecova was able to recover approximately 11,000 gallons of petroleum hydrocarbons from the site wells (Table 1). Table 2 summarizes the product recovery through November 1994. Free-phase hydrocarbon thickness' have shown a steady decline as a result of this work. Table 3 presents hydrocarbons thickness' throughout the investigation while Figure 4 is a graphical representation of product thickness versus time.

Free-phase Hydrocarbons To date most of the EFR data has been recovered from service station and terminals with underground storage tanks (USTs). Typically USTs have limited areas of FPH contamination present in and around the tank pit. This contamination can be related to overfilling tanks, corrosion of older tanks, failure of fuel lines, or accidental damage to dispensers (this could also be considered an emergency response action). The USTs are located in pit areas typically filled with gravel. The FPH moves quickly from the area of the leak or spill through the gravel to the underlying soil or groundwater. The native soil surrounding the tank pit is typically lower in hydraulic conductivity that the pit area. This change in hydraulic conductivity can cause the FPH to pool near the tank pit area. Once the release FPH has been detected in the alarm wells at the site, EFR can be initiated to minimize the continued movement of the release down-gradient.

The Atlanta District has been using EFR since mid-1994 as a remediation process at service stations and terminals. Table 4 is a compilation of the data from nine of those sites. The average hydraulic conductivity of the saturated zone was greater than 10^{-4} cm/sec. The geologic description of the vadose zone indicated about half the sites had similar geology to the saturated zone and about half had slightly lower hydraulic conductivity. The depth to water was typically greater that 25 feet and the initial uncorrected product thickness was less than one foot. Good hydrocarbon recoveries were obtained for all except service station 981 where treatments were halted after two. The traditional technology for all these sites would likely have been a combined SVE and Pump and Treat system.

Dissolved Hydrocarbon and Residual Below the Water Table The dissolved phase hydrocarbons are on a whole the smallest percentage of the hydrocarbons present in a release yet they can be the most mobile. The application of EFR has been reported to be highly successful but good data has not been reviewed.

The recovery is generally attributed to dewatering of the capillary fringe and soil pores within the radius of influence of EFR. As the dewatering occurs moisture in the soil will be evacuated and an increased air flow will be induced that will help to move the liquids and aerate the impacted soils.

TPH Inc. has contracted its service to the Mid-Atlantic District. They have pioneered the use of a mobile trailer to recover and treat dissolved hydrocarbons on-site. This technique has been typically applied to one or two wells at a site, and they claim numerous "closures" after about 12 treatments

W.E.S. Inc. installed semi-permanent proprietary equipment to dewater and vent the soil at an Amoco service station. The process was applied for approximately 45 days. After 11 months of monitoring after shutdown, concentrations remained below monitoring only limits.

Recently Amoco and Handex of Illinois performed EFR at a former Amoco service station in South Chicago. Three 4 inch EFR wells were installed because the area of contamination was thought to be quite large, and only one other well would otherwise have been available. The wells were located near, but not in the backfill of the tank pit. During a six hour period, nearly 3300 gallons of water from three wells were recovered from the site. The contamination at the site was thought to be due to residual hydrocarbons since no FPH had been observed at the site. During the EFR process, it was noted that the extracted water seemed to contain some FPH. Handex returned to the site three days later and noted the presence of three inches of FPH in one of the extraction wells and a few hundredths of an inch in the other two. This would seem to validate the premise that residual hydrocarbons that cause continued contamination can be freed and the residual source of contamination removed.

Pressure transducers were installed in wells up to 60 feet away from the EFR extraction wells. The wells that were monitored were not installed in the tank pit but rather in the native soil ($6.3 * 10^{-2}$, or 180 feet/day). The drawdown curve after six hours of extraction is shown in Figure 5. Note that a drawdown was observed nearly 60 feet from the EFR wells, but five feet from the extraction well the drawdown was only one foot. This raises a concern that a limited cone of depression may have been present that only freed up residual hydrocarbon from a limited radius from the well. The drawdown noted could have been due to a lack of integrity of the well bore affecting the drawdown. This is further validated by the fact that the 3300 gallons of water recovered translates to a radius of influence of about ten feet (assuming a saturated thickness of ten feet and a porosity of 0.30 per cent) around each well. This also raises a question as to the volume of contaminated water removed versus the size of the plume.

Vacuum monitoring points were also installed across the site. A plot (Figure 6) of log (vacuum) versus distance shows that good vacuum was measured 30 feet from the extraction well. A total of about 70 CFM was measured during the test, meaning about 20 CFM was drawn through each well. Most of this passed within a radius of 15 feet of the EFR wells. However, since the soil is not contaminated, the air flow was primarily to recover any smeared residual that is present.

Pilot Test Procedure

The purpose of pilot testing is to determine if EFR can remove significant hydrocarbons and if so, then to determine an initial schedule for treatments. It may be useful to determine the drawdown curve and the vacuum influence, but depending on project goals this can always be done at a later date.

The consultant will review the file on the site to determine the following information:

1. Site history (historical releases of hydrocarbons, remedial efforts or systems that were installed, FPH recovery, laboratory results)
2. Site hydrogeology (groundwater gradient, hydraulic conductivity, review of boring logs, any pilot testing information that may be available concerning radius of influence)
3. Geologic layering and heterogeneities and their relationship to the screened interval
4. Location and volume of contaminated groundwater and FPH, including the approximate concentration and type of contamination
5. Monitoring well construction (depth to water, length of screen, diameter of casing, etc.)
6. Review of regulatory requirements at the site (what does it take for monitoring only, natural attenuation, closure, etc.)

Once the files have been reviewed the consultant will prepare a proposal for the pilot test that will take into consideration the above information. The pilot test should be designed to maximize FPH, dissolved hydrocarbons, and vapor recovery at the site.

The data collected during the pilot test will be used to design a treatment procedure that will be able to recover the maximum amount of FPH and hydrocarbon vapor, while minimizing the amount of water recovered per hour at the site. This procedure will be developed in conjunction with the Amoco Remediation Coordinator and GMS. The design should take into consideration the following :

1. Estimated stinger length and number of wells necessary
2. Capability of the vacuum pump to maintain a vacuum of 20 inches of mercury
3. Vacuum truck volume proposed (including availability of the truck and the cost)

4. Estimate system flow rate
5. Anticipated emission rate for sizing any treatment requirements
6. Reporting frequency
7. Confirmation that the water will be transported to an approved facility, and the cost of transportation
8. Establish a system performance and monitoring plan, what to monitor and how to judge performance

Good data must be obtained on the following parameters during the pilot test:

1. Volume of hydrocarbons removed
2. Volume of water removed
3. Vapor flow rate from and the applied vacuum at the extraction wells
4. Vacuum and drawdown as a function of distance from the extraction wells (optional)

Equipment List:

* Interface probe
* Tool kit
* EFR manifold and stingers
* Calibrated anemometer
* Calibrated Bacharach TLV Sniffer with dilution probe (reads 1-100,000 ppm)
* Four to six 0-2" of water Magnehelic vacuum gauges
* One or two 0-15" of water Magnehelic vacuum gauges
* One 0-20" of water Magnehelic vacuum gauge
* Steel tape
* Calculator

Test Procedures:

* Gauge all monitor wells to obtain static water levels (locate transducers in wells not involved in test to monitor radius of influence)
* Test truck to determine the maximum vacuum truck is capable of producing
* Record vacuum reading at each monitoring point every 30 minutes
* Record TLV reading every 15 minutes for the first hour and every hour there after
* Record air flow with anemometer every 15 minutes for the first hour and every hour there after
* Calculate removal rate using Enhanced Fluid Recovery Data Sheet
* Determine and record the total amount of fluid recovered

Limitations

<u>Possible reasons for failure:</u>

1. Short circuiting - Does there appear to be possible short circuit routes in the test area such-as 1) grassy areas, 2) holes or cracks in pavement or concrete, 3) poor well seal, 4) poor surface seal around well, 5) water level too close to surface?

2. Well inefficiency - There could be a significant vacuum loss between the sand or gravel pack and the formation

3. Channeling - Are there channels (utility trenches, tank pit backfill, etc.) that could cause preferential flow?

4. Low soil permeability - Vacuum propagation may take a considerable period of time

5. Low volatility hydrocarbons

6. Shallow depth to water (typically less than five feet)

7. Very high saturated zone hydraulic conductivity

TABLE 1.

Enhanced Fluid Recovery
Wyco Pipe Line Company
Rapid City, South Dakota

Date	Well	Pounds of Vapor Removed	Equiv. Gallons Product	Cumulative Gallons Product
09/15/94	MW-7	383	61	61
09/16/94	MW-7	642	103	164
	MW-1	103	16	180
09/17/94	MW-7	173	28	208
	MW-1	642	103	310
09/18/94	MW-7	637	102	412
	MW-1	289	46	458
09/19/94	MW-7	454	73	531
09/20/94	MW-7	622	99	630
09/21/94	MW-7	681	109	739
09/22/94	MW-7	174	28	767
09/23/94	MW-7	619	99	866
09/24/94	MW-7	686	110	975
09/25/94	MW-7	333	53	1,028
09/26/94	MW-7	593	95	1,123
09/27/94	MW-7	626	100	1,223
	MW-10	191	31	1,254
09/28/94	MW-7,10	620	99	1,353
	MW-8	679	108	1,461

TABLE 1. (Cont.)

Date	Well	Pounds of Vapor Removed	Equiv. Gallons Product	Cumulative Gallons Product
09/29/94	MW-7,10	764	122	1,583
	MW-8	557	89	1,672
09/30/94	MW-7,10	631	101	1,773
	MW-8	346	55	1,828
10/01/94	MW-7,8,10	743	119	1,947
	MW-8 only	132	21	1,968
10/02/94	MW-7,8,10,13	1,085	173	2,142
10/03/94	MW-7,8,10,13	783	125	2,267
10/04/94	MW-7,8,10,13	995	159	2,426
10/05/94	MW-7,8,10,13	570	91	2,517
10/06/94	MW-7,8,10,13	997	159	2,676
10/07/94	MW-7,8,10,13	784	125	2,801
10/08/94	MW-7,8,10,13	868	139	2,940
10/09/94	MW-7,8,10,13	1,227	196	3,136
10/10/94	MW-7,8,10,13	938	150	3,286
10/11/94	MW-7,8,10,13	1,192	190	3,476
10/12/94	MW-7,8,10,13	1,828	292	3,768
10/13/94	MW-7,8,10,13	1,700	272	4,040
10/14/94 through 12/11/94 Estimate	MW-7,8,10,13	44,132	7,050	11,089

TABLE 2.

Results of Vac Truck Tank Gauging
Wyco Pipe Line Company
Rapid City, South Dakota

Date	Total Volume (gal.)	Water Volume (gal.)	Product Volume (gal.)
9/21/94	1,217	511	706
9/25/94	662	371	291
9/28/94	1,217	987	230
9/28/94	244	206	39
9/30/94	206	135	71
10/3/94	1,276	821	455
10/4/94	1,394	987	406
10/4/94	1,217	987	230
10/6/94	244	169	75
10/9/94	876	560	316
10/14/94	2,108	1,692	416
10/19/94	714	560	154
10/25/94	2,167	1,692	475
11/4/94	1,692	1,394	298
11/14/94	2,396	1,692	705
11/22/94	2,283	1,692	591
11/27/94	2,108	1,572	536
	Totals:	16,027	5,993

Table 3.

Summary of Product Thickness Measurements
Wyco Pipe Line Company
Rapid City, South Dakota

	Product Thickness (feet)							
Date	MW-1	MW-7	MW-8	MW-9	MW-10	MW-13	MW-17	MW-21
9/16/94	3.55	3.78						
9/17/94	2.48	6.28						
9/18/94	3.55	6.74						
9/19/94	3.53	5.83						
9/20/94	3.41	4.98						
9/21/94	3.26	6.53						
9/22/94	3.30	5.84						
9/23/94	3.22	7.76	6.36					
9/24/94	3.10	7.37	6.46		6.41	1.10		
9/25/94	3.01	7.16	6.32		6.52			
9/26/94	3.07	8.06	6.47		7.23	1.50		
9/27/94	2.95	7.31	6.24		7.08	1.65		
9/28/94	2.87	7.35	6.15		6.39	1.89		
9/29/94	2.72	6.45	5.49		6.74	2.12		
9/30/94	2.64	6.22	5.13		6.81	2.32		
10/1/94	2.45	5.74	4.83		6.80	2.53		
10/2/94	2.50	6.05	4.06		7.01	2.80		
10/3/94	2.10	5.72	3.08		6.49	0.94		
10/4/94	1.90	5.73	3.93		6.54	0.99		
10/5/94	2.28	6.22	3.29		6.85	1.15		
10/6/94	2.49	6.21	2.69		6.87	0.62		
10/7/94	1.78	4.93	2.43		5.91	0.28		
10/8/94	1.52	4.90	2.42		6.10	0.30		
10/9/94	1.55	4.80	1.85		6.25	0.47		
10/10/94	1.65	4.72	1.90		6.14	0.33		
10/11/94	1.69	4.66	1.61		6.20	0.55		
10/12/94	1.56	4.47	1.27		5.85	0.34		
10/13/94	1.36	3.40	0.76		3.37	0.06		
10/14/94	1.53	3.99	1.90		5.90	0.44		
11/4/94	0.61	2.18	1.23	0.01	3.65	0.30		
11/5/94	0.59	3.09	1.21	0.01	2.76	0.35		0.63
12/6/94	0.08	0.00	0.01	0.02	2.01	0.99	0.02	1.23

TABLE 4: Compilation of Data From Nine EFR Free Phase Recovery Sites

Amoco Service Station Number	Geology	Conductivity cm/sec	DTW, ft	Initial Product Thickness, ft	Total Product Recovered gal	Total Water Recovered gal	Number of Visits
6308	Fill to 10',silty sand 20-37'	2.6 E-4	26	<1 ft	520	1500	10
723	Silty Sand	2.5 E-3	26	.5 - 5 ft	570	3368	6
546	Clayey Sand	6.7 E-4	25	<.33	736	3166	11
347	Silty Sand	4.0 E-3	35	1 - 6 ft	2793	4740	9
061	Clayey silt, limestone	4.6 E-4	10 - 17 ft	None	26	400	2
678	limestone	6.0 E-4	40	< 1	161	3500	11
767	Clay	7.5 E-4	17	<.15	217	1437	6
176	Saprolite	9.2 E-4	25	<.6	224	1667	10
327	Clayey silt	1.0 E-3	30	<.35	22	3255	6

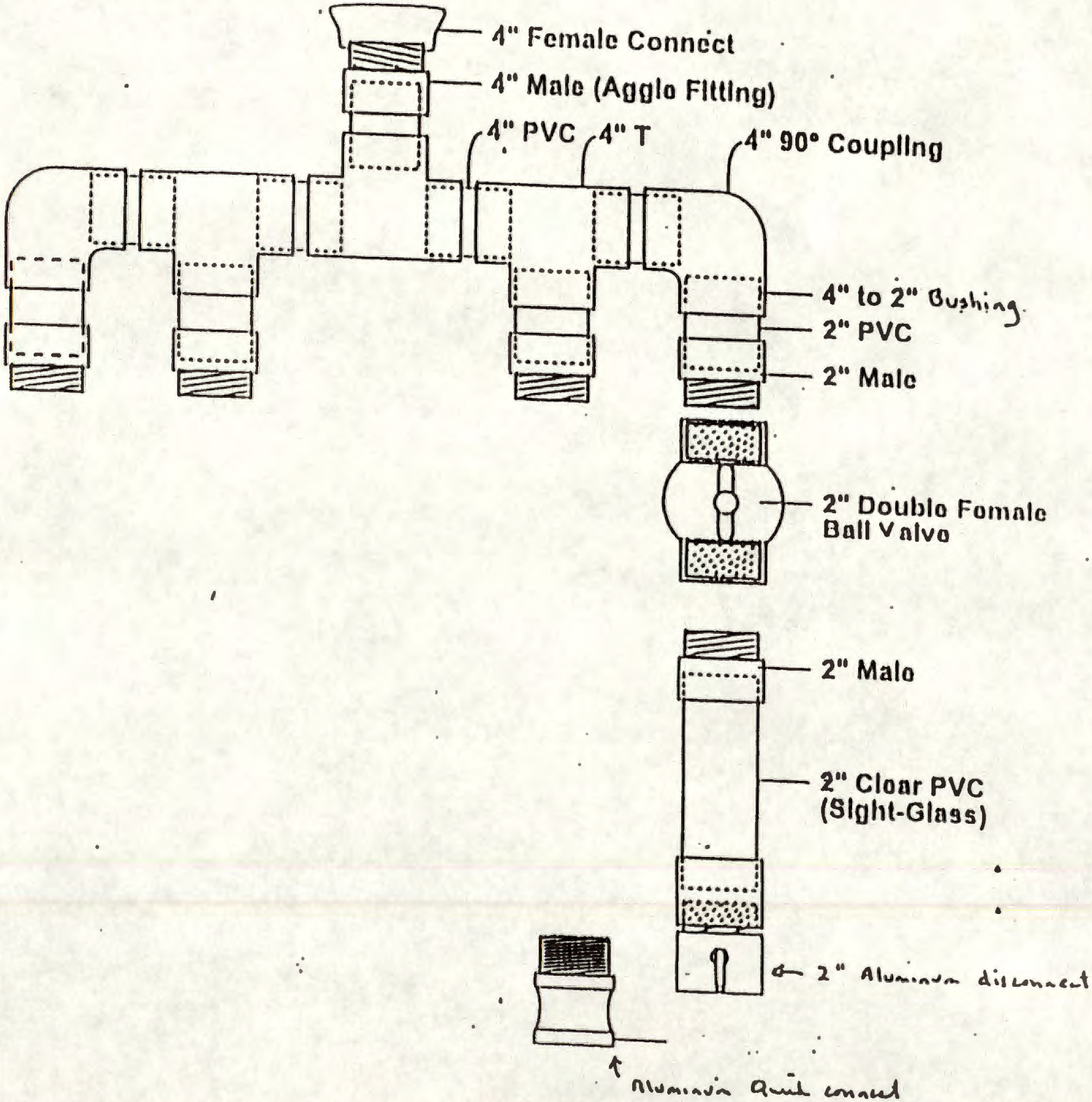
4" Female Connect
4" Male (Agglo Fitting)
4" PVC
4" T
4" 90° Coupling
4" to 2" Bushing
2" PVC
2" Male
2" Double Female Ball Valve
2" Male
2" Clear PVC (Sight-Glass)
2" Aluminum disconnect
Aluminum Quick connect

Figure 1

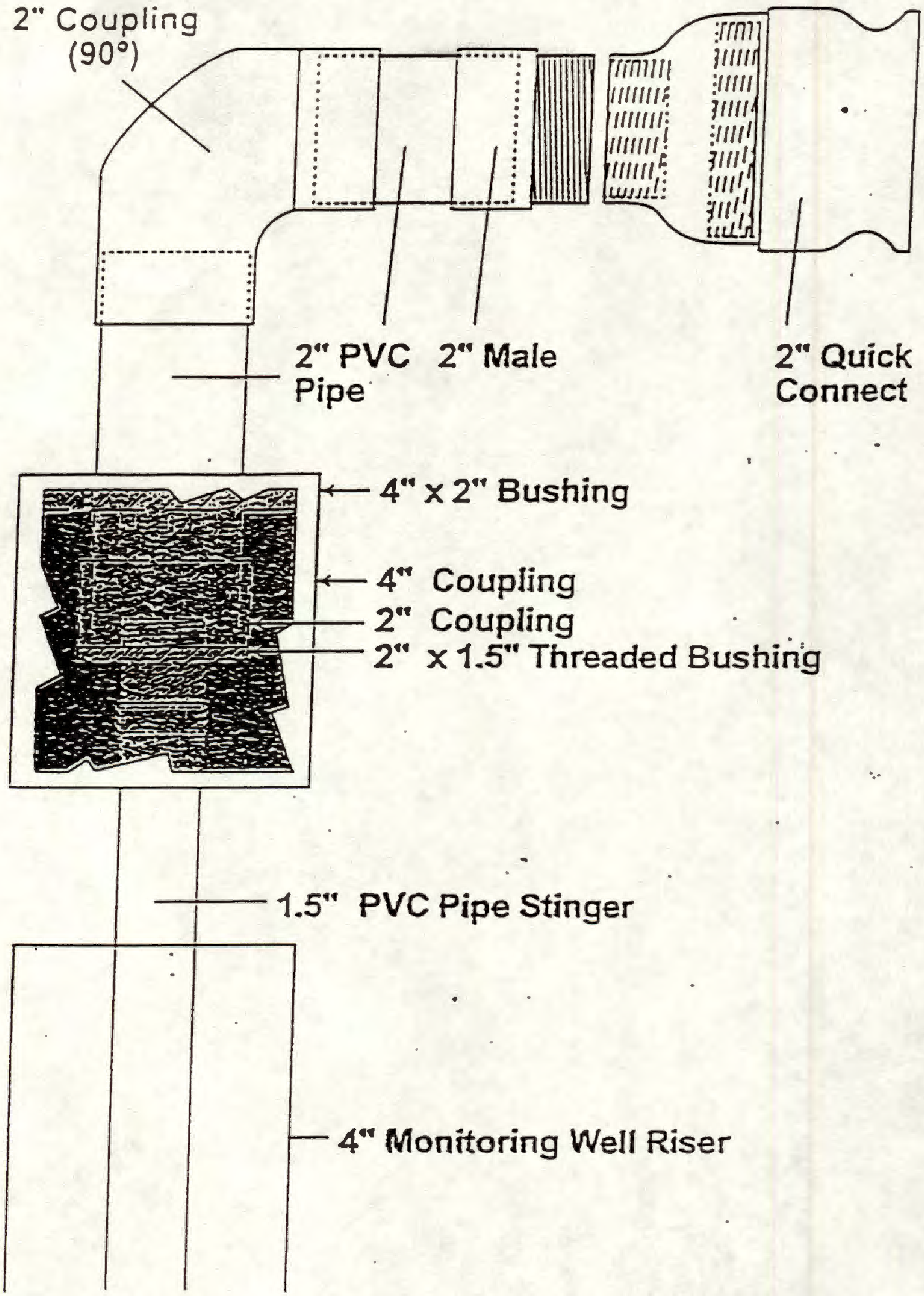

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Figure 2

EFR Data Sheet

EXTRACTION TIMES			CONCENTRATION(ppm)			RECOVERY DATA				
Start Time	End Time	Total Time	Initial ppm	Ending ppm	Average ppm	Vacuum In. Hg	FPM	CFM*	lbs/hr	POUND
									TOTAL	0.00

Pounds Per Hour (lb/hr) = ppm, (60 min./hr)x(CFM)(M.W.) / (1x10[6]) x (379 ft[3] /lb-mole)

Where: ppm, = parts per million by volume

Flow = Cubic Feet per Minute

M.W. = Molecular Weight(lb/lb-mole)

I.G.C. = Ideal Gas Constant (379 ft[3] /lb-mole)

Note: For Gasoline M.W = 75 grams/mole

For PCB M.W. = 165 grams/mole

*CFM Conversion Factor

Stack Dia.	Factor
3"	0.0491
4"	0.087
6"	0.1964

Date:______

Location:______

Method: EFR

Vac. Company:______

______

Operator:______

Extraction Wells:______

______

Total Pounds Removed:______

Equiv. Gals. of Product:______

Total Gallons of Water:______

Note: Gasoline is 6.26 lb/ gal

Client:______

Project:______

System Operator:______

______

Tyree Brothers Env. Services

Figure 4

Product Thickness vs. Time
Wyco Pipe Line Company
Rapid City, South Dakota

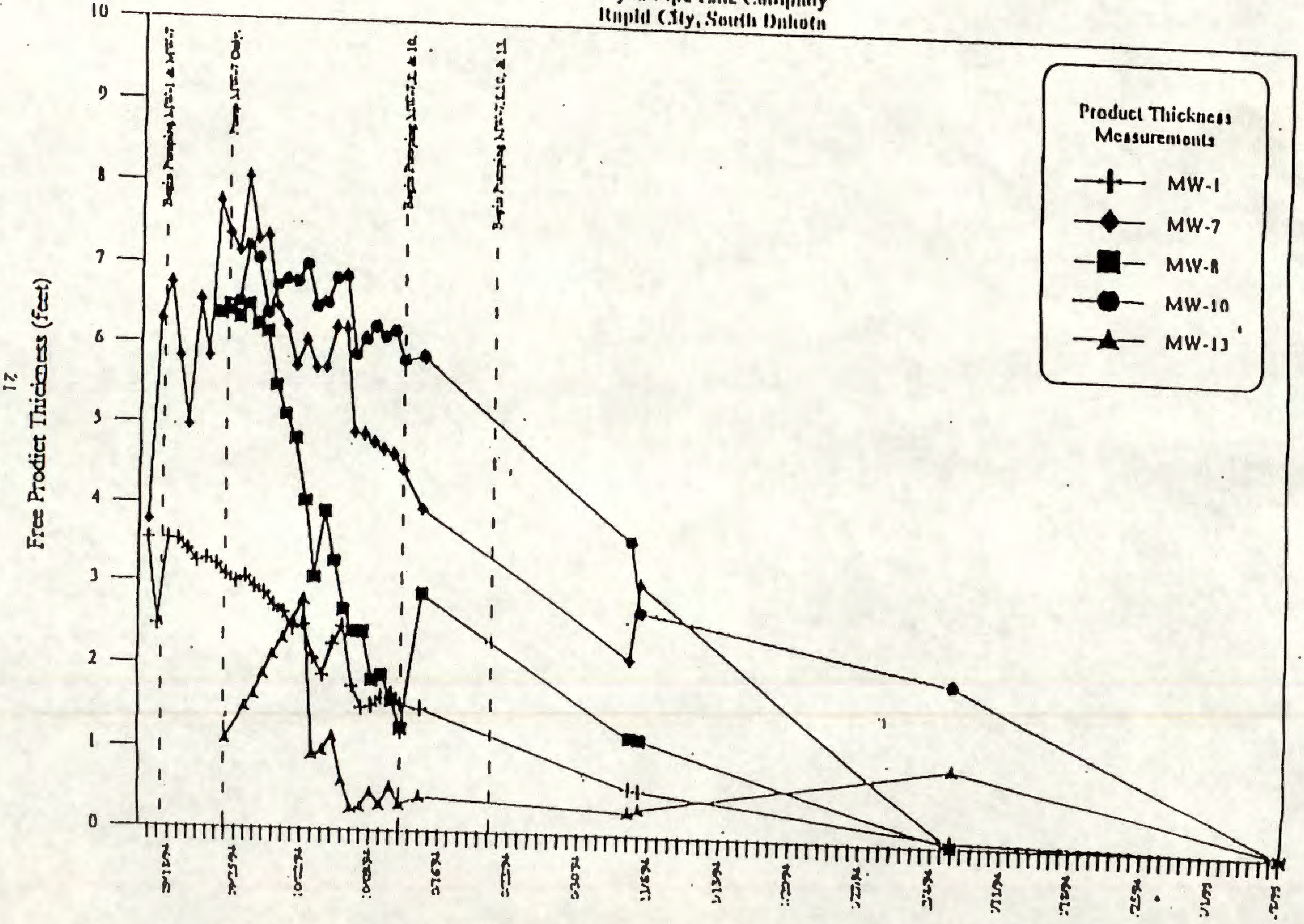


FIGURE 5:
Water Table Drawdown During an EFR Procedure

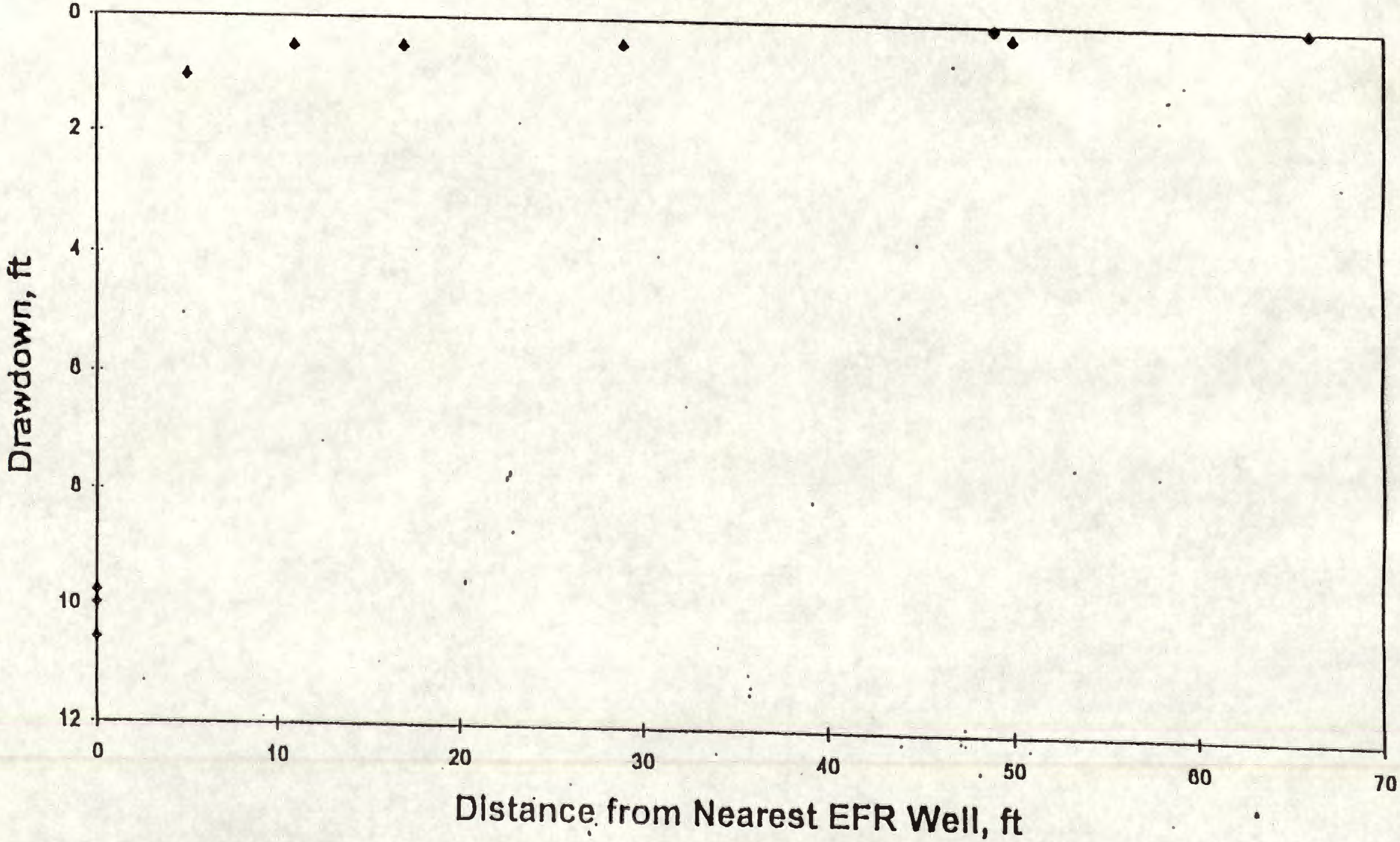
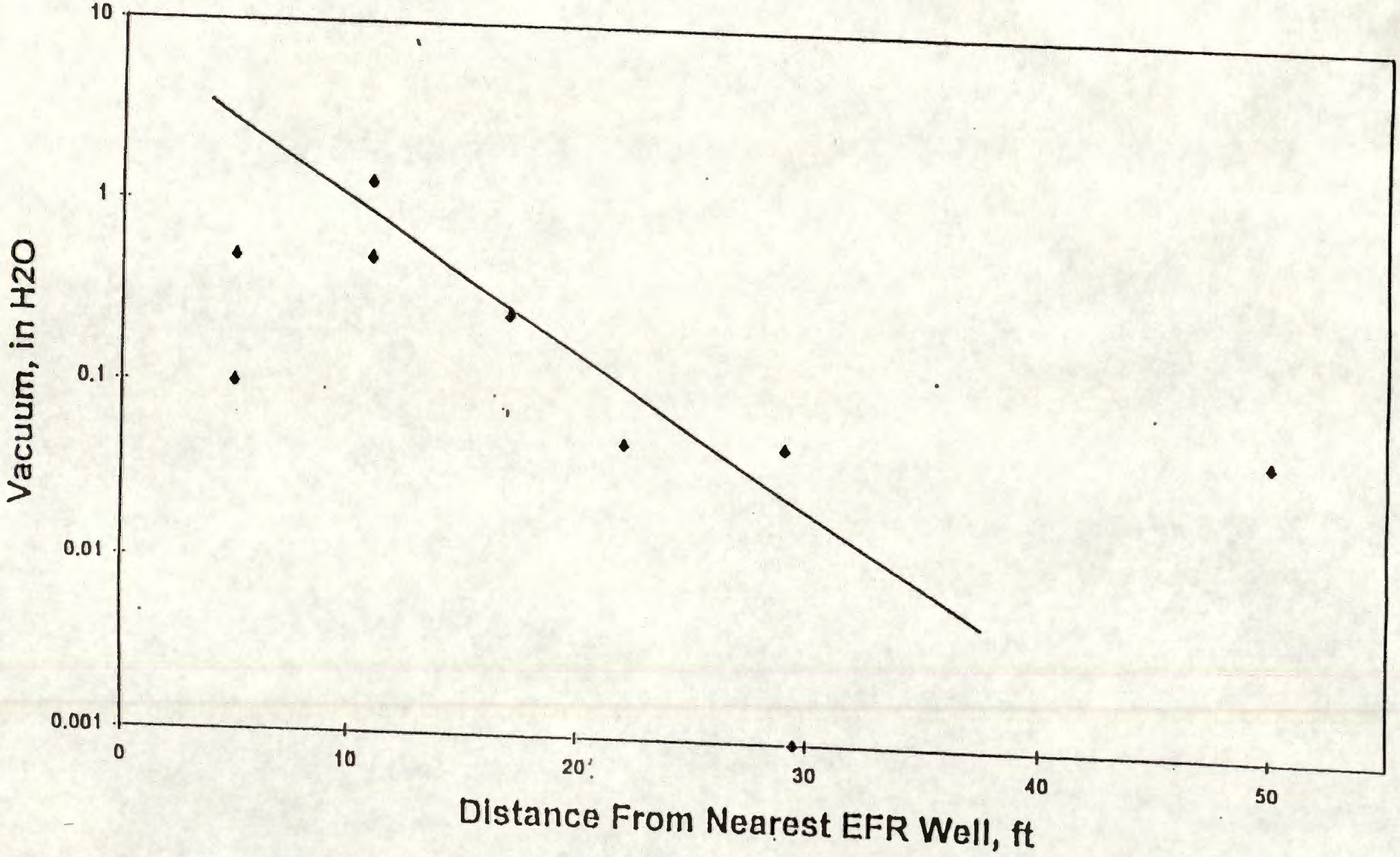
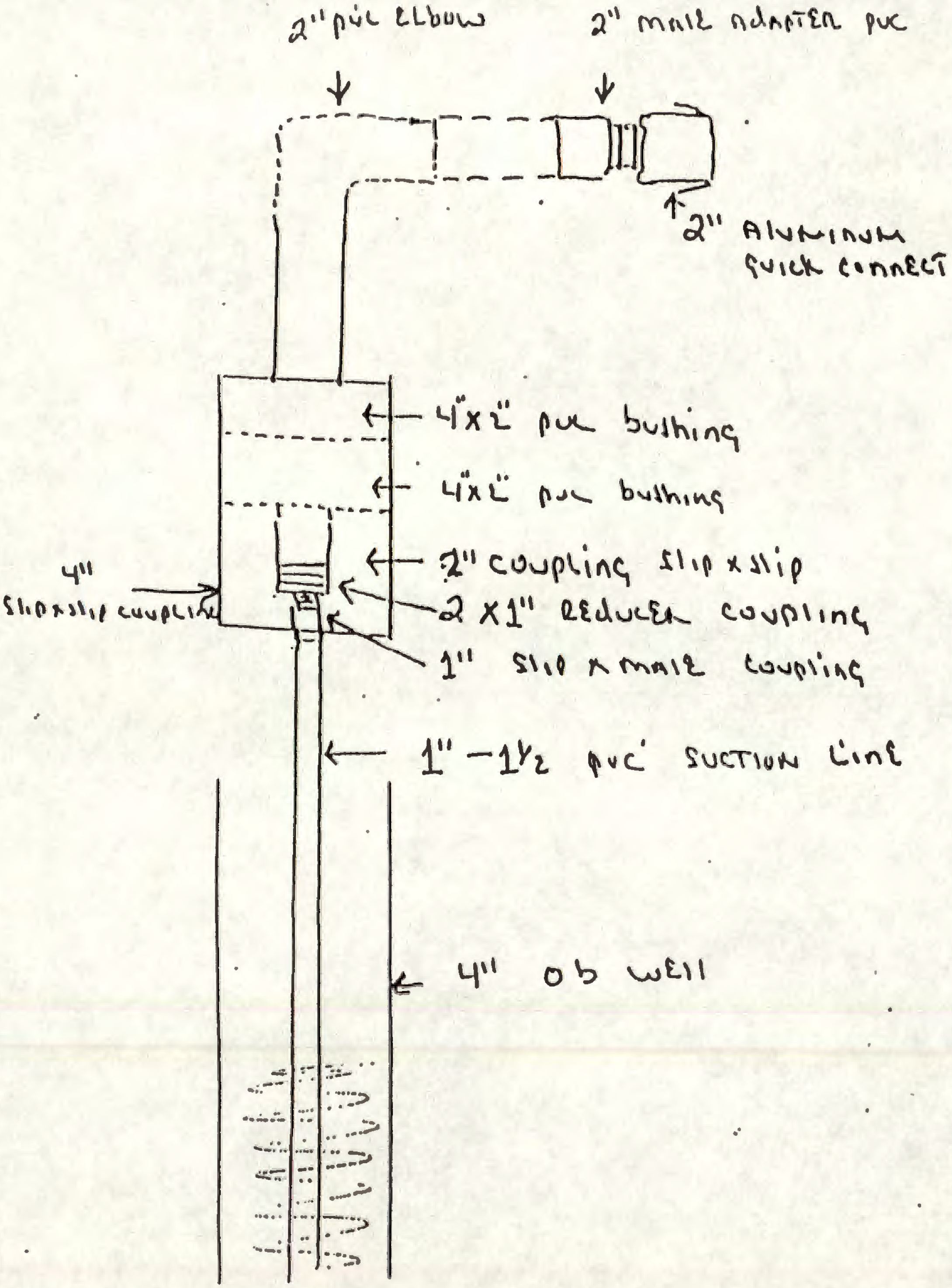


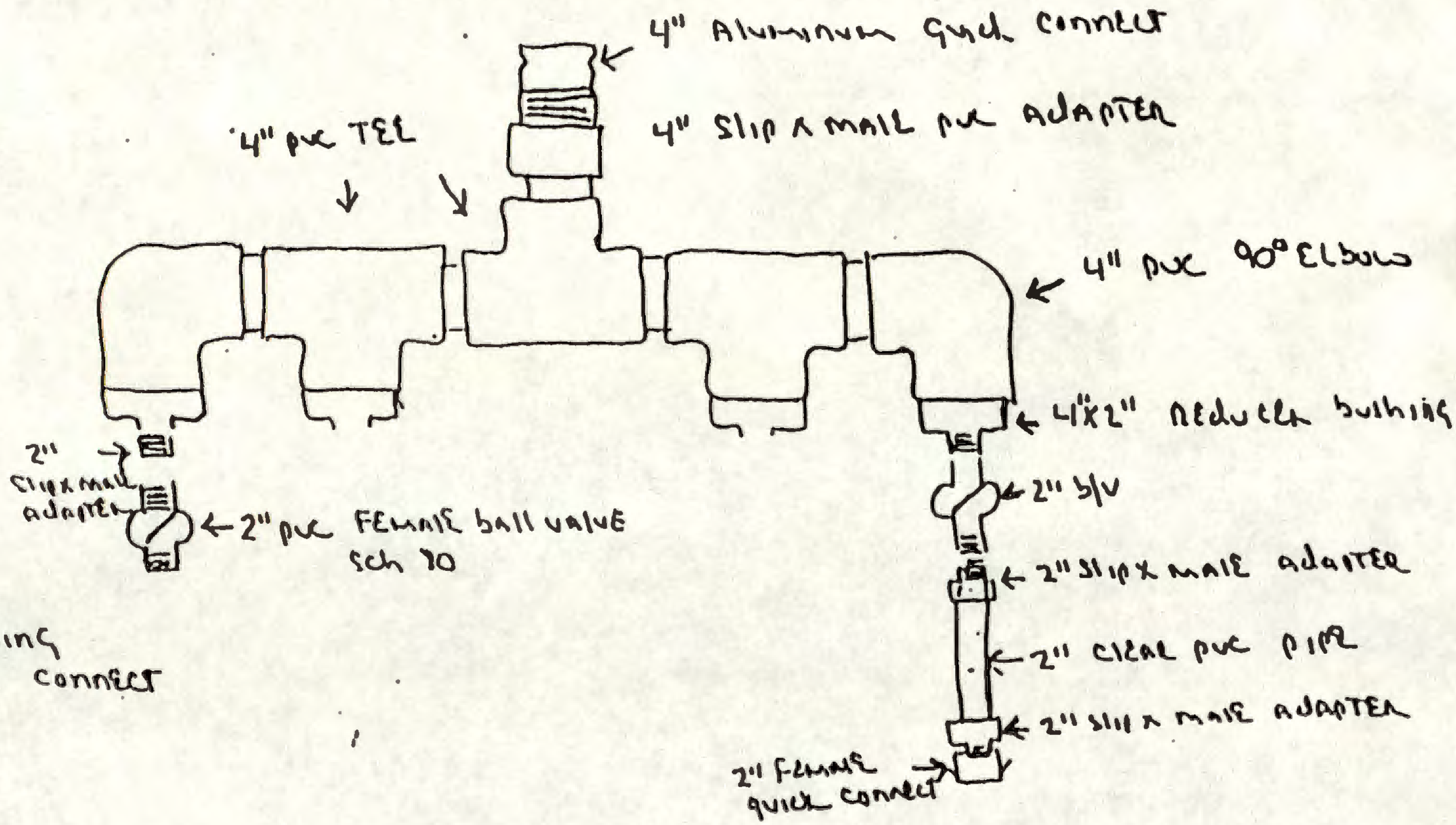
FIGURE 6:
Vacuum Distribution During an EFR Procedure to Recover Dissolved Hydrocarbons





MATERIAL USED:

4 - 4" pvc coupling slip x sl
12 - 4 x 2" pvc bushing slip x slip
4 - 2" slip x slip couplings
16 - 2" slip x male couplings
4 - 1" x 2" reducer bushings
4 - 1" slip x male bushing
4 - 2" pvc elbows
4 - 2" quick connects (Alum) (sets)
10ft - 2" pvc pipe solid
4ft - 2" clear pvc pipe
4 - 2" female thread ball valves sch 80 pvc



MAT LIST

2 - 4" pvc Elbow
3 - 4" pvc TEE
1 - 4" Slip x male coupling
1 - 4" Aluminum Quick connect
10' - 4" solid pvc pipe

1 - pvc Glue 705
1 - pvc primer

Baltec
ASSOCIATES, INC.

460 Old Post Road
Bedford, NY 10506

914 234-9580
Fax: 914 234-0564

April 03, 1996

Mr. Joseph Haas
NYSDEC - Region 1
SUNY, Building 40
Stony Brook, NY 11429

Re: Amoco S/S #60581
1680 N. Ocean Ave.
Holtsville, New York
Spill Number 94-03038

On February 22, 1996, Baltec Associates, Inc. (Baltec), conducted Enhanced Fluid Recovery (EFR) at the above referenced site. EFR was performed on the on-site wells W-5, W-6, and W-11. Vacuum-truck services were provided by Tyree Brothers Environmental Services.

The wells chosen (W-5, W-6, W-11) historically contained Light Non-Aqueous Phase Liquid (LNAPL) or product. Upon arrival at the site, however, Baltec did not observe the presence of product in any of these wells, as gaged with an interface probe. Depth to water was observed to be 15.57, 14.98 and 15.92 feet below the top of well casing in wells W-5, -6, and -11, respectively. A 1-inch diameter stinger pipe was placed to a depth of 16.2 feet in W-5, a 2-inch diameter stinger pipe to a depth of 15.5 in W-6 and a 1-inch diameter stinger to a depth of 16.7 feet below the top of the well casings. The stinger assemblies from the three wells were piped to a manifold with 2-inch diameter vacuum hoses, allowing simultaneous operation. A 3-inch diameter vacuum hose connected the manifold to the vacuum truck.

EFR was conducted for approximately five hours, at which point the tank on the vacuum truck was filled to capacity. During that time, periodic velocity and hydrocarbon concentration measurements were taken from the exhaust of the vacuum pump. These measurements appear in the attached data sheet. A combustible gas indicator, calibrated to the Lower Explosive Limit, (LEL) was used to measure the gasoline vapor concentration. An anemometer was used to measure the vapor velocity from the 3-inch diameter exhaust pipe. A technology description is attached.

An estimated 1,450 gallons of contaminated ground water were removed, as well as 85 pounds of gasoline vapors. The gasoline vapor mass removed is questionable, as the vacuum truck arrived on-site containing approximately 600 gallons of an unknown liquid. It is therefore unknown whether the combustible gas vapors observed in the vacuum pump exhaust were from the wells or from the contents of the truck. Calculations for estimating the mass of gasoline vapors removed are attached.

If there are any questions, please do not hesitate to contact me.

Sincerely,

Marcis Jansons
Project Engineer

cc: C. Wein, Amoco Corporation
C. Larsen, Tyree Environmental Technologies

60581/efr2-22

Enhanced Fluid Recovery
(EFR)

Technology Definition

Vacuum truck is utilized to remove contamination as total fluids including gasoline vapors, free-phase product and contaminated ground water from monitoring wells through "stinger" or "drop-pipe" placed inside and sealed in well.

Benefits

- Rapid Response
- Mobile
- Capable of High Removal Rates
- Trenching and Excavating Not Required
- Addresses "Smear Zone" and Localized Areas of Elevated Contaminant Concentrations
- Introduces Oxygen to Subsurface Accelerating Biodegradation
- High Vacuum Allows Use in Low Permeability Formations

Limitations

- Vacuum Lift Limited by Depth to Ground Water. Successfully Applied at Depth to Ground Water of 44 feet. Limit Unknown.
- Vacuum Truck Tank Capacity is Limited
- Not Cost-Effective at Low Contaminant Concentrations

Introduction

Enhanced Fluid Recovery (EFR) is a technique used to remove contamination from the subsurface in the liquid, vapor and dissolved phases. It is a modified form of vacuum enhanced recovery, where a vacuum is applied to a well and total fluids extracted. EFR is a mobile method capable of quickly removing large quantities of contaminants from the subsurface without some of the limitations of a permanent remediation system.

Technology Description

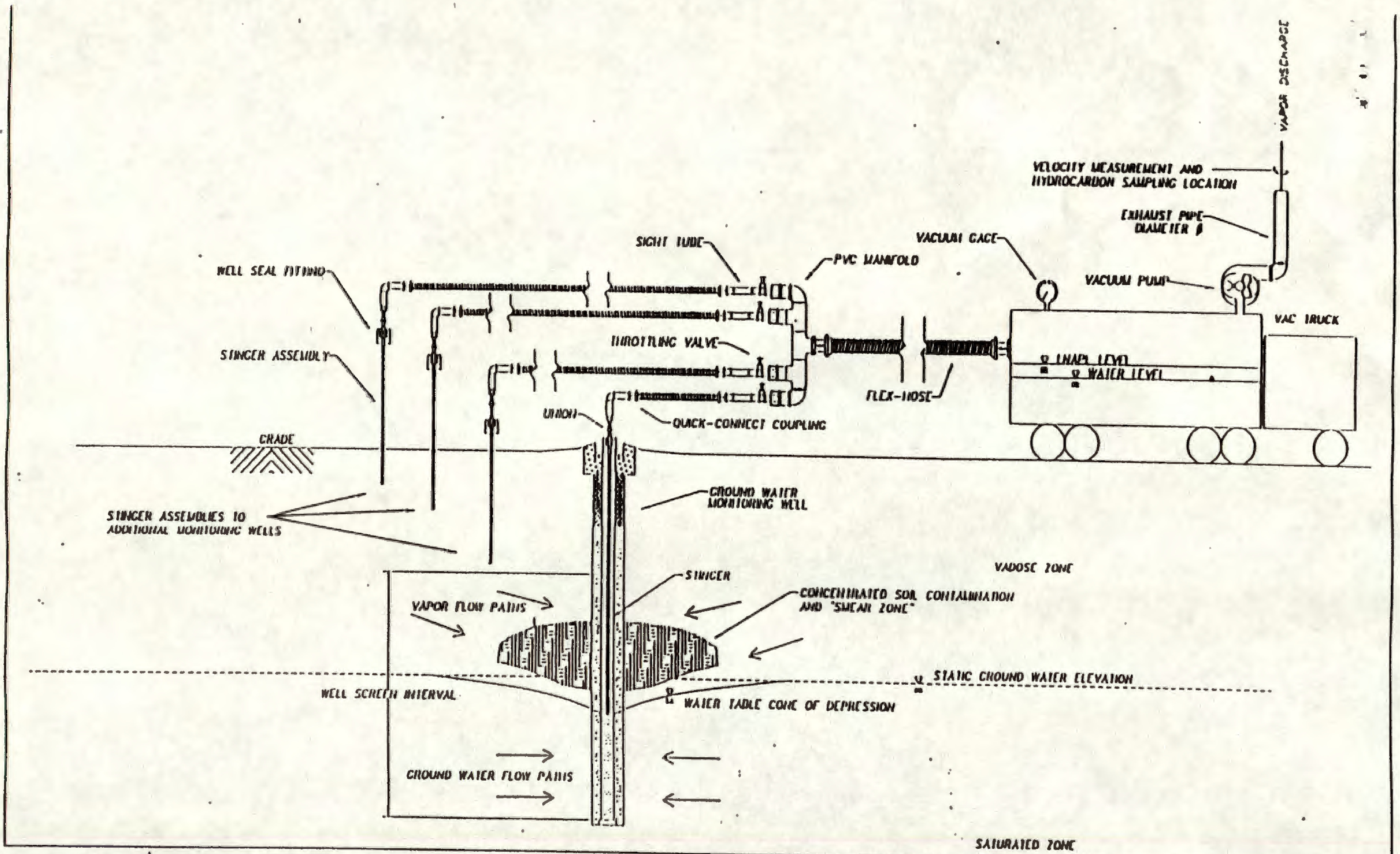
In EFR, a vacuum truck applies a vacuum to a pipe called a "stinger" or "drop-tube", which is inserted into a standard ground water well and sealed by a fitting at the wellhead. The depth of the stinger is site-specific, but generally is placed near the water table. As vacuum is applied to the stinger a pressure gradient is developed relative to the surrounding soil formation. The resulting inflow of liquid and vapor is removed through the stinger. Water table mounding which would otherwise be associated with an applied vacuum is prevented because the extracted fluid is removed through the opening at the bottom of the stinger. This allows air flow through and contaminant volatilization from the "smear-zone", which is often a continuous source of ground water contamination. All fluids including soil vapors, free-phase hydrocarbons and ground water are extracted from the well and accumulated in the tank of the vacuum truck. A diagram illustrating a typical EFR setup is shown in Figure 1.

A stinger can be placed in several wells at one time, with the piping connected connected to the vac-truck through a manifold. This allows a larger area of a site to be affected at any one time. The duration of an EFR event is typically a full working day, and mostly limited by the volume of the tank on the vacuum truck and the yield of the well used.

The goals of EFR are to remove localized liquid product, higher concentration dissolved phase hydrocarbons and concentrated soil contamination. Liquid product, ground water and soil gas are removed by suction from the well and air movement developed through areas of soil contamination. Product is thus allowed to evaporate from soils which under static conditions are submerged. A secondary benefit of EFR is that ambient air is drawn into the subsurface, providing oxygen for biological hydrocarbon degradation.

EFR is a mobile technique, which can be implemented in a fraction of the time required to set up a permanent water or soil treatment system. This allows rapid address of on and off-site contamination, limited only by piping length and truck access. Trenching and excavation work is not required, possibly making this form of remediation more palatable to adjacent property owners impacted by on-site releases, over permanent treatment system installations.

EFR can be a one-time quick-response treatment to remove contamination from a localized area, or can be applied systematically as an integral part of the site remediation plan. Areas of elevated contamination can be periodically treated with EFR until contamination levels decrease to the level at which natural attenuation can be utilized as a remediation technique.



Baltec ASSOCIATES, INC.

Enhanced Fluid Recovery (EFR)
Piping Setup, Application and Effect Diagram

FIGURE 1

JOB NUMBER	DRAWN	APPROVED	DATE
AMGEN	MJ		03/04/96

Effectiveness

The benefit gained by performing EFR at a site is gauged by estimating the total mass of contaminants recovered during the procedure. This is done by summing the masses of liquid, dissolved and vapor phase contamination removed. Free-phase hydrocarbon mass is gaged by measuring the thickness of the product layer in the tank of the vac-truck after EFR and converting this volume to a mass based on the density of the contamination. The dissolved mass of contaminant is calculated from the total volume of water in the vac-truck tank and laboratory analysis of a sample taken from the tank. Due to contaminant solubilities, however, the fraction of contamination in this dissolved phase is small and considered negligible. The majority of removed contaminants are often in the vapor phase. This mass is exhausted from the tank to the atmosphere by the vacuum pump. The contaminant mass removal rate is calculated from contaminant concentrations and flow rate measurements taken from the effluent at the vacuum pump discharge. To verify that the vac-truck tank does not contain volatile material prior to its application, ambient air is allowed through the piping system while the vacuum pump exhaust is monitored for the presence of combustible gases.

Limitations

EFR relies on vacuum to withdraw fluids from a well. Absolute vacuum is equal to 33.9 feet of water column, the maximum depth from which water can be lifted by a vacuum, although EFR has been performed successfully at a site where the water table was at a depth of 44 feet. This is attributed to the high velocity of the vapors traveling through the stinger, which can carry substantial volumes of entrained water. At these depths, the length of the stinger becomes critical. Trial and error is required to determine the stinger length which provides the optimum vapor and liquid flow. The maximum depth to water at which EFR can be used has not been determined.

Site constraints may limit the locations where EFR can be applied, as the vacuum truck must have access to the monitoring well. Presumably, though, a vacuum truck will be able to travel to where a drilling rig has been to install the well being treated. The volume of the tank on the vacuum truck will limit the amount of fluids that can be extracted during one event if provisions for a holding tank have not been made.

EFR Contaminant Removal Estimation Calculations

The mass of vapor-phase contamination removed during an EFR event is calculated based on measurements taken at the exhaust of the vacuum pump. Contaminant concentrations in the exhaust stream and volumetric flow rate are monitored and recorded during the EFR event. The Ideal Gas Equation is used to estimate the specific volume of the contamination, to which the contaminant concentration and flow rate is applied to quantify contaminant mass flow rates. This mass flow rate is then multiplied by the duration of the EFR event to estimate total mass removed.

The contaminant concentrations in the vacuum pump exhaust are measured with a combustible gas indicator equipped with a set of dilution probes to accommodate the wide range of concentrations encountered. Volumetric flow rate is calculated from exhaust stream velocity as measured using an anemometer and the diameter of the exhaust pipe where the anemometer reading was taken. The calculations are shown below.

The Ideal Gas Equation,

1) $$PV = \frac{mRT}{M}$$

is rearranged to determine the specific volume of gasoline vapor:

2) $$\frac{V}{m} = \frac{RT}{PM}$$

where:

V=volume of gasoline contamination, in feet^3

m=mass of gasoline contamination, in pounds

R=universal gas constant, $1545 \frac{ft\ lbf}{lb\ mol\ R}$

T=temperature of vacuum pump exhaust in degrees Rankine, assumed to be 560°R

P=pressure of vacuum pump exhaust in $\frac{lbf}{ft^2}$, assumed to be 14.7 psi, or $2,116.8 \frac{lbf}{ft^2}$

M=molecular weight of gasoline contamination, in $\frac{lb}{lb-mol}$, assumed to be $75 \frac{lb}{lb-mol}$

Volumetric flow rate is assumed to be given by:

3) $Q = VelA$

where: Q=vacuum pump exhaust volumetric flow rate, in $\frac{ft^3}{min}$

Vel=velocity of vacuum pump exhaust stream, in $\frac{ft}{min}$, as measured with an anemometer

A=cross-sectional area of vacuum pump exhaust pipe, in ft^2

Hydrocarbon concentrations as measured by combustible gas indicators typically give readings in parts per million by volume or:

4) $$\text{Conc.}=\frac{ft^3 gasoline}{(1{,}000{,}000)ft^3}\frac{vapor}{air}$$

where: Conc.=concentration of gasoline vapors in parts per million by volume

Multiplying equation 4) by equation 3) and dividing by 2) yields the mass contaminant flow rate or:

5) $$\dot{m}=\frac{(P)(M)(Vel)(A)(Conc.)}{(R)(T)(1{,}000{,}000)}$$

where: $\dot{m}$=mass contaminant flow rate, in $\frac{lbs}{min}$

Recognizing that the cross-sectional area of a circular pipe is:

6) $$A=\pi\frac{D^2}{576}$$

where: A=cross sectional area in ft^2
D=nomonal pipe diameter, in inches

Substituting 6) and the constants above into 5) yields:

7) $$\dot{m}=\frac{(Vel)(D^2)(Conc.)}{1E9}$$

Multiplying 7) by time in minutes will yield the total mass of gasoline contamination removed over that time interval:

8) $\text{Mass} = \dot{m}\,t$

where: t=time in minutes over which mass removal is calculated

Extracted vapor concentrations will change over the course of the EFR event, and therefore anemometer and gas concentrations are taken periodically throughout the day. Equation 8) above is used over each time interval separately, and the masses removed over each measurement interval are summed to determine mass of contamination in the vapor phase removed over the course of the event.

To the mass removed in the vapor phase is added the mass of free-floating product in the vacuum truck tank as measured by gauging the volume of the product in the tank. The mass of contaminant in solution is considered negligible, although can be determined from chemical analysis.

Site ID:	s/... [illegible]501
Site Address:	1600 N. Ocean Ave.
City, State:	Holtsville, NY
Spill #:	04-3030

Vac-Truck Provider:	Tyree Environmental Services
Volume of Vac-Truck:	2,000 gallons
Assumed Molecular Weight of Contaminants=	75 lb/lb-mol
Temperature of Vacuum Pump Exhaust=	100 deg F
Diameter of Vacuum Pump Exhaust=	3 inches
Background Vacuum Pump Exhaust Combustible Gas Concentration:	N/A %LEL

	Monitoring Well ID Treated			
	MW- 5	MW- 6	MW- 11	N/A
Initial DTLNAPL (ft)	N/A	N/A	N/A	N/A
Initial DTW (ft)	15.57	14.98	15.92	N/A
Diameter of Well (in)	4	4	4	N/A
Depth of Stinger (ft)	16.2	15.5	16.7	N/A
Diameter of Stinger (in)	1	2	1	N/A

Time	MW- 5	MW- 6	MW- 11	N/A	Combustible Gas Concentration (% LEL)	Dil Ratio	Corrected Combustible Gas Concentration (% LEL)	Corrected Combustible Gas Concentration (ppm)	Effluent Velocity (ft/min)	Vac-Truck Vacuum ("Hg)	Combustible Gas Removal Rate (lb/min)	Combustible Gas Mass Removed (lb)
8:40	X				100	1	100	14,000	2,800	20	0.35	
9:00	X	X			100	1	100	14,000	2800	20	0.35	7.06
9:45	X	X	X		100	1	100	14,000	2800	10	0.35	15.88
10:36	X	X	X		100	1	100	14,000	2700	10	0.34	17.36
11:45	X	X	X		100	1	100	14,000	2700	10	0.34	23.48
12:05	X	X	X		100	1	100	14,000	2600	10	0.33	6.55
12:40	X	X	X		66	1	66	9,240	2600	10	0.22	7.57
13:00	X	X	X		52	1	52	7,280	2600	10	0.17	3.41
13:25	X	X	X		48	1	48	6,720	2200	10	0.13	3.33
13:30	X	X	X		48	1	48	6,720	2200	10	0.13	0.67

	MW- 5	MW- 6	MW- 11	N/A
Final DTLNAPL (ft)	N/A	N/A	N/A	N/A
Final DTW (ft)	N/A	N/A	N/A	N/A

Total Volume LNAPL Removed: 0 gallons

Total Volume Ground Water Removed: 1,450 gallons

Total Combustible Gas Mass Removed: 85.3

Total Mass LNAPL Removed: 0

Total Mass Contaminant Removed: 85.3

EFR Data Sheet

Explanations

Initial DTLNAPL
Depth to Liquid-Phase Non-Aqueous Liquid in Well prior to EFR as measured from top of Casing, in feet

Initial DTW
Depth to water table in Well prior to EFR as measured from top of Casing, in feet

Diameter of Well
Nominal diameter of well upon which EFR is performed, in inches

Depth of Stinger
Length of "stinger" as measured from the top of well casing, in feet

Diameter of Stinger
Nominal diameter of "drop pipe" or "stinger", the pipe which is inserted into a well from to which a vacuum is applied during EFR, in inches

Time
The time at which a measurement is made

Monitoring Well ID
The identifier of a well which is being treated with EFR

X
X identifies which wells are piped to vacuum truck at time measurements are taken

Vac-Truck Provider
Name of company providing vacuum truck service

Volume of Vac-Truck
Volumetric capacity of holding tank on vacuum truck, in gallons

Assumed Molecular Weight of Contaminants
Assumed molecular weight of extracted contaminants, in lb/lb-mol

Temperature of Vacuum Pump Exhaust
Temperature of vacuum pump exhaust or temperature of contaminant vapors where measurements are taken, in degrees Fahrenheit

Diameter of Vacuum Pump Exhaust
Nominal diameter of vacuum pump exhaust pipe where anemometer velocity reading is taken, in inches

EFR Data Sheet

Background Vacuum Pump Exhaust Combustible Gas Concentration
Combustible gas concentration in vacuum pump exhaust with tank inlet open to ambient, used to verify tank does not hold volatiles prior to EFR, in % of the Lower Explosive Limit

Combustible Gas Concentration
Concentration of volatiles in vacuum pump exhaust, as read by combustible gas indicator in % of the Lower Explosive Limit, assumed to be 1.4% by volume for gasoline vapors, prior to correction for dilution probe

Dil Ratio
Dilution ratio of probe used to measure concentration of volatiles in vacuum pump exhaust

Corrected Combustible Gas Concentration (%LEL)
Concentration of volatiles in vacuum pump exhaust, corrected for dilution ratio of probe used to take measurement, in % of the Lower Explosive Limit

Corrected Combustible Gas Concentration (ppm)
Concentration of volatiles in vacuum pump exhaust, corrected for dilution ratio of probe used to take measurement, in parts per million by volume

Effluent Velocity
Velocity of vacuum pump exhaust, as measured with an anemometer, in feet per minute

Vac-Truck Vacuum
Level of vacuum in vacuum truck tank, as read on tank's vacuum gage, in inches mercury

Combustible Gas Removal Rate
Mass flow rate of gasoline vapors from vacuum pump exhaust, as calculated by $m'=(P)(M)(Vel)(A)(Conc.)/(R)(T)(1E6)$, where m is mass flow rate, P is pressure of exhaust vapor, M is molecular weight of gasoline vapor, Vel is exhaust vapor velocity, A is cross sectional area of exhaust vapor flow, Conc. is gasoline vapor concentration in exhaust vapor, R is the universal gas constant and T the exhaust vapor temperature in pounds per minute

Combustible Gas Mass Removed
Mass of gasoline vapor exhausted from vacuum pump over time interval between measurements, in pounds

Total Combustible Gass Mass Removed
Total summed mass gasoline vapors removed over course of EFR event, in pounds

Total Mass LNAPL Removed
Total mass of Light Non-Aqueous Phase Liquid present in vac-truck tank after EFR, as determined by volume of product in tank assuming specific gravity of 0.8, in pounds

Total Mass Contaminant Removed
The sum of gasoline mass removed in vapor and liquid phase, in pounds

EFR Data Sheet

FLH

Depth to Liquid-Phase Non-Aqueous Liquid in Well after EFR as measured from top of Casing, in feet

Final DTW

Depth to water table in well after EFR as measured from top of Casing, in feet

Total Volume LNAPL Removed

Volume of Light Non-Aqueous Phase Liquid present in vac-truck tank after EFR, as measured with a stick gage, in gallons

Total Volume Ground Water Removed

Total volume of water in vac-truck tank after EFR, in gallons