HARGIS + ASSOCIATES, INC.
HYDROGEOLOGY • ENGINEERING

Mission City Corporate Center
2365 Northside Drive, Suite C-100
San Diego, CA 92108
Phone: 619.521.0165
Fax: 619.521.8580

Revision 1.0 Technical Memorandum

VIA: E-MAIL & U.S. MAIL

Date: August 7, 2006 Project No: 857.04e

To: Mr. Jeffrey Dhont
U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
Mail Code H-7-1
San Francisco, CA

cc: Ms. Susan Keydel, EPA
Ms. Eva Davis, EPA
Mr. Joe Kelly, Montrose
Mr. Paul Sundberg, Montrose
Karl Lytz, Esq., Latham & Watkins
Kelly Richardson, Esq., Latham & Watkins
Mr. Safouh Sayed, DTSC
Mr. John Dudley, URS
Ms. Natasha Raykhman, CH2M Hill
Mr. Steven Acree, EPA

From:

Michael A. Palmer, PG 5915, CHG 146 Roger A. Niemeyer, PG 3616, CHG 43

Re: DNAPL Boiling Test Results, Montrose Site, Torrance, California

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This technical memorandum has been prepared to document the results of laboratory testing to evaluate the boiling behavior and vaporization of dense non-aqueous phase liquid (DNAPL) and site groundwater when heated. These data were collected to further evaluate electrical resistance heating (ERH) and other potential thermal technologies for remediating DNAPL at the Montrose site. Specifically, this testing was conducted to evaluate the change in the boiling temperature and the relative vaporization rate of DNAPL and water as the more volatile chlorobenzene component of the DNAPL is removed. It was anticipated that as chlorobenzene is removed from the DNAPL, the effectiveness of the process to treat/remove the remaining DNAPL would decrease, thereby affecting the cost and efficiency of a thermal remedy. Boiling

rate and vapor production data obtained from the laboratory testing will be used during the DNAPL feasibility study to evaluate potential treatment times and energy requirements for ERH.

The laboratory testing was conducted by Spectra Laboratories located in Tacoma, Washington in two phases. The first phase of testing was conducted with only DNAPL to check out the test procedures and equipment. An attempt to use the same procedure with a DNAPL-groundwater mixture was unsuccessful, as described below. Therefore, the laboratory procedure was modified for the Phase 2 testing. During the second phase of testing, both DNAPL and site groundwater were placed in a larger flask immersed in a mineral oil bath and the temperature was gradually raised while the amount of DNAPL and water captured over time was monitored.

The test procedures and results for the Phase 1 and Phase 2 testing are summarized below:

Phase 1 Testing: DNAPL Only

This test was conducted using 100 milliliters (ml) of DNAPL using a modified distillation procedure based on ASTM Method D-86: Standard Test Method for Distillation of Petroleum Products at Atmospheric Pressure. During this test DNAPL was heated in a stoppered flask mounted over a hot plate. After the initial DNAPL boiling point was reached the temperature was increased to maintain a boiling condition as the more volatile fraction vaporized. The flask had a sidearm that allowed the vapors generated during boiling to be condensed and retained in a graduated cylinder. Test results are presented in terms of “percent of the DNAPL captured” versus temperature. During the Phase 1 test, the temperature was measured with a thermometer placed in the headspace above the DNAPL near the flask sidearm. The percent captured is calculated as the volume of vapor condensate collected in the receiving graduated cylinder divided by the initial volume of DNAPL placed in the flask.

The results from the Phase 1 DNAPL distillation test are presented in Table 1 and are shown graphically on Figure 1. The initial boiling point for the DNAPL was about 128 degrees Celsius (^{o}C) as measured by the thermometer placed in the headspace above the DNAPL. The relationship between temperature and the percentage of DNAPL captured exhibits a relatively linear trend up to the point where about 45 percent of the DNAPL had boiled off. The temperature in the flask above the boiling DNAPL during this period ranged from 128 ^{o}C to 135 ^{o}C. Laboratory analysis of the captured condensate was not part of this testing. However, based on past analyses, the Montrose DNAPL is known to consist of about equal percentages of chlorobenzene and dichlorodiphenyltrichloroethane (DDT). Given the considerably higher vapor pressure of chlorobenzene, which is more than 6 orders of magnitude higher than that of DDT at room temperature, the composition of the vapor condensate captured up to this point likely consisted primarily of chlorobenzene.

A gradual steepening of the curve is apparent on Figure 1 between the points where 45 percent and 60 percent of the DNAPL was captured. After 60 percent of the DNAPL had been boiled off, there was a dramatic increase in temperature required to maintain the DNAPL boiling rate. At this point the remaining DNAPL was likely composed primarily of DDT. This could not be

confirmed during this study since laboratory chemical analyses were not included in the scope of this testing program. However, it is known from previous laboratory analyses that the DNAPL from the Montrose site is composed of approximately equal proportions of chlorobenzene and DDT. Since the vapor pressure of chlorobenzene is approximately ten million times greater than that of DDT it is likely that chlorobenzene represented the majority of the initial mass boiled off and that the remaining mass consisted of DDT.

The relationship between the temperature and the percentage of DNAPL captured returned to a relatively linear trend during the period when 75 percent to 93 percent of the DNAPL was being boiled off. At the end of the test a solid residue remained in the flask. Although the volume of the residue could not be directly measured the lab reported that based on visual inspection it appeared to represent about 5 percent of the original DNAPL volume.

Phase 2 Testing: DNAPL and Groundwater

An attempt was made to repeat the test using 50ml DNAPL and 50ml site groundwater with the same equipment used in the Phase 1 testing, however, the second test was unsuccessful due to repeated violent vapor generation referred to as “bumping” which resulted in the test being terminated. The experimental procedure and equipment were therefore modified for the Phase 2 testing. The Phase 2 test was conducted using 100 ml of DNAPL and 100 ml of groundwater in a larger, stronger flask. Due to its greater density, the DNAPL occupied the bottom portion of the flask and the water occupied the upper portion and a distinct interface formed between the two liquids at the mid-point. The flask was set in a mineral oil bath which allowed improved temperature control and allowed the DNAPL and water to be heated simultaneously, rather than from the bottom. As in the Phase 1 testing the flask had a sidearm that allowed the generated vapors to be condensed and recovered into a graduated cylinder. During the Phase 2 testing the temperature was measured with two thermometers, one placed in the mineral oil bath and the other into the liquid in the flask near the DNAPL-water interface. The temperature was raised gradually over a two day period and the volume percent of both groundwater and DNAPL recovered over time was recorded.

The results from the DNAPL-groundwater boiling test are presented in Table 2 and are shown graphically on Figure 2. Results are presented in terms of the percent of combined DNAPL and water vapor condensate captured over time along with the system temperatures. Curves are also provided which show the individual percentages of the DNAPL and water fractions captured compared to the total volume of liquids initially added to the flask.

Boiling at the DNAPL-water interface was observed once the temperature of the liquids in the flask reached 96 ^{o}C. During the Phase 2 test, DNAPL and groundwater vapor condensate were not observed in the receiving graduated cylinder until the temperature reached about 112 ^{o}C at the DNAPL-water interface. After this temperature was reached, vapor generation increased and both DNAPL and water vapor began condensing in the sidearm of the flask. During the early stages of vapor capture, the volume of DNAPL that was captured in the graduated cylinder was about twice the volume of water that had been captured (Figure 2). The DNAPL capture

curve began to level off after about half of the DNAPL had been captured (Figure 2). As discussed previously, because the DNAPL is composed of about 50 percent chlorobenzene and 50 percent DDT, it is likely that the DNAPL captured up to that point was primarily chlorobenzene. After 50 percent of the initial liquid had been captured, the rate of DNAPL capture decreased to below that of water (Figure 2). The lower relative DNAPL capture is expected given that the remaining DNAPL is likely composed of DDT.

Based on these results, it appears that increasing the temperature of the DNAPL at the Montrose plant property may result in a significant rate of DNAPL vaporization. Once the more volatile chlorobenzene fraction of the DNAPL is volatilized, the rate of volatilization likely would decrease, and much higher temperatures would then be necessary if the vaporization rate of the less volatile DDT fraction were to be maintained. It appears that this change in volatilization rate would occur at a temperature range of 150ºC to 340°C, assuming the DNAPL is at atmospheric pressure.

If you have any questions or comments regarding these test results, please contact us.

TABLE 1
PHASE 1 : DNAPL BOILING TEST

Client: Hargis + Associates
Spectra Project # 2005070001
Client ID: UBT-1-DNAPL
Analyst gta

% DNAPL Condensate Captured	Headspace Temperature (^oC)	Elapsed Time (min:sec)	Observations
0	128	**0**	Initial Boiling Point
5	128	**0:27**	
10	129	**1:14**	
15	129	**1:55**	
20	129	**2:39**	
25	129	**3:27**	
30	130	**4:09**	
35	131	**4:53**	
40	132	**5:40**	
45	135	**6:16**	
50	138	**6:58**	
55	143	**7:51**	
60	149	**9:12**	
65	225	**9:49**	
70	339	**13:27**	
75	351	**13:42**	
80	354	**14:15**	
85	356	**15:05**	
90	358	**16:29**	
93	359	**16:47**	

Observations:

Temperature rose sharply between 60% and 65% DNAPL recovered.

When the temperature reached 175°C, some vapor was observed leaving the condensor tube.

Loss could not accurately be measured, as the distillation residue was a solid material.

FOOTNOTES

DNAPL = Dense non-aqueous phase liquid
% = Percent
ºC = Degrees Celsius

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TABLE 2
PHASE 2: DNAPL-GROUNDWATER BOILING TEST

Client: Hargis + Associates
Date: 10/20/2005 - 10/21/2005
Spectra Project # 2005070001
Client Sample ID: UBT-1-DNAPL/Groundwater

DAY 1

Time of Day	Elapsed Time (hours:minutes)	Bath Temperature (^oC)	Interface Temperature (^oC)	Actions/Observations
9:30	0:00	--	--	
11:30	2:00	--	62.2	No Boiling. Condensation in flask & neck
11:45	2:15	--	--	Increased heat
12:00	2:30	--	62.8	Increased heat
13:20	3:50	--	63.9	Increased heat
13:45	4:15	--	66.7	Increased heat
14:00	4:30	79.4	71.1	Condensation at elbow
14:15	4:45	83.3	73.9	
14:30	5:00	86.1	76.7	Increased heat
15:00	5:30	93.9	83.3	Increased heat. Intermittent bubble where thermometer enters interface.
				Condensation still only in flask and at elbow.
15:15	5:45	94.4	85.6	Increased heat
15:30	6:00	95.6	86.1	Increased heat
15:45	6:15	97.2	87.2	Increased heat
16:00	6:30	98.9	88.9	Increased heat. Approximately 1 bubble/sec. from interface at thermometer.
16:20	6:50	103.3	92.8	
16:30	7:00	106.1	96.1	Light, steady boiling at DNAPL/Water interface. Boiling beginning at water surface around thermometer.
16:45	7:15	109.4	100.0	No condensate observed in receiver. Turned off heat.

DAY 2

Time of Day	Elapsed Time (hours:minutes)	Bath Temperature (^oC)	Interface Temperature (^oC)	Distillate Captured (% of Total)			Actions/Observations
				% of Total	DNAPL*	Water*	
7:15	0:00	--	--				Began heating at previous day's final setting.
8:15	1:00	115.0	99.4				
8:30	1:15	121.7	105.6				First drop condensate recovered.
8:45	1:30	123.9	108.3				
9:00	1:45	127.2	111.7				
9:15	2:00	128.3	112.8	5	5	trace	
9:30	2:15	129.4	111.7	12.5	8.5	4	Light, steady boiling at DNAPL/water interface.
9:45	2:30	130.0	115.0	15	10	5	Light, steady boiling at DNAPL/water interface.

TABLE 2
PHASE 2: DNAPL-GROUNDWATER BOILING TEST

Client: Hargis + Associates
Date: 10/20/2005 - 10/21/2005
Spectra Project # 2005070001
Client Sample ID: UBT-1-DNAPL/Groundwater

DAY 2 (continued)

Time of Day	Elapsed Time (hours:minutes)	Bath Temperature (°C)	Interface Temperature (°C)	Distillate Captured (% of Total)			Actions/Observations
				% of Total	DNAPL*	Water*	
10:00	2:45	130.6	115.6	20	13	7	Light, steady boiling at DNAPL/water interface.
10:20	3:05	130.6	111.1	26	16	10	Light, steady boiling at DNAPL/water interface.
10:45	3:30	135.0	111.1	31	19	12	Light, steady boiling at DNAPL/water interface.
11:00	3:45	134.4	108.9	35	22	13	Light, steady boiling at DNAPL/water interface.
11:30	4:15	135.0	108.3	41	24	17	Light, steady boiling at DNAPL/water interface.
12:00	4:45	136.7	109.4	46	25	21	Light, steady boiling at DNAPL/water interface.
13:15	6:00	137.8	107.2	57	26	31	Light, steady boiling at DNAPL/water interface.
13:50	6:15	136.7	--	60	26	34	Light, steady boiling at DNAPL/water interface.
15:30	8:15	147.2	--	70	28	42	Heat turned off.
17:00	9:45		**Final Volumes:**	**72**	**29**	**43**	

NOTE:

* DNAPL and Water captured is expressed as a percent of the total starting volume of the combined liquids. As the starting mixture was approximately 50% DNAPL and 50% Water, complete capture of one or the other would be expressed as "50%".

FOOTNOTES
DNAPL = Dense non-aqueous phase liquid
°C = Degrees Celsius
-- = No temperature recorded
% = Percent

Figure 1: Phase 1 DNAPL Boiling Test Results

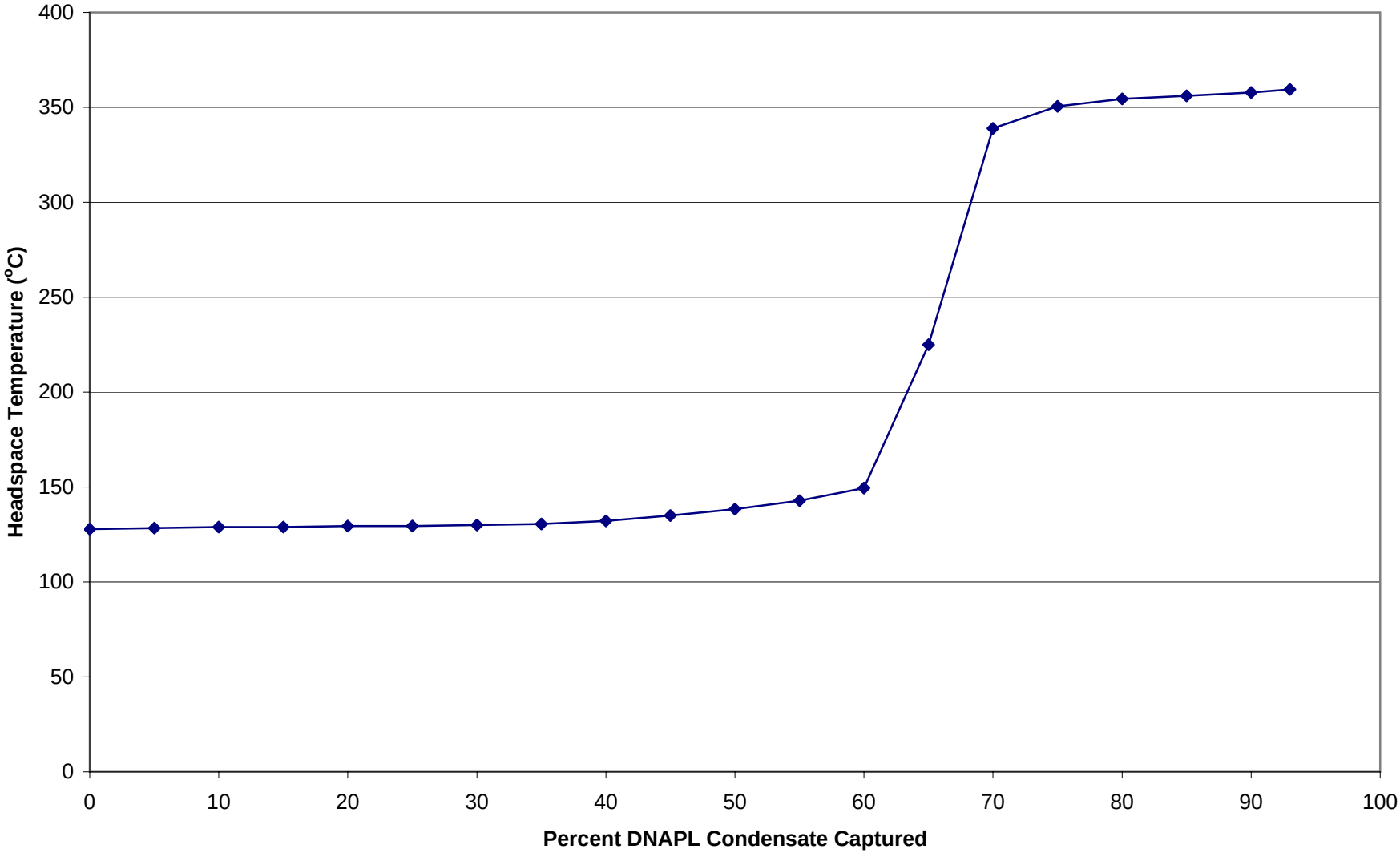
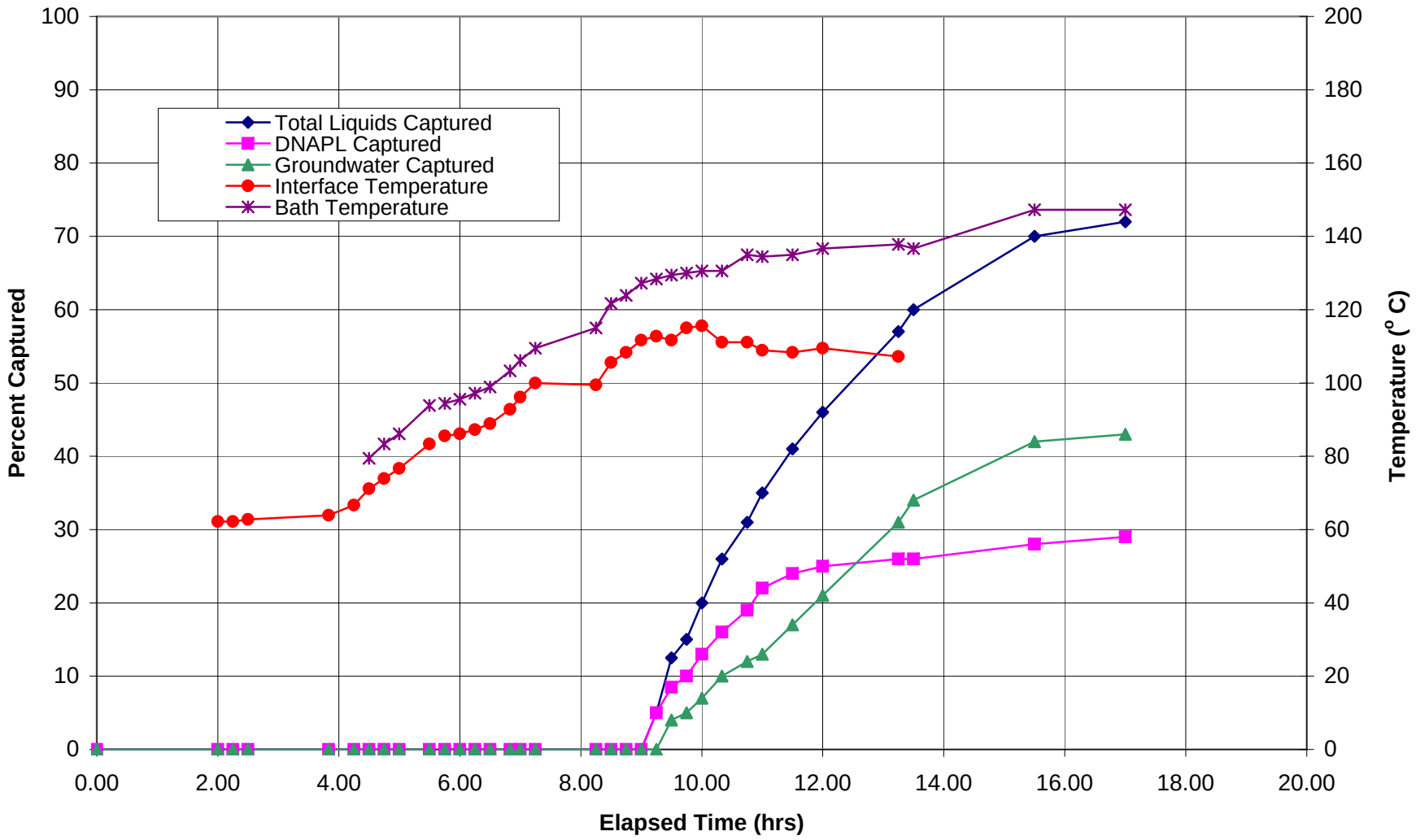
Figure 2: Phase 2 DNAPL-Groundwater Boiling Test Results