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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

memorandum

TO: Distribution

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FROM: Don Dreesen/Mel Beikmann

MAIL STOP/TELEPHONE: D443/7-4318

SYMBOL: EES-4-92-93

SUBJECT: Results of the winter flow experiments conducted on December 7-8, February 7-8, and February 28-29, 1992.

DESCRIPTION OF WINTER FLOW REGIME

A winter flow regime has been proposed as a method of maintaining a non-freezing environment following the loss of circulation in the HDR Reservoir test facility when ambient temperature is below 32°F. The regime, as presently envisioned, would automatically convert the surface facility from reservoir circulation to low rate reservoir production through the entire operating system except the EE-3A wellhead, the EE-2A x-mas tree, and the make-up/feed pump/water supply system.

Once a shut-down of the surface facility is detected or initiated by the DMACS control system the following actions are initiated by the DMACS HH/LL alarm sequence.

(1) The main injection pumps are shut-down.

(2) The production well high-low valve is closed.

(3) The heat exchanger louvers are left in automatic control and should maintain (until the control system air is reduced to ~ 60 psig.) an outlet temperature of T_{set} (70°F) if a reasonable flow rate is established.

(4) The heat exchanger fans are shut down.

(5) A 10 second delay is completed.

(6) The injection well high-low valve is closed and the winter bypass valve upstream of the high-low valve is open to establish flow to the EE-3A vent tank.

(7) The system control valves are set in the winter bypass mode: PCV1* open, PCV2* on automatic control (until the control system air is reduced to ___ psig.)

The proposed regime should be capable of protecting the system from the following events:

(1) A shut down of the surface facility by the DMACS control system following any HH/LL alarm condition.

(2) Loss of site electric power. (some options of the winter flow regime require UPS for DMACS control system and the control air supply to protect equipment.

(3) Loss of main injection pumps.

(4) Loss of heat exchanger cooling.

(5) Loss of make-up or feed pumps.

(6) Loss of water supply.

(7) Opening of pressure relief valve with automatic re-closure at or before reaching 20% of the set pressure.

(8) Closure of production well high-low valve or injection well high-low valve with opening of winter by-pass valve.

Protection from freezing would not, or might not occur in the winter flow regime following any of the following:

(1) A major rupture of the pressure system which would short circuit the winter flow system. (The most likely location of such a rupture would be the rupture of one or more heat exchanger tubes).

(2) Opening of pressure relief valve <u>without</u> an automatic re-closure before reaching 20% of the set pressure.

(3) Loss of system air before the high-low valve logic becomes operative.

PRELIMINARY RESULTS OF DEMONSTRATIONS

First Demonstration

A summary of the data collected is listed in the Tables and Figures. The first winter flow demonstration was completed on 12/7-8/91 at the end of Exp. 2078A. An attempt was made to use DMACS controls to provide automatic control of the flow rate. PCV1A was controlled using T8. We were unable to quickly develop a PID control setting that was compatible with the long time delay between the control signal and the system response. The effort to develop control logic was abandoned. Manual control was used to complete the demonstration.

A 4 to 5 gpm flow per bundle kept the heat exchangers warm for more than 10 hours at an ambient temperature of 27°F to 30°F. The outlet flow from the heat exchangers was maintained above 99°F and the vent flow at the EE-3A vent tank was maintained above 82°F.

The EE-2A producing temperature (Figure 1) declined from 310°F to 175°F in 13 hours. The temperature then increased to 185°F the next hour and decreased to 150°F the following two hours. This producing temperature behavior has not been explained.

Second Demonstration

A second demonstration was completed on 2/7-8/92 at the end of Exp. 2078C. The facility was set up so that a transition from circulation to winter flow could be made automatically. It was hoped that no manual adjustments would be needed to develop a winter flow rate that would protect the system. It did not work and several lessons were learned:

1. The high producing temperature early in the winter flow regime raises the possibility of over-heating the cold side of the facility (make-up/feed systems and injection system designed for a maximum 150°F service).

2. The make-up/feed pump bypass system has no shut-down in the winter flow regime. There is a high possibility that very hot water may flow through a low-temperature, low-pressure service hose between FCV2 and CV6A.

3. The check valves in the feed pump discharge lines were leaking enough that the feed pumps were starting to get warm to the touch before the make-up/feed system was isolated.

The heat exchangers were instrumented with 10 thermal couples to check for cold spots and to provide data for future modelling of heat exchanger performance (Figure 2). After 13 hours, the heat exchanger temperatures spanned a range from 57°F near the bottom of the bundles to 145°F under the closed louvers. The fluid outlet temperature had declined to 75°F when these measurements were made.

Third Demonstration

A third demonstration was conducted on 2/27-28/92 in the middle of Exp. 2078D. Another attempt was made to make the transition from circulation to winter flow automatically. The heat exchanger louvers were left in automatic control to prevent over heat of the injection system. The winter bypass choke (VCFP) was not set low enough and a 6 minute flow of 154 gpm decreasing to 45 gpm occurred. The injection system was heated to 256°F before the flow was shut-down. There is no record of the temperature in the make-up/feed system bypass but it might have been as high as 268°F.

The use of automatic louvers kept the discharge temperature under 100°F once a winter bypass flow rate of 11 to 12 sgpm (estimated because no flow checks were made) was achieved.

HEAT EXCHANGER MODEL

A simple model of the heat exchanger has been developed to predict the performance of the heat exchangers with the louvers closed. The model assumes that convection and radiation of heat off of the structural surfaces provide the primary heat dump to atmosphere. The model ignores the heat that is dumped through the buoyantly driven air leaks in the closed louvers. This factor is indirectly included when the convection coefficient is adjusted to match the performance data. (See Attachment for more information.)

The convection heat transfer parameters were adjusted to predict the 5.0 gpm data point (07:30 Exp. 2078 C). The model was then used to predict the flow rate needed to keep the two bundles of the heat exchanger above 70°F (outlet temperature) with an ambient temperature of -30°F and a black body radiation temperature of -10 °F. The model predicts a flow rate of 6.1 gpm (3.05 gpm per bundle). This needs to be demonstrated during severe winter conditions before unmanned operation under frigid conditions is attempted.

The model was then used to predict the flow rate needed to keep the two bundles of the heat exchanger above 70°F (outlet temperature) with an ambient temperature of 20°F, a 30 mph wind, and a black body radiation temperature of-10°F. The model predicts a flow rate of 20 gpm (10 gpm per bundle). This needs to be demonstrated by conducting a test with high winds before unmanned operation under windy conditions is attempted.

CONCLUSIONS

1. While there are no fundamental problems with the winter flow regime concept, the early time system control problem is more difficult than we originally thought it would be. With propper controls the regime will protect the system with very moderate flow rates for all proposed system failures except flow diversions.

2. Some kind of automatic temperature/pressure control will be required to maintain the appropriate flow rates through a 16 hour protection interval (16:00 to 08:00). The production temperature will decrease from 350°F to less than 200°F (see Figure 1). The early time flow rate must be very low and increase gradually with time. Pressure control is needed to prevent boiling in the production (high temperature) system. Temperature control is needed to prevent overheating of the injection and make-up/feed systems.

3. A reconfiguration of the make-up/feed system is needed to provide a system that is compatible with the winter flow regime. The system should reduce or eliminate the possibility of flow diversion to the water supply tanks.

4. Preliminary results, using the lump parameter model of the (shut-down) heat exchanger, suggest that a 10 gpm per bundle flow rate will protect the heat exchanger and surface system from freezing under a worst case winter condition (20°F with 30 mph winds with 160° fluid inlet temperature). See Attachment. All testing to date has been done at 20°F to 32°F with negligible to moderate winds (< 10 mph). Testing during below zero temperatures and during high wind conditions is needed to validate the model.

DATA SUMMARY FOR WINTER FLOW TESTS

Table 1

EXPERIMENT 2078A December 7-8, 1991

Time	Air Tamb	Water temp. T2A	Water temp. T5	Water temp. T8	F4*[a]	T5-Tamb	T5-T8	T2A-T5
(hr:mn)	(°F)	(°F)	(°F)	(°F)	(gpm)	(°F)	(°F)	(°F)
17:41	—	310	91	51	76.0	Shut	down	production
19:00	—	246	105	63	17.0	—	42	141
20:00	--	245	163	123	19.0	—	40	82
21:00	—	211	122	123	0.0	—	0	89
22:00	—	183	88	100	0.0	—	-12	95
23:00	—	198	101	95	9.0	—	6	87
24:00	—	189	101	80	9.0	—	21	88
02:00	—	195	101	85	9.0	—	16	94
04:00	27[b]	186	102	82	9.0	75	20	84
06:00	27[b]	177	101	82	9.0	69	19	76
07:00	29	170	99[c]	78	9.0	70	21	71
08:00	—	181	121[d]	84	9.0	—	37	60
09:00	—	166	117[d]	82	5.2	—	35	49
10:00	29	142	107[d]	55	8.9	31	52	35

Notes for Table 1

(a) Flow rates are estimates with flow through two - 1-1/2" flow meters. One meter was not showing a reading and the second was reading 53.6% of the flow indicated. The flow split was determined by combining the flow (intermittently) through a single bundle to obtain a reading. The active meter is rated for a minimum flow of 15 gpm.

(b) Light to moderate breeze.

(c) Separator was bypassed at 06:25.

(d) Bundle #2 on the heat exchanger was removed from the flow stream at 07:02.

Table 2
EXPERIMENT 2078C February 7-8, 1992

	Air temp.		Water temp.					T5-	T4-	Tlv-	T1-
Time	Tamb	Tlv(a)	T1	T4	T5	T8	F4*(b)	Tamb	T5	Tamb	T4
(hr:mn)	(°F)	(°F)	(°F)	(°F)	(°F)	(°F)	(gpm)	(°F)	(°F)	(°F)	(°F)
19:02	22	___	323	309	70	69	104.0	Shut down circulation			
23:15	20	202	249	212	113	79	11.0	93	99	182	14
00:30	20	190	243	212	122	99	11.0	102	90	170	37
01:40	20	185	230	196	109	99	9.0	89	85	165	31
03:00	20	176	225	187	104	91	9.0	84	83	158	38
04:20	20	162	221	179	99	85	9.0	79	80	142	34
05:00	20	162	217	176	95	82	7.0	75	81	142	42
06:00	20	163	213	172	90	82	7.0	70	82	143	41
07:00	19	153	190	166	85	78	5.0	66	81	144	41
09:00	23	142	185	152	74	72	5.0	51	78	119	24
10:15	24(c)	167	201	170	110	70	16.0	86	60	143	33
11:00	26(c)	178	202	184	120	99	16.0	94	64	152	31

Notes for Table 2.
(a) Thermal couple #10 located just under the louvers, in the middle of bundle 4, 12 ft from the end of the bundle.
(b) Flow rates are estimates with flow through two 1-1/2" flow meters, one which was showing no reading, the second showing a reading. The flows were intermittently diverted to a single meter to obtain a more accurate reading. The meters are rated for a minimum flow of 15 gpm.
(c) 3 to 4 mph wind.

Table 3
EXPERIMENT 2078D February 27-28, 1992

	Air	Water temp.					T5-	T4-	T2A
Time	Tamb	T2A	T4	T5(a)	T8	F4*(b)	Tamb	T5	-T4
(hr:mn)	(°F)	(°F)	(°F)	(°F)	(°F)	(gpm)	(°F)	(°F)	(°F)
17:50	36	337	314	76	73	90.0	Shut down production		
20:00	30	252	232	63	78	9.3	33	169	24
22:00	28	241	213	73	63	11.2	45	140	28
00:00	29	231	207	75	72	13.1	46	132	24
02:00	29	220	200	78	73	13.1	49	122	20
04:00	29	215	197	81	76	14.9	52	116	18
05:34	27	211	189	84	78	14.9	57	105	22
06:00	27	209	188	88	78	11.2	61	100	21
07:00	27	205	184	74	78	11.2	57	124	21
08:00	34	203	180	85	72	14.9	51	109	23
09:45	39	197	181	92	50	14.9	53	95	6

Notes for Table 3.
(a) Louvers set in automatic at 70°F.
(b) Flow rates are estimates with flow through two - 1-1/2" flow meters. One meter was not showing a reading and the second was reading 53.6% of the flow indicated. The flow split was determined from data taken during Exp. 2078C. The active meter is rated for a minimum flow of 15 gpm.

Distribution:

Jim Albright
Ray Ponden
Dave Duchane
Don Brown
Ray Ponden
Joe Skalski
Jim Thomson

Figure I

EE-2A Wellhead Temp

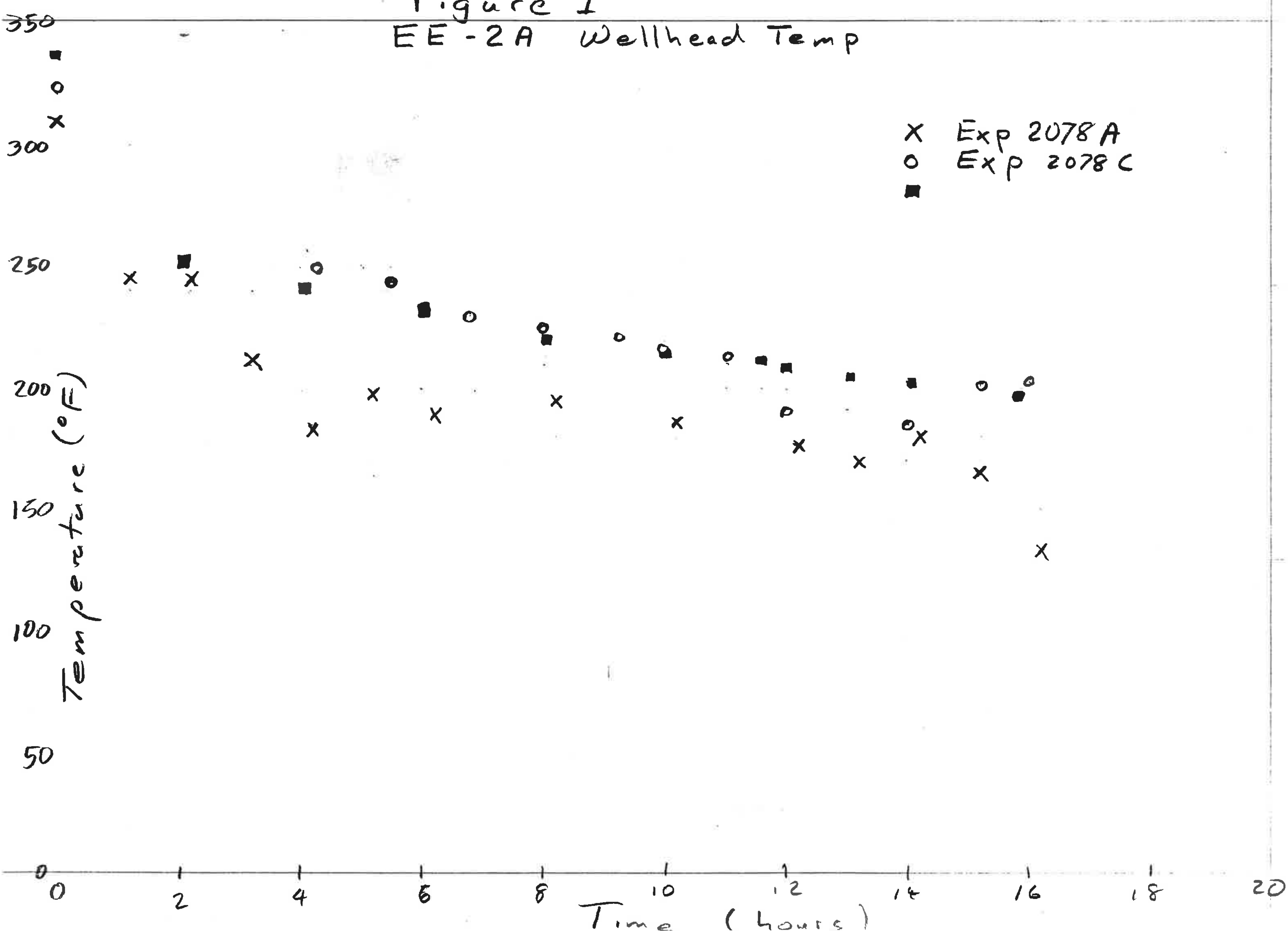
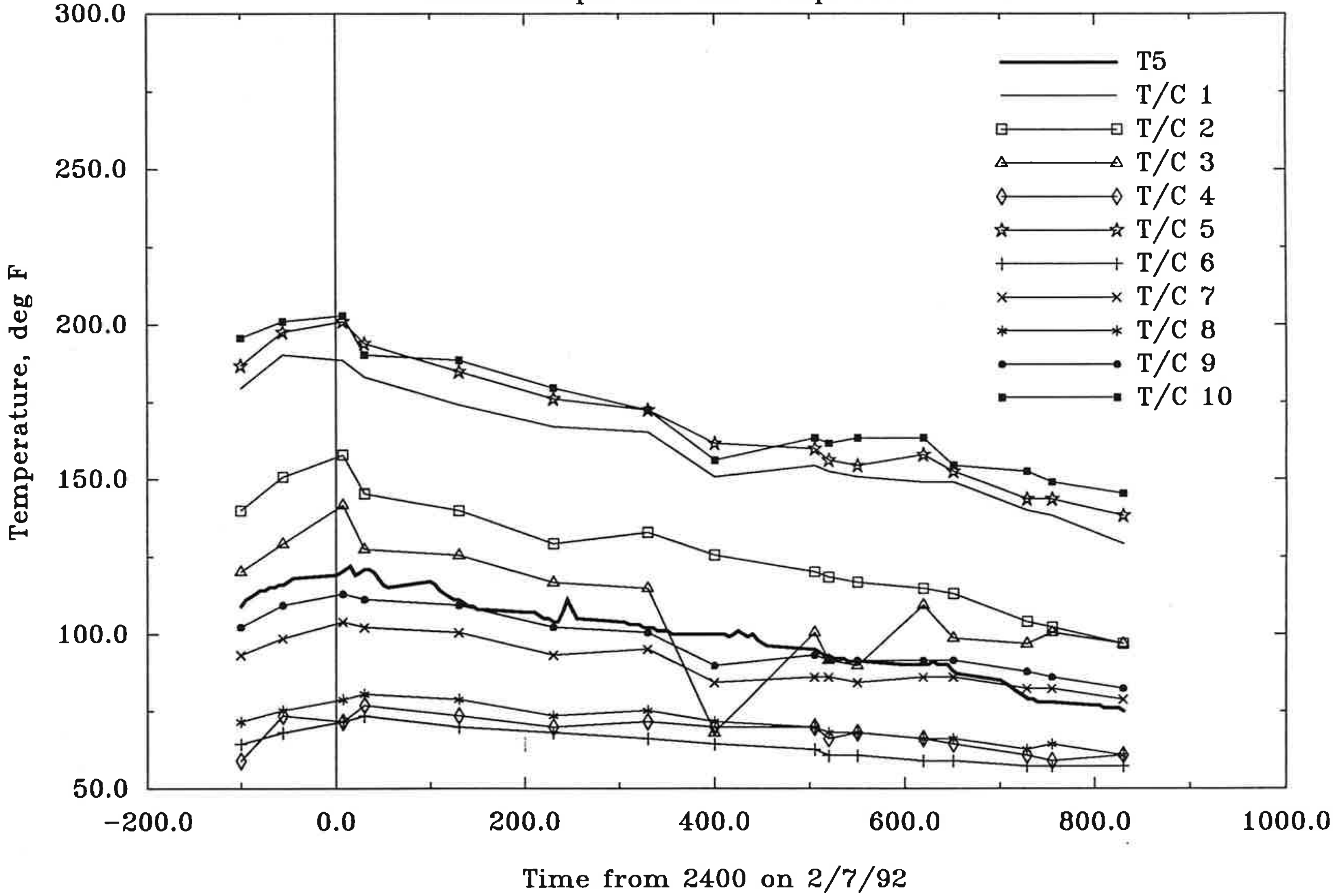


Figure 2

Heat Exchanger Winterization Test

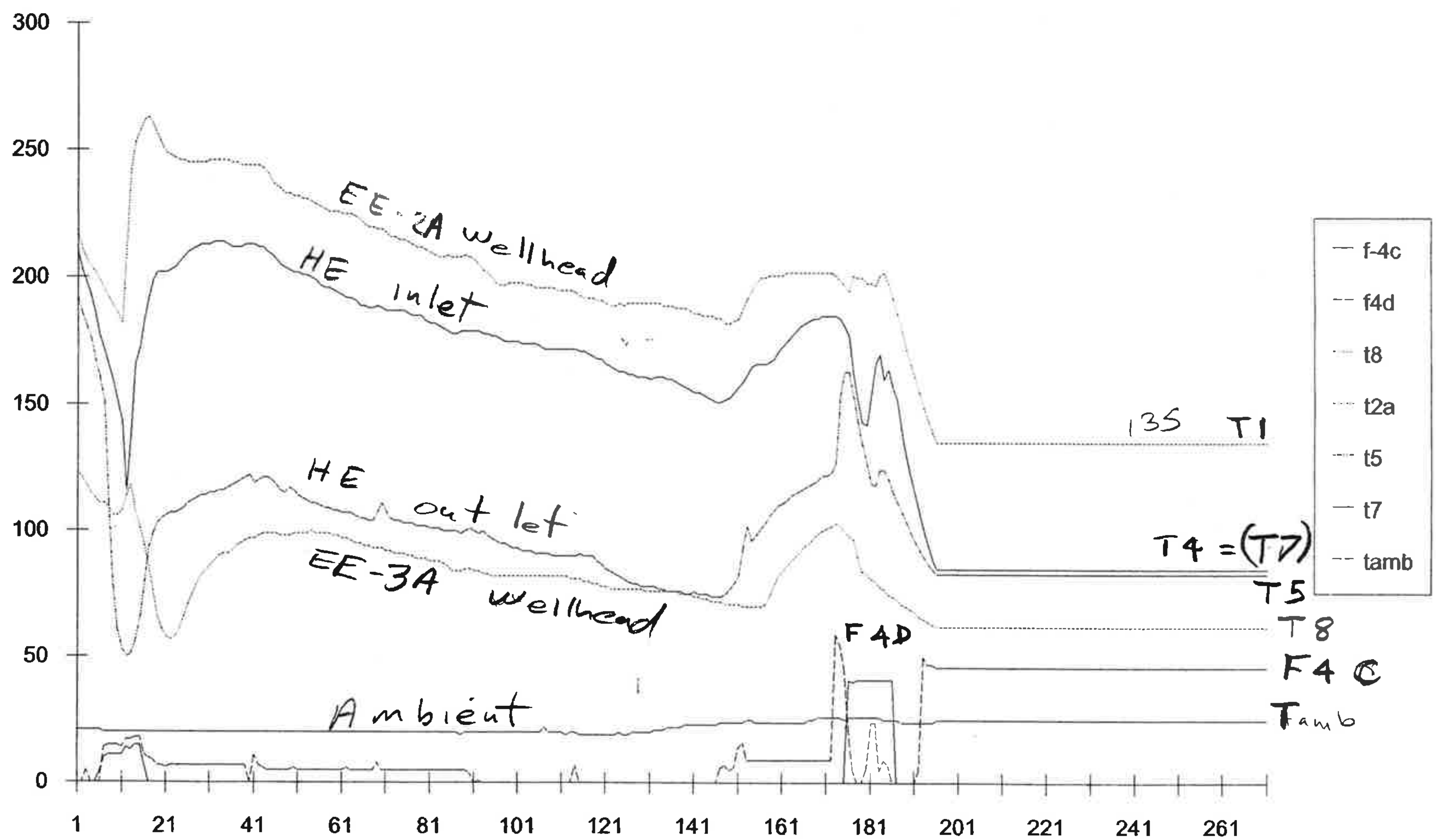
Thermocouple and Exit temperature data



Exp 2078 C

Figure 3

Heat Exchanger Winterization Experiment, DMACS data



Attachment

The simple model uses a lumped parameter approach to predict heat exchanger performance in the winter flow regime. In this approach the radiation component is treated separately with all of the convection terms lumped together. This accomplished by using a First Law energy balance on the heat exchanger and solving for a lumped convection coefficient. This coefficient is entered in another model to predict heat exchanger exit temperature versus flow rate.

The problem with this method is that one cannot easily predict performance over a wide range of ambient conditions, (i.e. windy vs. calm). In order to predict the change in heat transfer characteristics with such large differences in ambient conditions a comparison was made using a horizontal flat plate. The plate was at a constant temperature, 100 deg. F., and of the dimensions of the top surface of two bundles of the heat exchanger. A comparison was made between convection coefficients for the following ambient conditions:

1. T_{amb}=-30 deg F. no wind.
2. T_{amb}= 20 deg F., no wind. *
3. T_{amb}= 20 deg F., 30 m.p.h. wind.

* case 2 represents the ambient conditions for the winter flow portion of experiment 2078C.

Using correlations for natural convection the coefficients for cases 1 and 2 were calculated. The coefficient for case 1 is 7.81 W/m^2 K., conditions in case 2 produce a coefficient of 6.57 W/m^2 K. Case 1 is 19% higher than case 2. This shows that the lumped parameter model can be an adequate predictor over a wide range of ambient temperatures under calm conditions. A forced convection correlation was used for case 3. The ambient conditions in case 3 provide a coefficient of 39 W/m^2 K. This is 6 times the coefficient found in case 2, identical ambient temperatures. One can attempt to predict the effects of wind by multiplying the lumped coefficient by this factor. This seems like a reasonable approach until experimental data is obtained during windy conditions to prove the validity of this method.

Attachment

T_{amb} = 20 deg F. no wind

GPM	T_{exit}
2.00000	16.2128
3.00000	44.5931
4.00000	63.6233
5.00000	77.3077
6.00000	87.6349
7.00000	95.7107
8.00000	102.2039
9.00000	107.541
10.00000	112.004
11.0000	115.792
12.0000	119.050
13.0000	121.881
14.0000	124.363
15.0000	126.560
16.0000	128.514
17.0000	130.267
18.0000	131.846
19.0000	133.278
20.0000	134.581

T_{amb} = -30 deg F. no wind

GPM	T_{exit}
2.00000	-21.7461
3.00000	14.3765
4.00000	38.4660
5.00000	55.7288
6.00000	68.7316
7.00000	78.8848
8.00000	87.0403
9.00000	93.7348
10.00000	99.3326
11.0000	104.0838
12.0000	108.166
13.0000	111.712
14.0000	114.822
15.0000	117.571
16.0000	120.020
17.0000	122.213
18.0000	124.191
19.0000	125.982
20.0000	127.613

T_{amb} =20 deg F. 30 mph wind

GPM	T_{exit}
10.00000	22.7079
11.0000	29.3824
12.0000	35.4442
13.0000	40.9749
14.0000	46.0415
15.0000	50.7021
16.0000	55.0019
17.0000	58.9809
18.0000	62.6753
19.0000	66.1140
20.0000	69.3225
21.0000	72.3245
22.0000	75.1378
23.0000	77.7809
24.0000	80.2679
25.0000	82.6118
26.0000	84.8270
27.0000	86.9207
28.0000	88.9057
29.0000	90.7873
30.0000	92.5746
31.0000	94.2750
32.0000	95.8956
33.0000	97.4400
34.0000	98.9138
35.0000	100.3223