NSTX CALCULATION

TITLE OH Coil Thermal/Hydraulic Analysis

CALC. NO. 13-6 DATE 4/8/97

ORIGINATOR A Brooks CHECKER Rev. 0

PURPOSE:

To determine temperatures resulting from ohmic heating during normal operation in OH Coil and to verify adequacy of cooling configuration to recool coils in requisite time.

REFERENCES:

System Requirments Document "NSTX-SRD-13-015 r0 dD, Magnet Systems"

Project Spreadsheet "NSTX PF Coils 4/3/97" located on NSTX_Project_Folder Fileshare under Technical Info/PF Coils

ASSUMPTIONS:

See attached writeup.

CALCULATION:

Calculations were performed using a 1D Transient Thermal/Hydaulic finite difference Fortran code called "cool1db.f" , previously developed and presently modified for NSTX, running on NERSC A machine.

CONCLUSION:

See attached writeup.

A 1-D transient thermal/hydraulic analysis was performed on the NSTX OH Coil to assess ohmic heating during single and double swing OH operation. Calculations were performed using a 1D Transient Thermal/Hydaulic finite difference Fortran code called "cool1db.f" , previously developed and presently modified for NSTX, running on NERSC A machine. Modifications made for NSTX allows for additional heating from inleakage from surrounding structure (ie the CS tiles in the case). Additional modifications allowed for uncooled conductor sections electrically in series with cooled sections. (ie inner to outer leg jumpers in TF Coils)

The OH coil is made from 4 layers, each wound two in hand for a total of eight lengths of conductor. The conductors are electrically in series but hydraulically in parallel. Since each conductor length is made from identical cross section conductor but vary only in length, the longest one (layer 4) was run through the transient.

Material Properties

The following are the material properties for the copper and water used within cool1db.f

```
c SI UNITS (m, kg, s, C)
c   Conductor Material - OFHC Copper ( 101 )
      CuDens(t)=8942.  ! kg/m3
      CuSpht(t)=386.   ! J/kg-C
      CuCond(t)=400.   ! w/m-C
      CuRho(t)=1.724e-8*(1+.0041*(t-20.))  ! ohm-m

c   Coolant Material - Water
      Wdens(t)=999.9-(t+5.462)**2/265.84 ! kg/m3
      Wdvisc(t)=2.916e-4+2.0747e-7*(t-85.0)**2 ! N-s/m2
      Wcond(t)=0.6818-(t-114.1)**2/1.124e5 ! w/m-C
      Wspht(t)=4174.0+(t-52.78)**2/54.32 ! J/kg-C
```

Geometery and other Inputs

The coil geometry was taken from the referenced spreadsheet "NSTX PF Coils 4/3/97" by Charley Neumeyer and confirmed against attached drawings. Some differences were found with this latest design and that used when these calculations were first preformed but were not judged to warrant reanalysis.

The geometry is modeled using 1.0 m long elements as inputted below. Note the data input follows the coolant path. (entering at the bottom of the coil)

The following is the free formatted input to cool1db.f for the Double Swing OH operation:

```
2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75m/s$          /title
107                                                         / n
107*1.0                                                     / dx
107*1.4132e-4                                               / Ac
107*10.0                                                    / s
107*1.5                                                     / f
107*1.7814e-5                                               / Aw
107*0.01496                                                 / Pw
107*2.75                                                    / v
107*1                                                       / icool
6                                                           /ncur,   number of values in time vs current table
     0.  00000.
     0.  00000.
     0.  24000.
   0.5208  24000.
   0.5208  00000.
   600.  00000.
2                                                           / npul
60.                                                         / dtpr. printout interval for all Length plots
1.                                                          / dtpr2 printout interval for all Time plots
3                                                           / npr  numgber of nodes to save output
1 54 107                                                    / nodes
10.                                                         / t0
120.                                                        / tmax
600., 1200.
1.00                                                        / dTmax  max change in T for iteration
27*0., 51*-20.0,  27*0.                                     / Ql additional heating per unit length ( ie from CS )
1                                                           / nrep
```

Results

The attached plots show the results of two cases run:

OH Double swing with 600 sec rep rate and 0.5208 s ESW at 24 KA
OH Single swing with 300 sec rep rateand 0.2375s ESW at 24 KA.

There are 8 figures associated with each case. On each Temperature vs Path Length Figure are plots at select times during the transient. On each Temperature vs Time figure are plots of Conductor Average Temperature, Conductor Max Temperature, Conductor (Water) Surface Temperature, and Water Temperature. Please note that the Conductor average temperature and the Water temperature are the basic nodal values calculated. The Conductor max temperature and surface temperature are extrapolated and interpolated respectively from those basic nodal values based on inputted data.

Figure 1	Conductor Average Tempertature vs Path Length
Figure 2	Water Tempertature vs Path Length
Figure 3	Conductor Max Tempertature vs Path Length
Figure 4	Conductor Surface Tempertature vs Path Length
Figure 5	Pressure Drop vs Path Length
Figure 6	Node 1 Temperature vs Time (Layer 4 Bottom at water inlet)
Figure 7	Node 54 Temperature vs Time (Layer 4 midsection)
Figure 8	Node 207 Temperature vs Time (Layer 4 Top at Water Outlet)

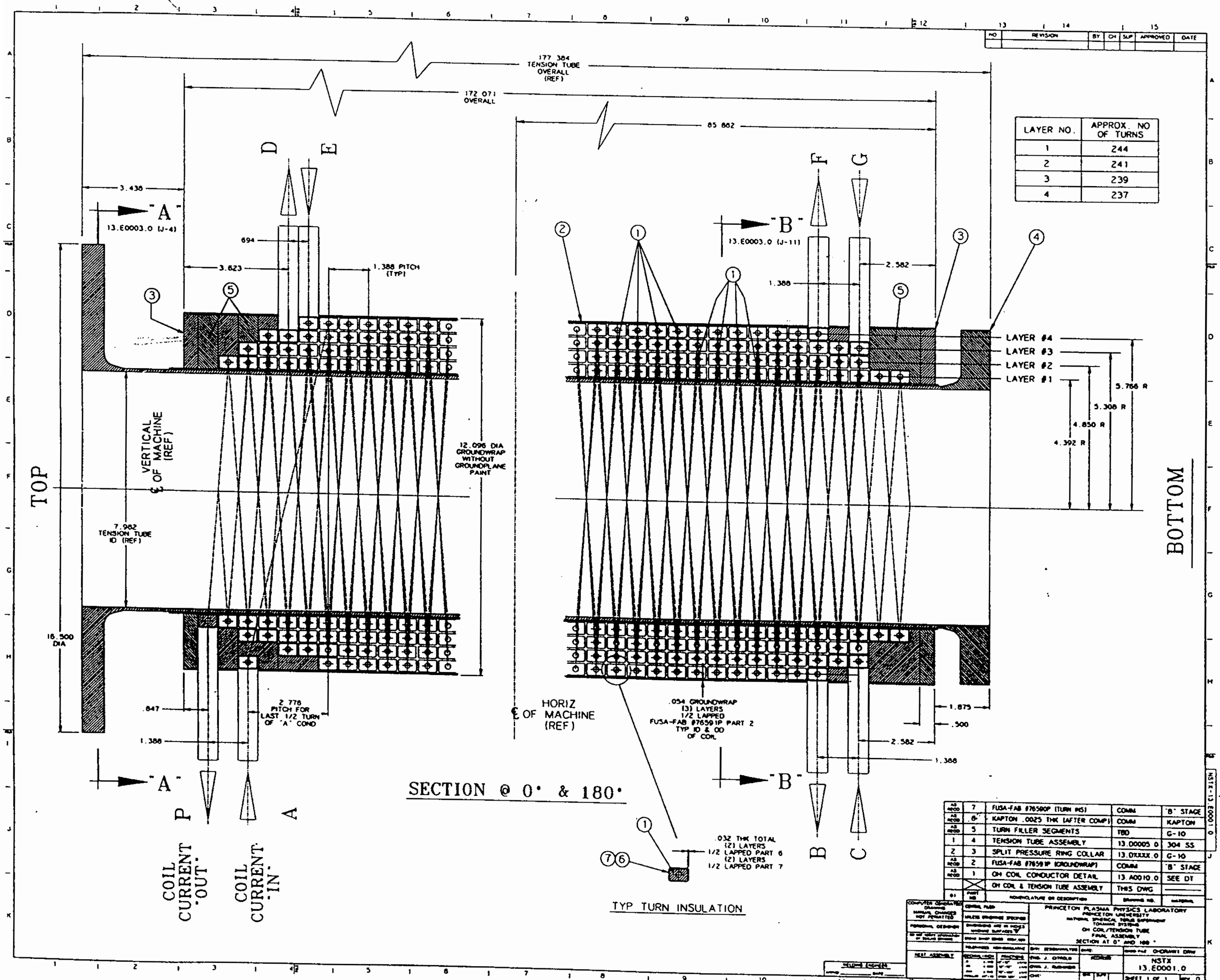
Conclusions

During OH Double swing operation the OH reaches a maximum of 95 C using 10 C inlet water with 400 psi pressure drop through the channel. The coil recools in a little more than 7 minutes and so does not ratchet under the 10 minute rep rate. The heat inleakage from the center stack accounts for about 5 C temperature rise.

During OH Single swing operation the OH reaches a maximum of 44 C during the first pulse and then fully ratchets to 65 C during the second and subsequent pulses.

While the inner three layers were not analysed explicitedly, earlied work showed that by adjusting the flow to the inner times to match transport time through the conductors length results in a uniform cooldown layer to layer:

Layer 1	2.09 m/s
Layer 2	2.31 m/s
Layer 3	2.53 m/s
Layer 4	2.75 m/s



177.384 TENSION TUBE OVERALL (REF)
172.071 OVERALL
85.862
LAYER NO. / APPROX. NO OF TURNS
1 244
2 241
3 239
4 237
TOP
BOTTOM
"A"
13.E0003.0 (J-4)
"B"
13.E0003.0 (J-11)
3.436
3.623
.694
1.388 PITCH (TYP)
2.582
1.388
LAYER #4
LAYER #3
LAYER #2
LAYER #1
5.766 R
5.308 R
4.850 R
4.392 R
VERTICAL ℄ OF MACHINE (REF)
12.096 DIA GROUNDWRAP WITHOUT GROUNDPLANE PAINT
7.982 TENSION TUBE ID (REF)
16.500 DIA
.647
1.388
2.776 PITCH FOR LAST 1/2 TURN OF "A" COND
℄ OF HORIZ MACHINE (REF)
.054 GROUNDWRAP (3) LAYERS 1/2 LAPPED FUSA-FAB #76591P PART 2 TYP ID & OD OF COIL
1.875
.500
SECTION @ 0° & 180°
.032 THK TOTAL (2) LAYERS 1/2 LAPPED PART 6 (2) LAYERS 1/2 LAPPED PART 7
TYP TURN INSULATION
COIL CURRENT "OUT"
COIL CURRENT "IN"
A
B
C
D
E
F
G
P
7 FUSA-FAB #76500P (TURN INS) COMM "B" STAGE
6 KAPTON .0025 THK (AFTER COMP) COMM KAPTON
5 TURN FILLER SEGMENTS TBD G-10
4 TENSION TUBE ASSEMBLY 13.00005.0 304 SS
3 SPLIT PRESSURE RING COLLAR 13.0XXXX.0 G-10
2 FUSA-FAB #76591P (GROUNDWRAP) COMM "B" STAGE
1 OH COIL CONDUCTOR DETAIL 13.A0010.0 SEE DT
OH COIL & TENSION TUBE ASSEMBLY THIS DWG
PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY
OH COIL/TENSION TUBE FINAL ASSEMBLY SECTION AT 0° AND 180°
NSTX
13.E0001.0
NSTX-13.E0001.0

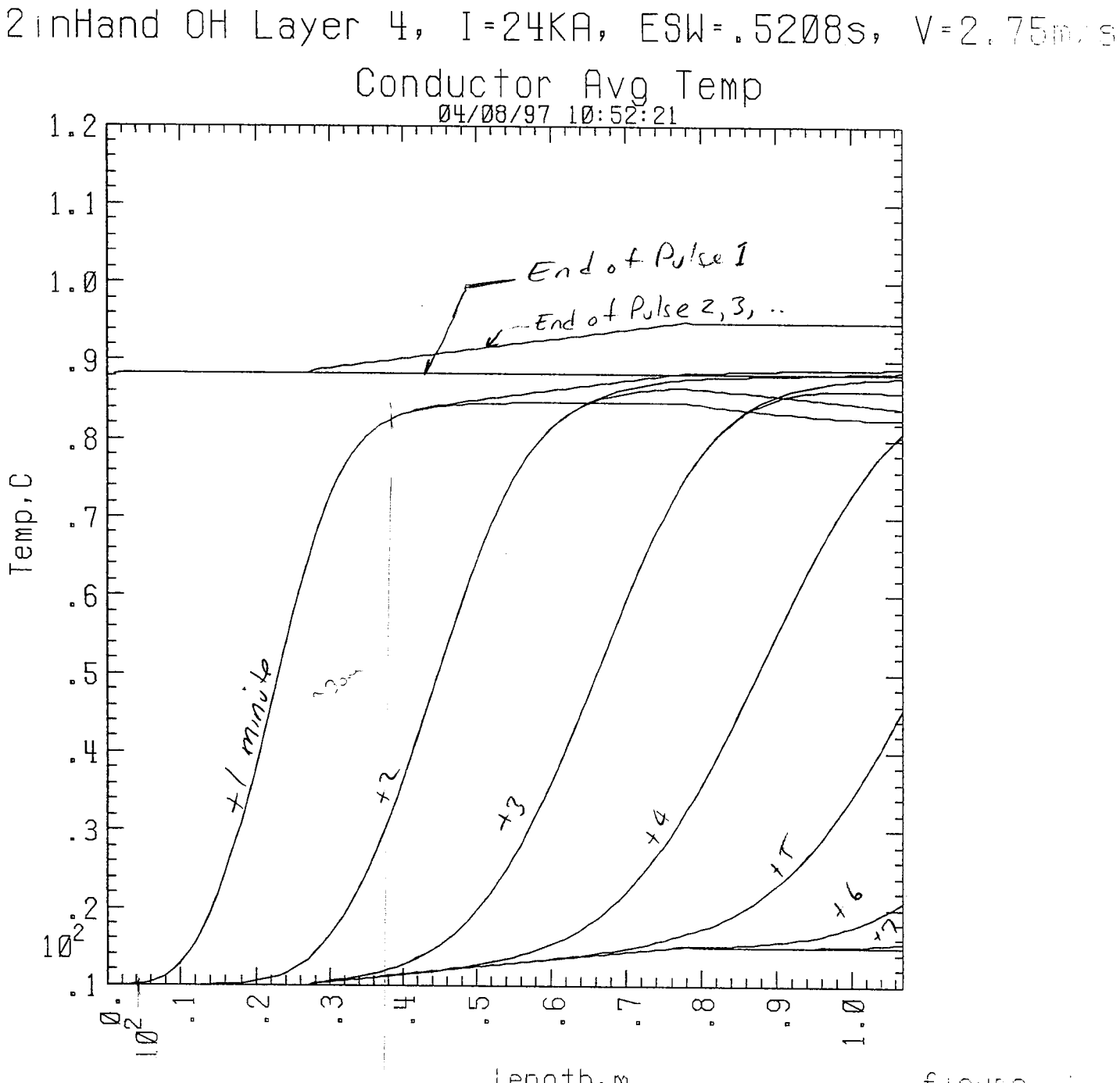

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75m/s
Conductor Avg Temp
04/08/97 10:52:21
End of Pulse 1
End of Pulse 2, 3, ..
+1 minute
+2
+3
+4
+T
+6
+7
Temp, C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length, m

figure 1

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75m s

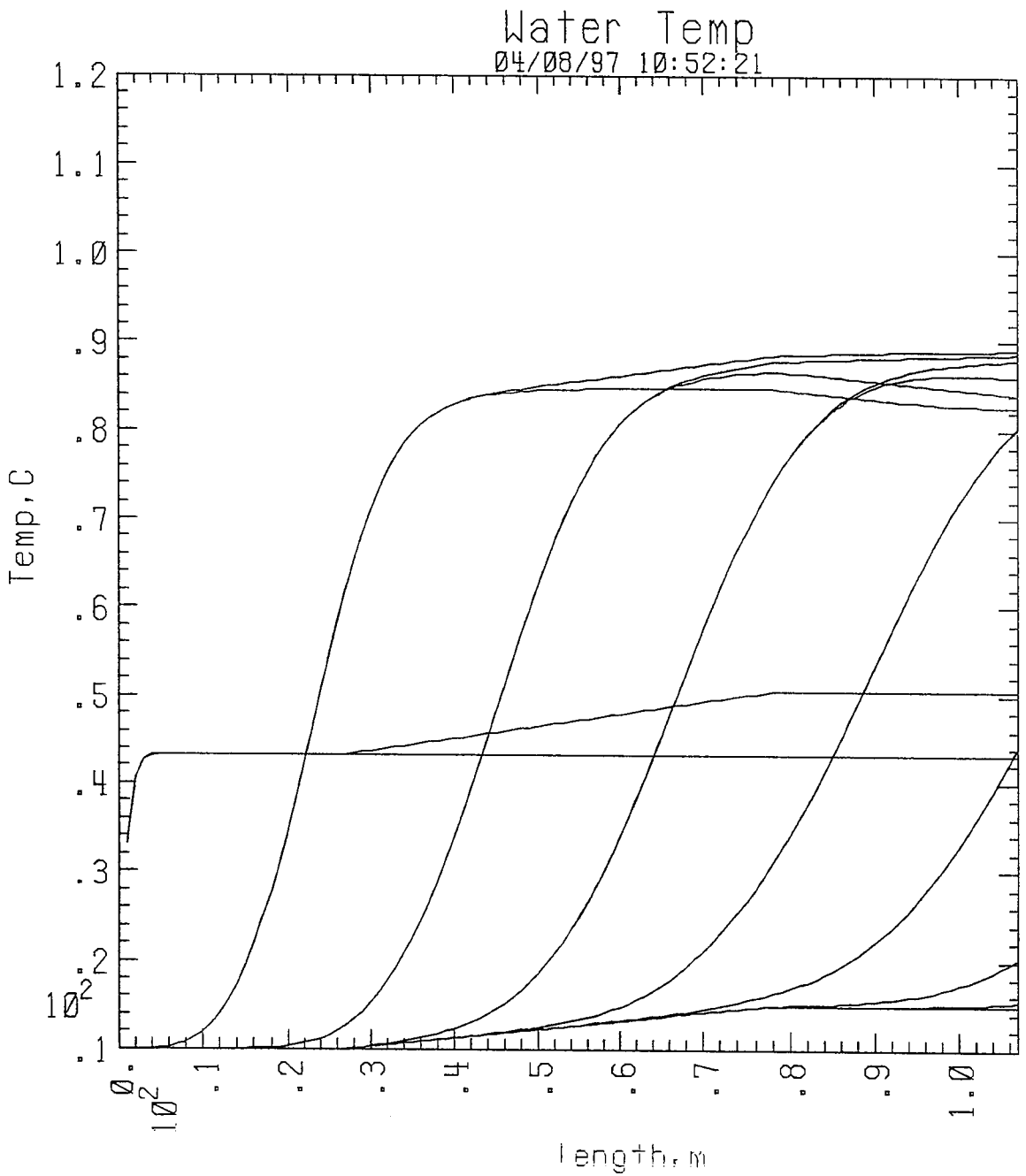


figure 2

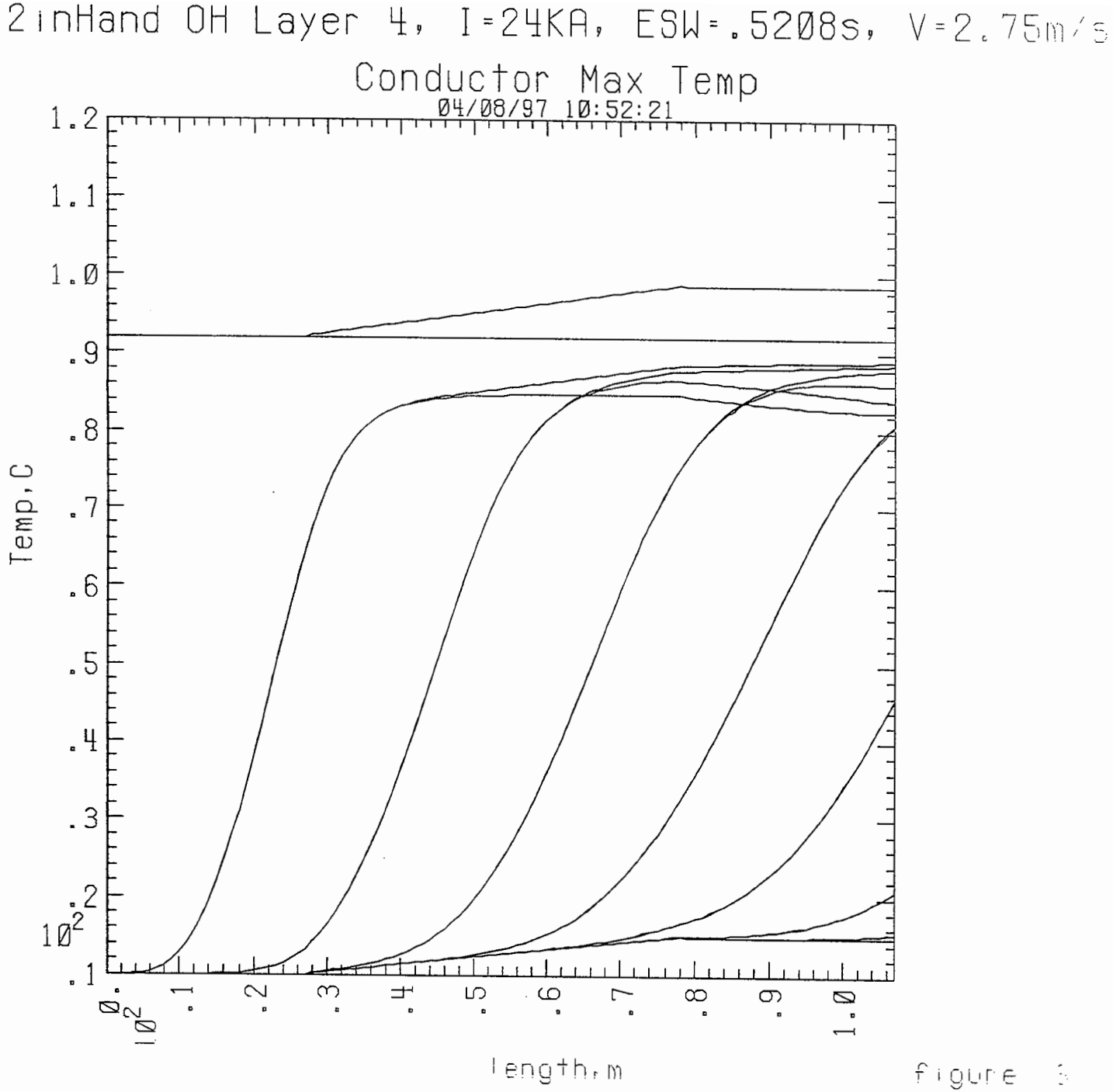

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75m/s
Conductor Max Temp
04/08/97 10:52:21
Temp,C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^2
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length,m

figure 5

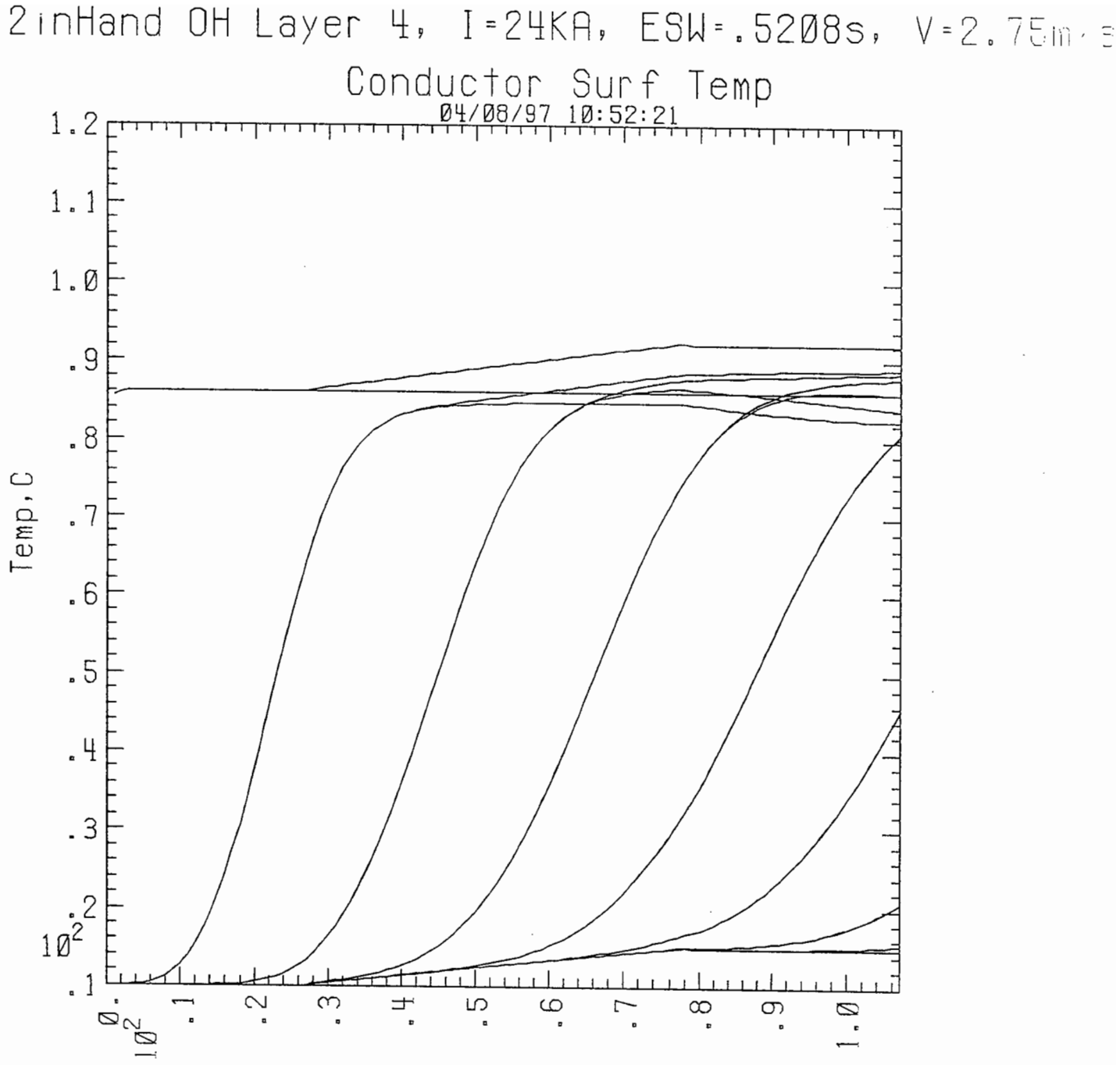

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75m/s
Conductor Surf Temp
04/08/97 10:52:21
Temp,C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^2
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length,m

figure 4

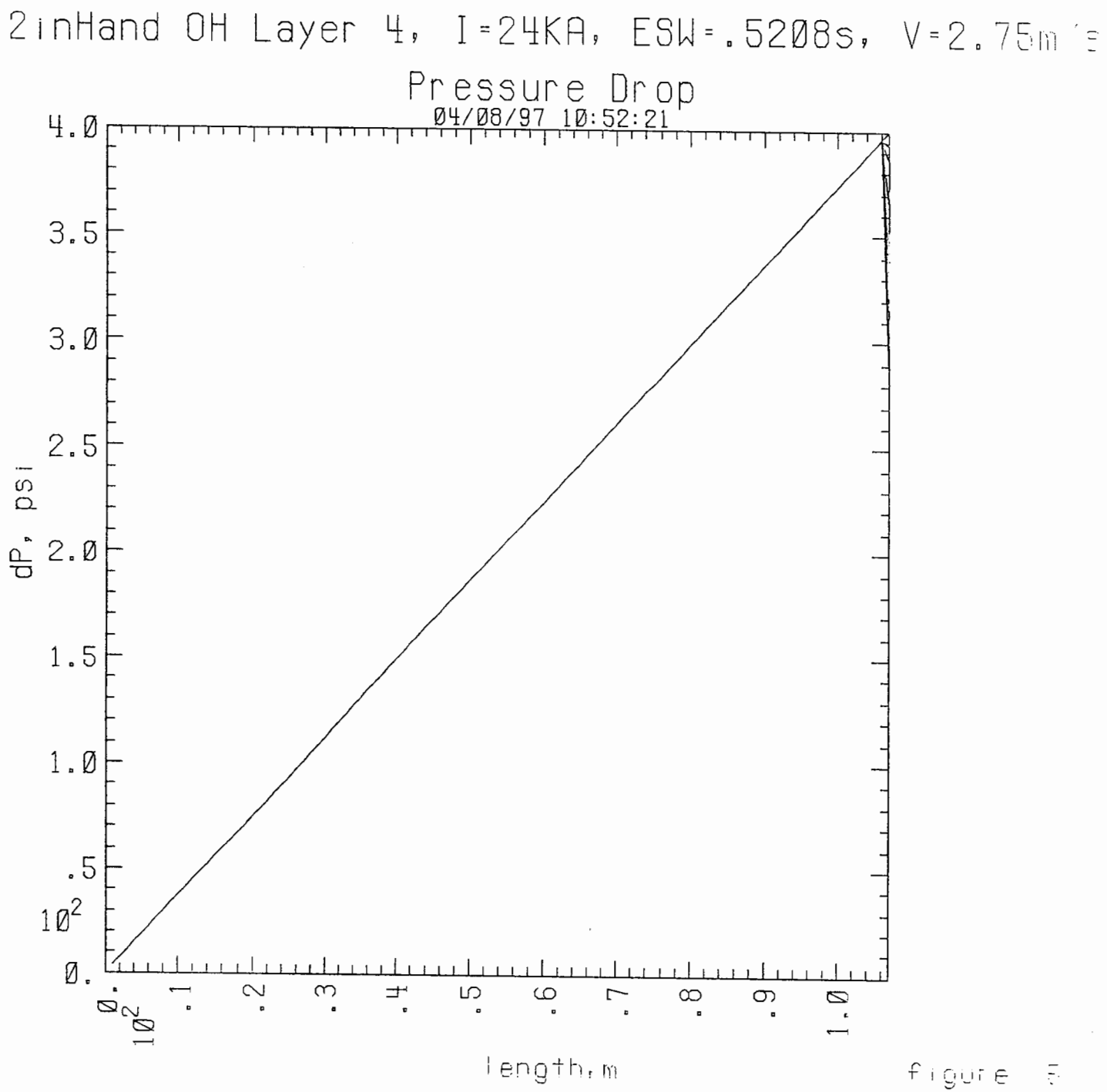

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75m/s
Pressure Drop
04/08/97 10:52:21
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
10^2
0.
dP, psi
0.
10^2
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length,m

figure 5

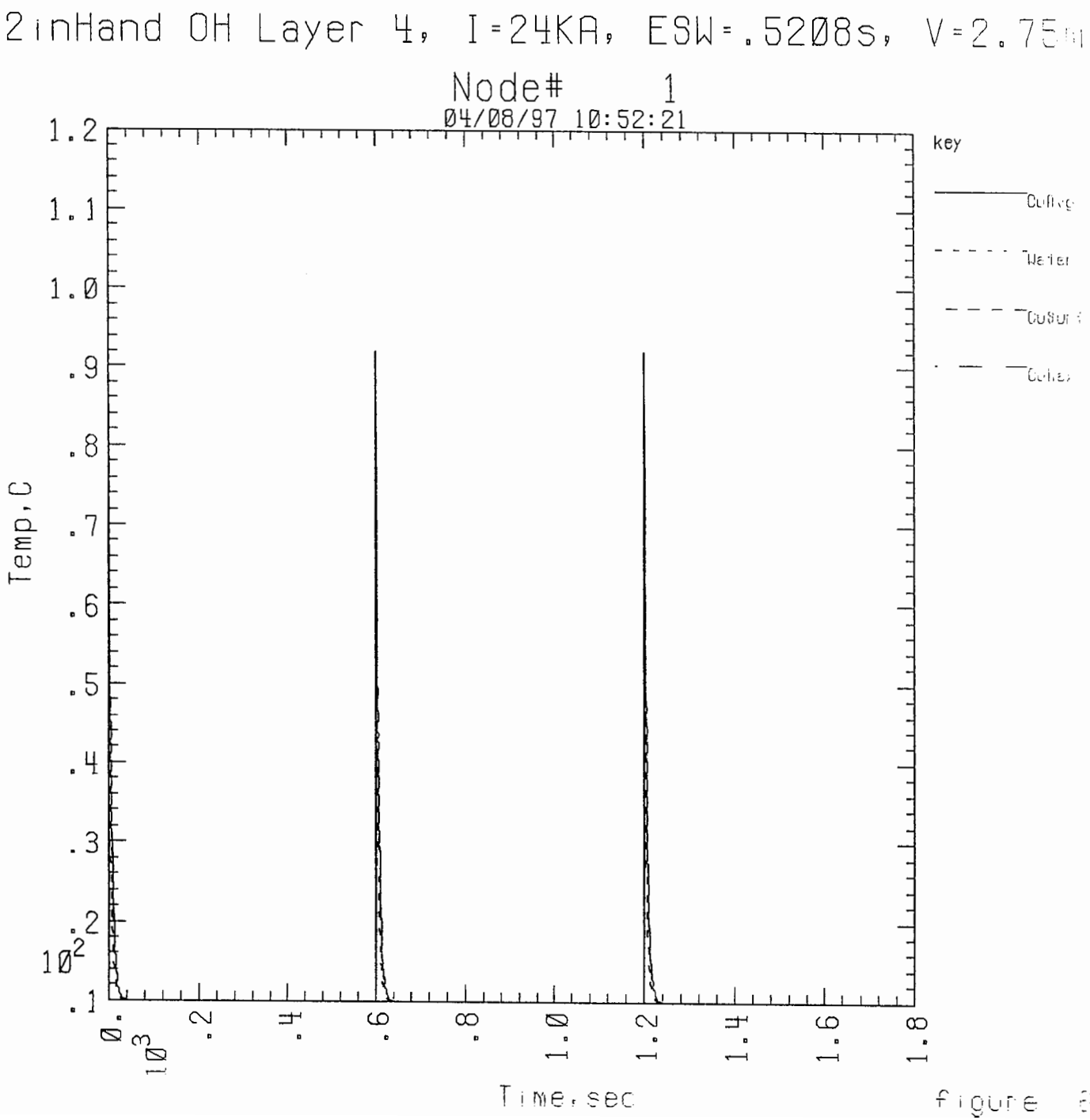

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75
Node# 1
04/08/97 10:52:21
key
Temp,C
Time,sec
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

figure 8

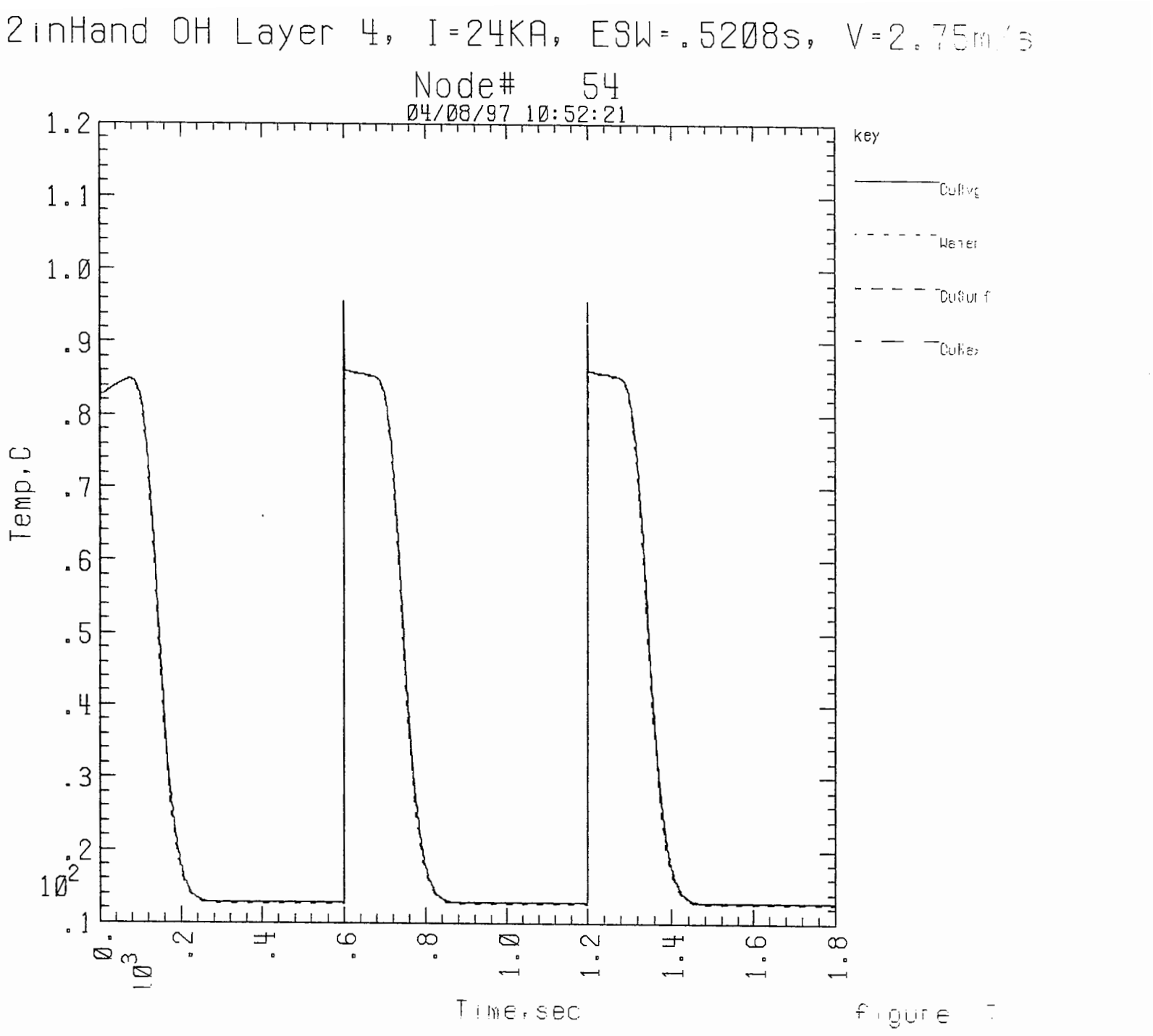

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75m/s
Node# 54
04/08/97 10:52:21
key
CuAvg
Water
CuSurf
CuAxs
Temp,C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
Time,sec

Figure 7

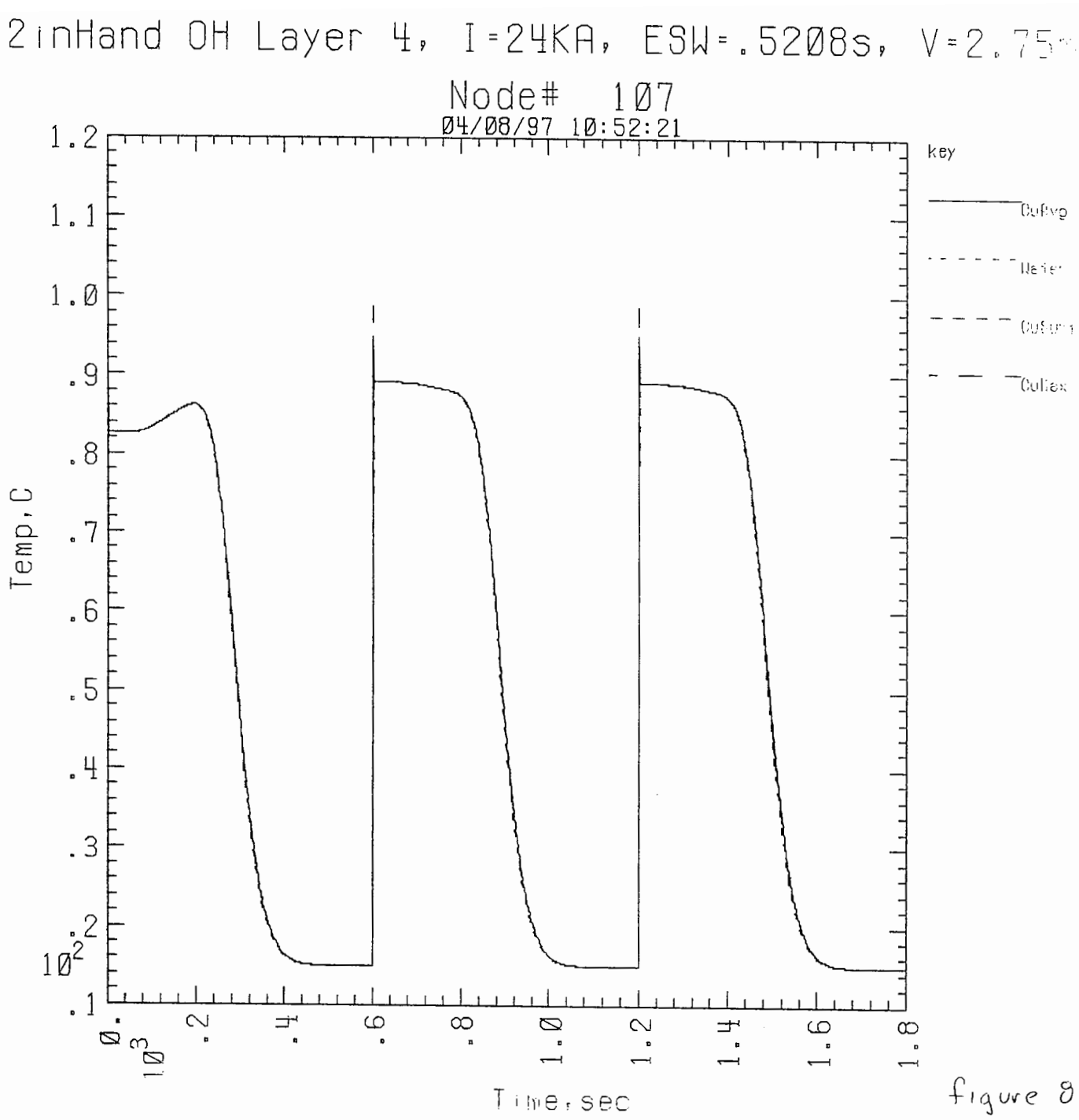

2inHand OH Layer 4, I=24KA, ESW=.5208s, V=2.75
Node# 107
04/08/97 10:52:21
key
Temp,C
Time,sec
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

figure 8

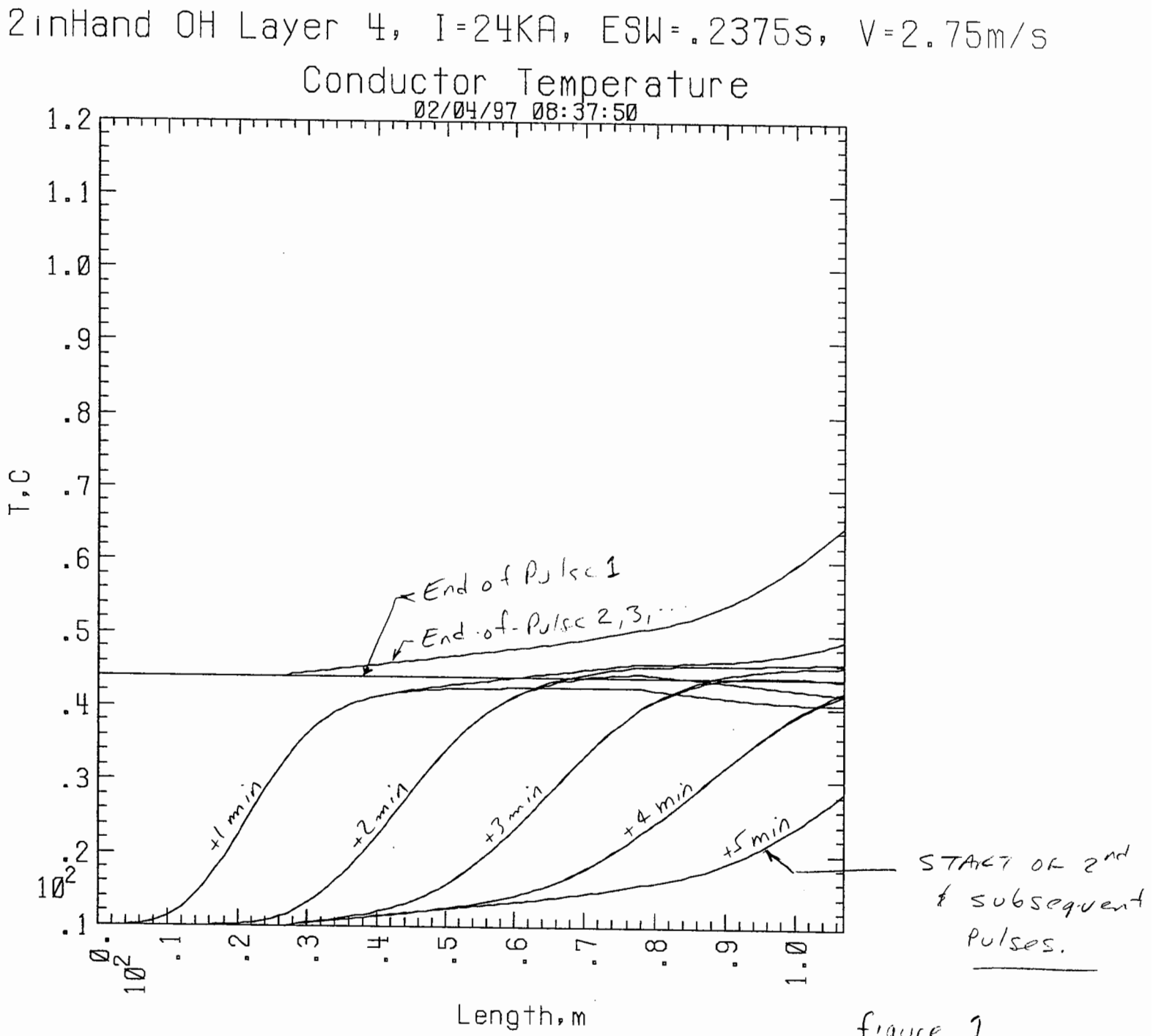

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.75m/s
Conductor Temperature
02/04/97 08:37:50
T,C
Length,m
End of Pulse 1
End of Pulse 2,3,...
+1 min
+2 min
+3 min
+4 min
+5 min
START OF 2nd & SUBSEQUENT PULSES.

figure 1

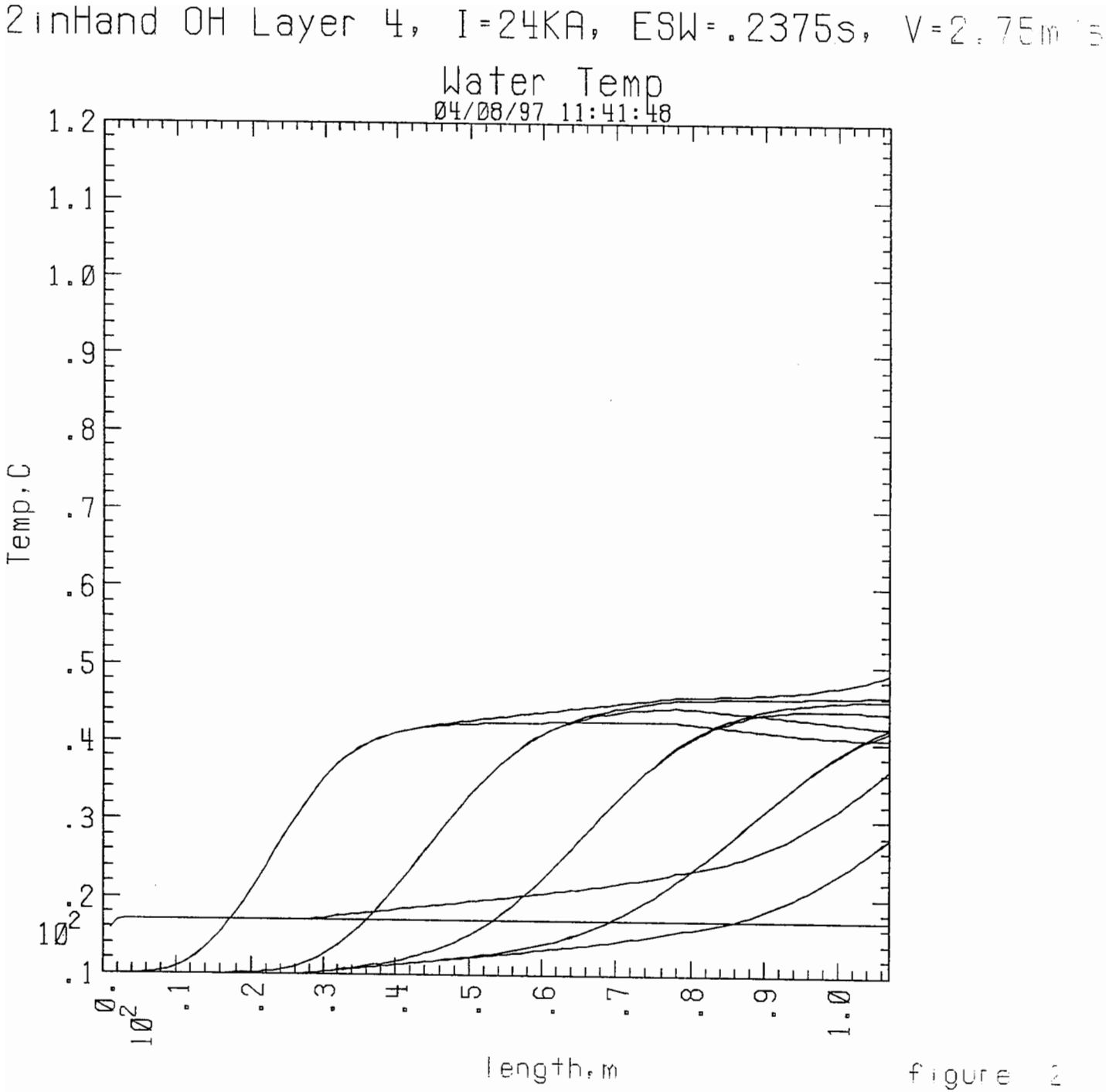

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.75m/s
Water Temp
04/08/97 11:41:48
Temp,C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^2
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length,m

figure 2

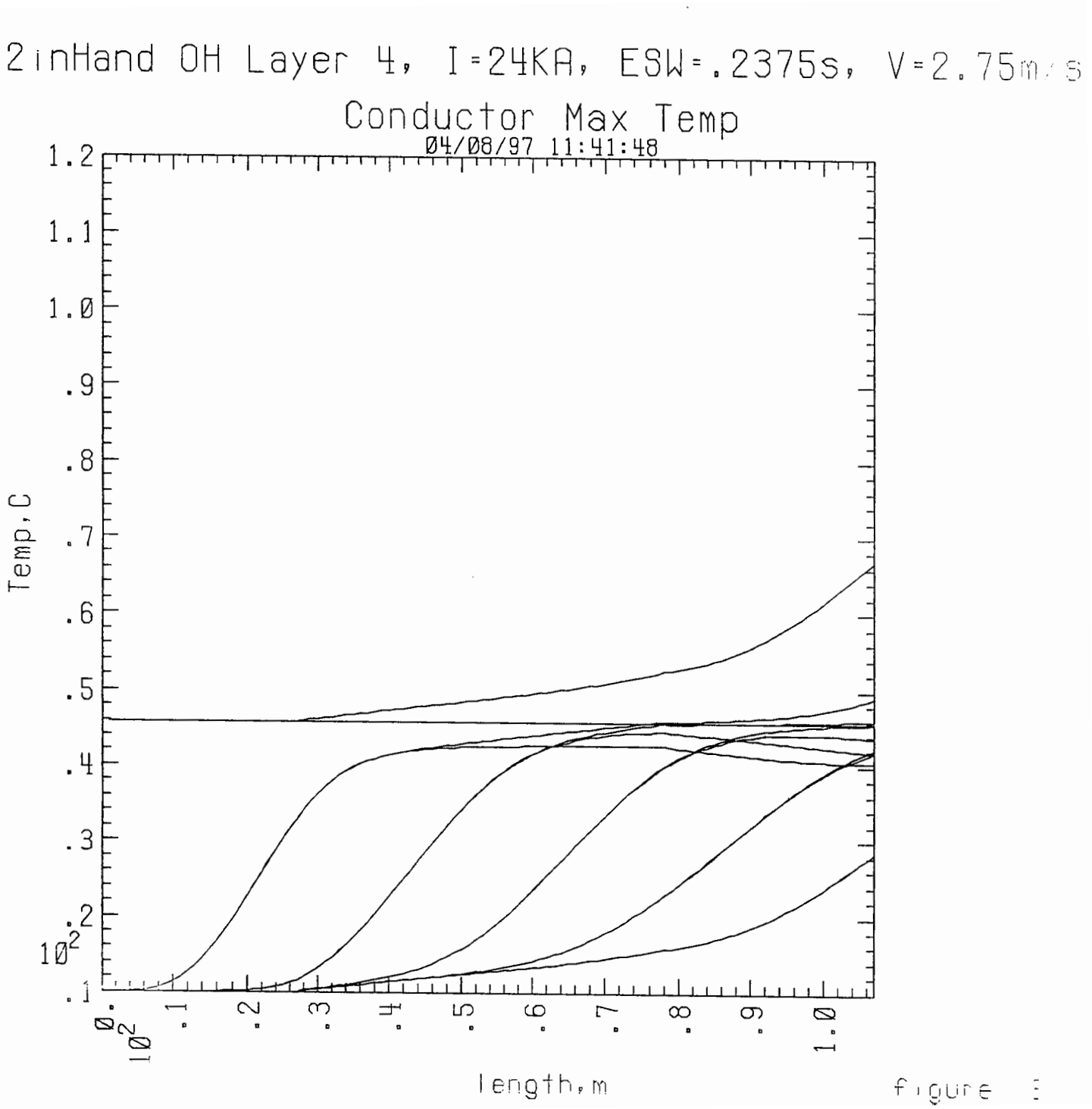

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.75m/s
Conductor Max Temp
04/08/97 11:41:48
Temp,C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^2
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length,m

figure 3

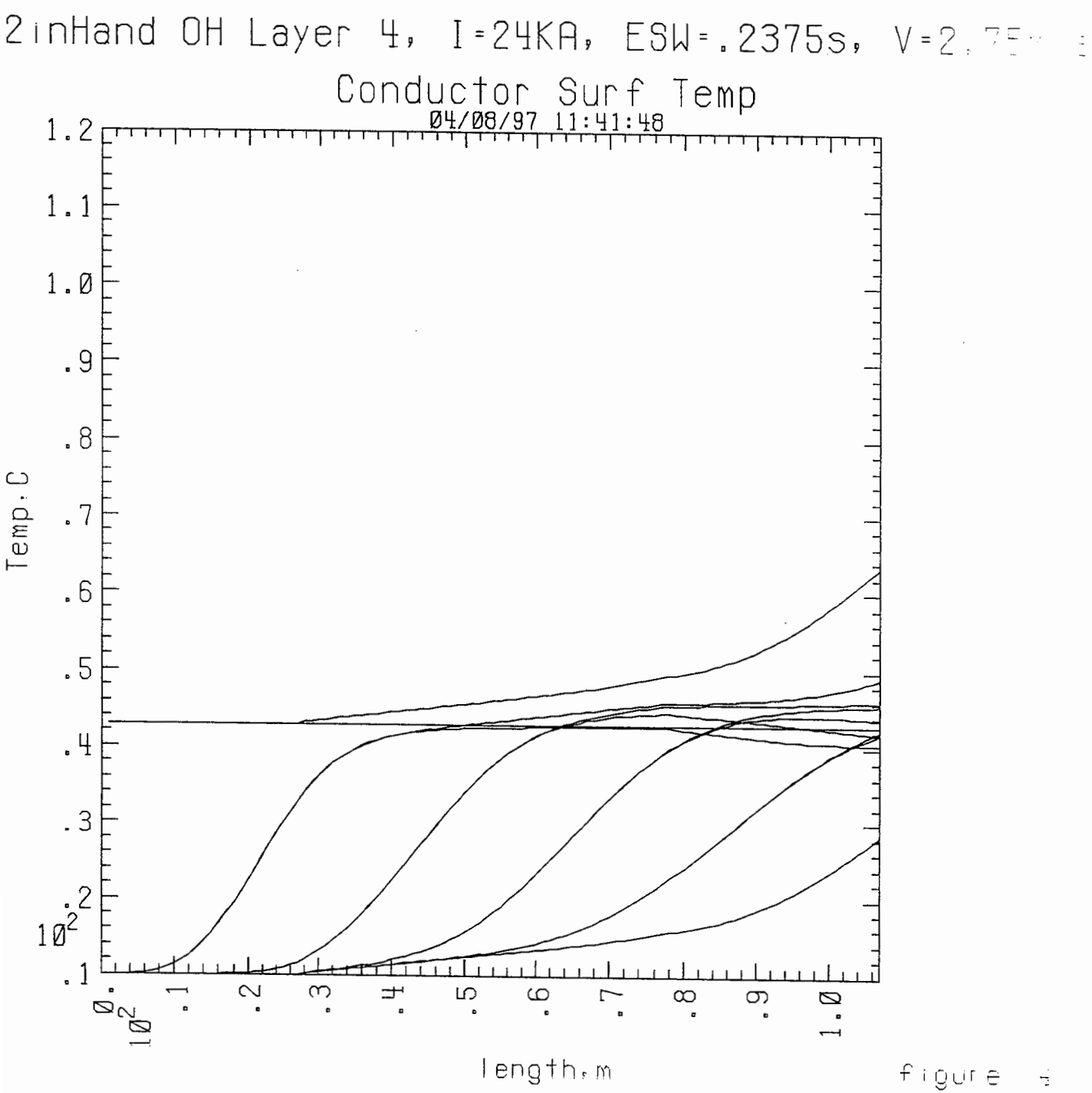

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.7E
Conductor Surf Temp
04/08/97 11:41:48
Temp.C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^2
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length,m

figure 4

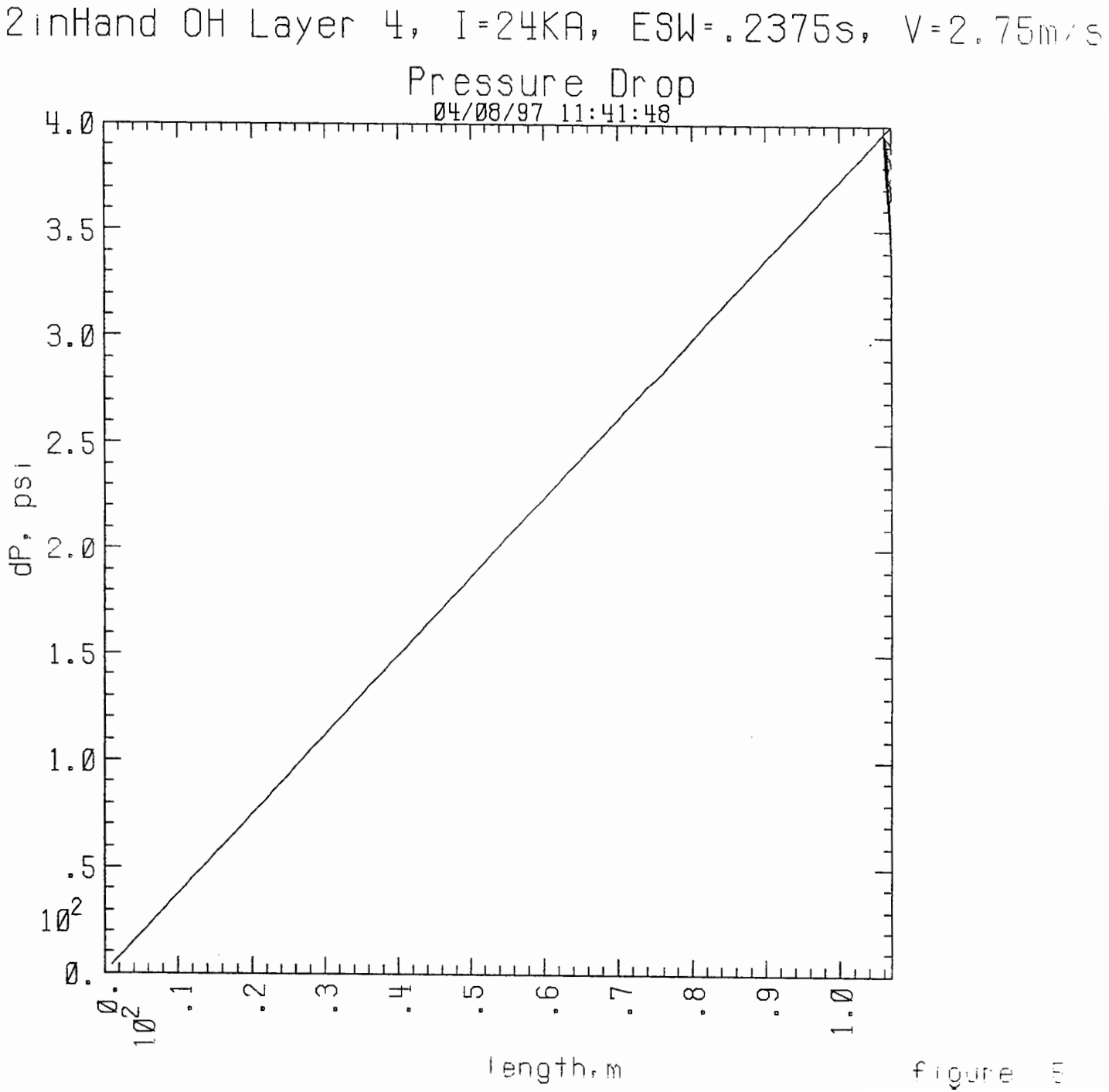

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.75m/s
Pressure Drop
04/08/97 11:41:48
dP, psi
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
10^2
0.
0.
10^2
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
length,m

figure 5

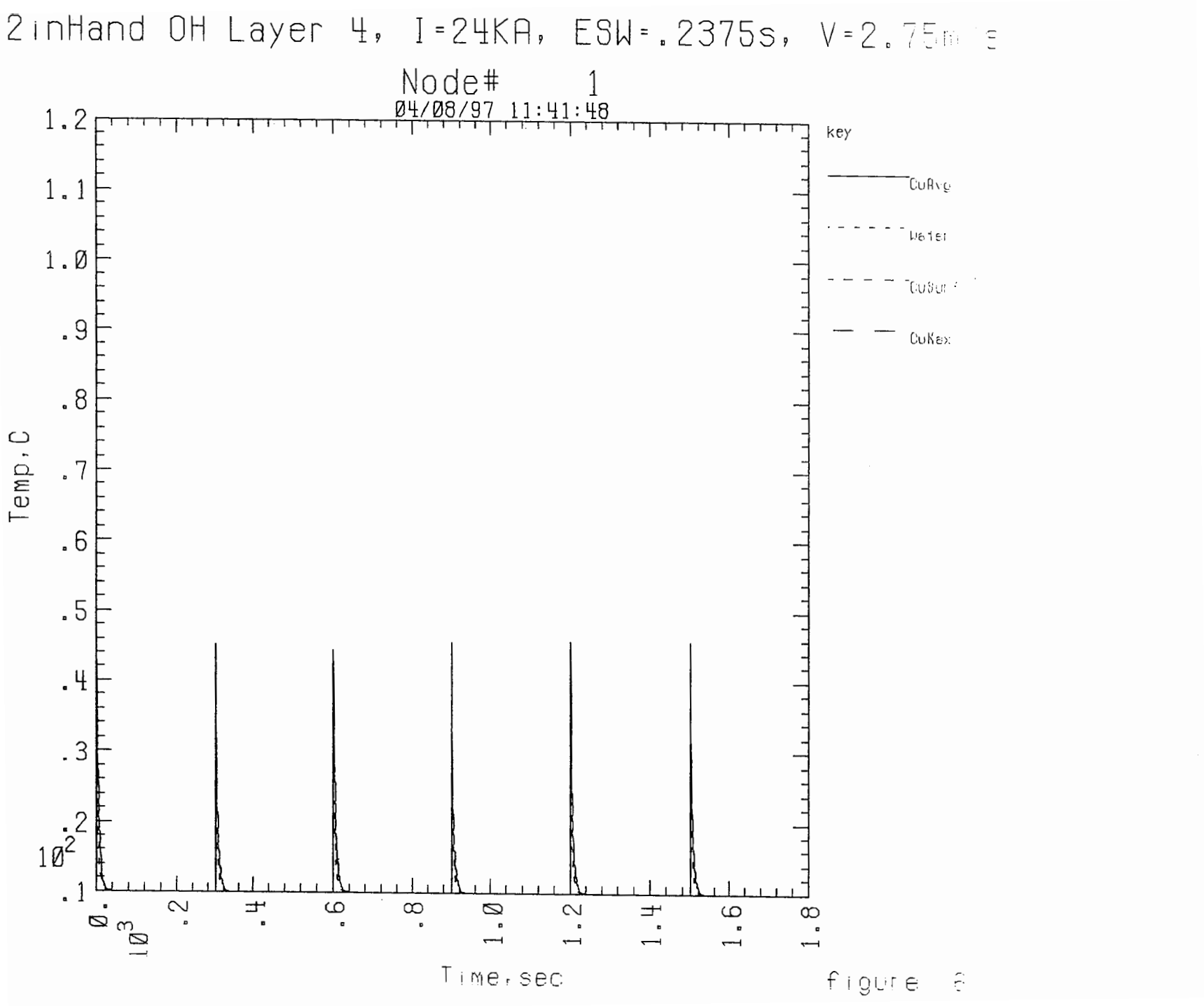

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.75m
Node# 1
04/08/97 11:41:48
key
CuAvg
Water
CuSur
CuMax
Temp,C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
Time,sec

figure 3

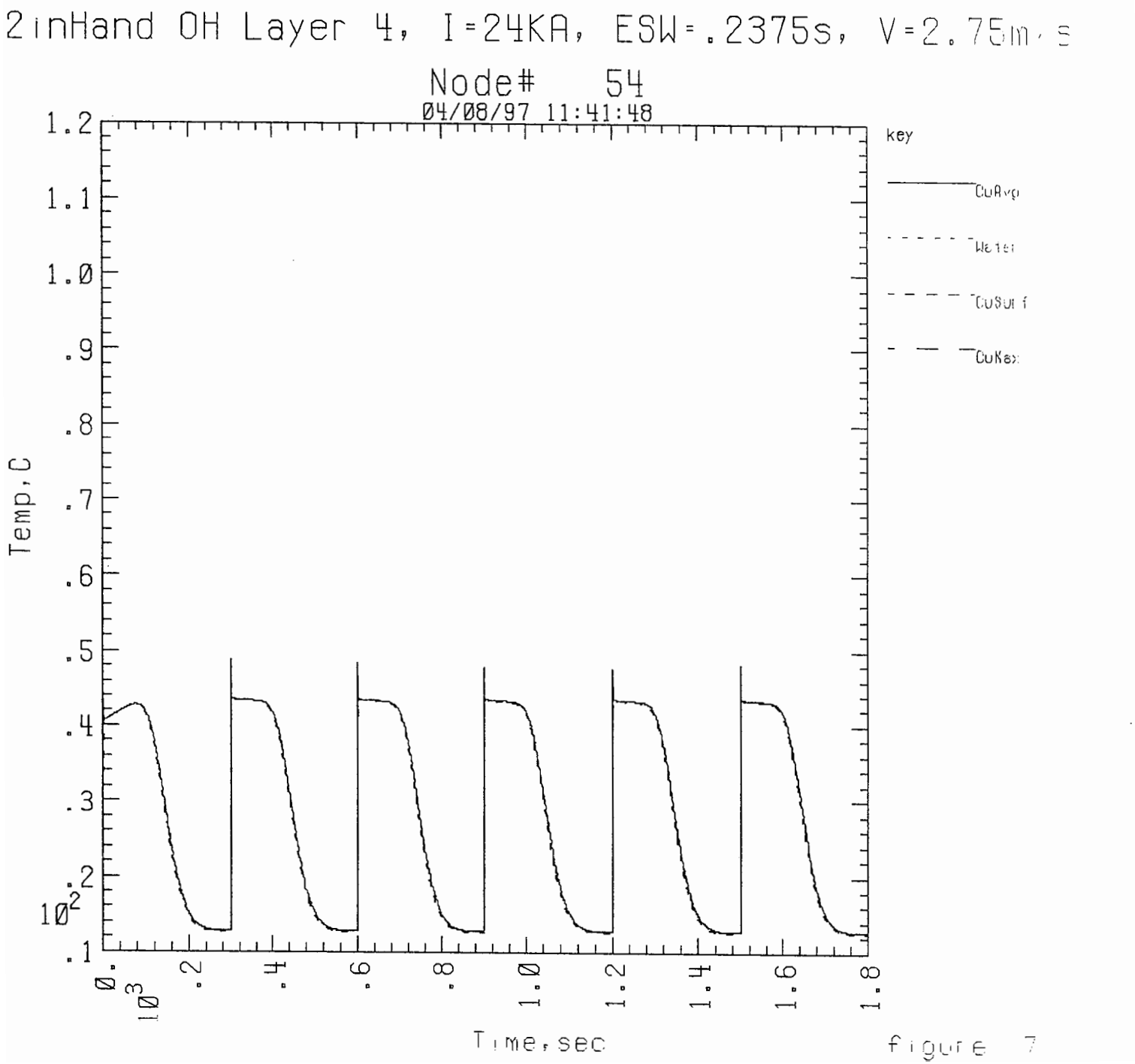

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.75in/s
Node# 54
04/08/97 11:41:48
key
CuAvg
Water
CuSurf
CuMax
Temp,C
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
Time,sec

figure 7

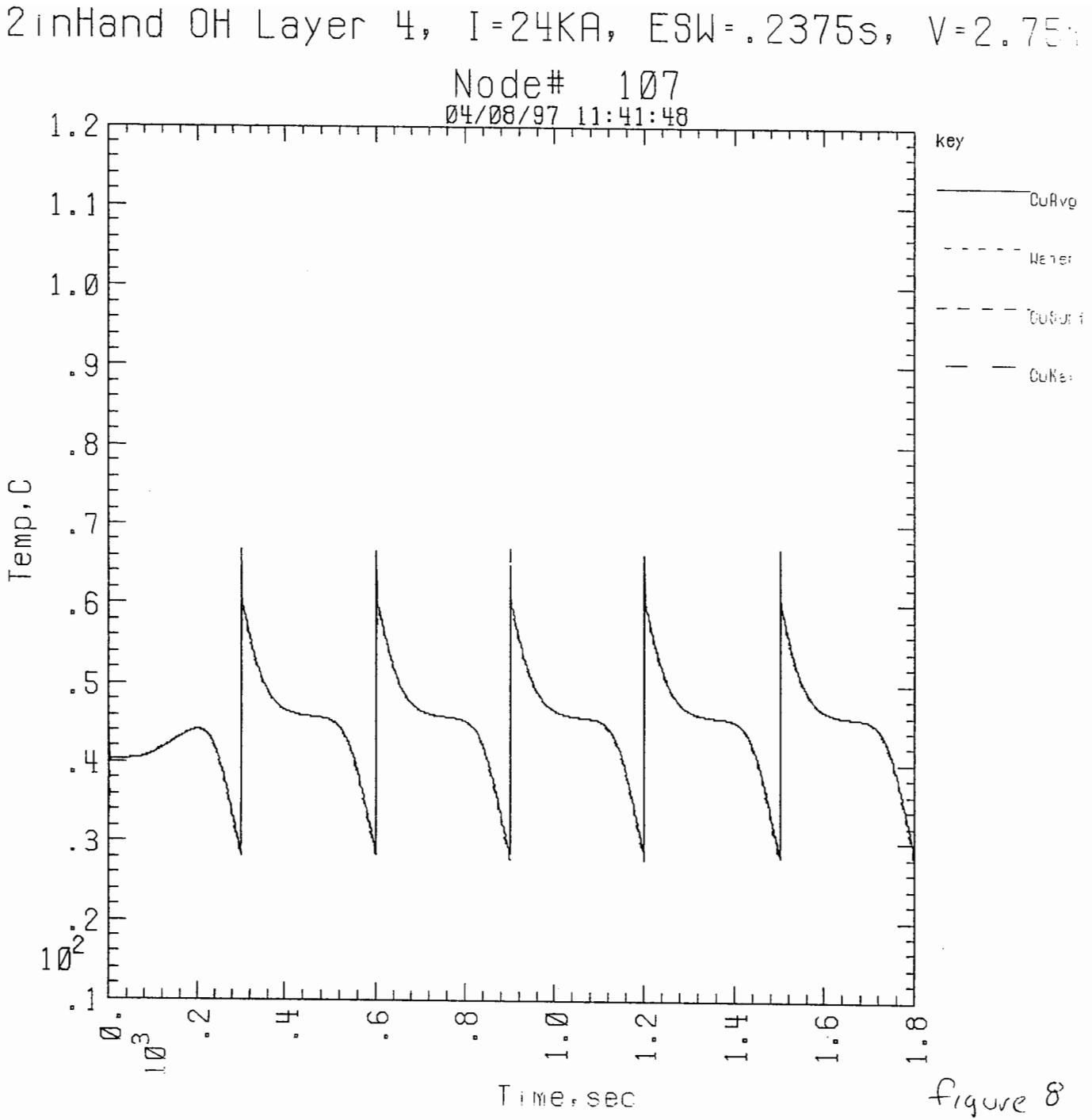

2inHand OH Layer 4, I=24KA, ESW=.2375s, V=2.75
Node# 107
04/08/97 11:41:48
Temp,C
Time,sec
key
CuAvg
Water
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
10^2
0.
10^3
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

figure 8