Intrusion of a liquid
finger into a boiling isotherm

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CONTROLLED
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4/11/00 This scientific notebook documents work performed on project 20-01402-661 concerning the infiltration of a liquid finger into a boiling isotherm.

Initial entry 4/11/00 by Melissa Hill MH

5/10/00 JP

Thermocouple calibration

Objective - calibrate thermocouples to be used in the infiltration of a liquid finger into a boiling isotherm experiment.

Method - check thermocouple readings against media of known temperature (ice and heated water).

Equipment and materials
- corning hot plate
- ice
- 1L glass beaker
- calibrated thermometer (S/N C96-833
- HP34970A meter
- Omega Precision Fine Wire Thermocouple with 72 inch leads.

Procedure

① Thermocouples were placed in a beaker filled with ice along with a calibrated thermometer. Sixty four thermocouples were labeled T1 thru T64.

Temperatures are recorded below

Calibrated thermometer - 1.1°C

T1 - 1.1	T26 - 1.2	T51 - 0.0
T2 - 0.4	T27 - 0.6	T52 - 0.9
T3 - 0.7	T28 - 1.1	T53 - 1.1
T4 - 0.3	T29 - 2.9	T54 - 0.2
T5 - -1.2	T30 - 2.1	T55 - 1.7
T6 - 2.4	T31 - 1.6	T56 - 0.9
JP 5/10/00 T7 - ~~2.3~~ 1.9	T32 - 1.5	T57 - 1.0
T8 - 2.3	T33 - 2.3	T58 - 0.7
T9 - 2.2	T34 - 1.1	T59 - 2.2
T10 - 2.7	T35 - 0.4	T60 - 1.5
T11 - 1.5	T36 - 1.6	T61 - 1.4
T12 - 1.5	T37 - 1.4	T62 - 1.1
T13 - 1.0	T38 - 0.2	T63 - 2.7
T14 - 2.0	T39 - 2.0	T64 - 1.2
T15 - 3.0	T40 - 2.3	
T16 - 1.3	T41 - 1.1	
T17 - 1.5	T42 - 0.2	
T18 - 1.5	T43 - 2.1	
T19 - 0.4	T44 - 0.9	
T20 - 1.1	T45 - 0.7	
T21 - 1.3	T46 - 1.7	
T22 - 1.3	T47 - 0.4	
T23 - 1.9	T48 - 2.1	
T24 - 0.4	T49 - 0.0	
T25 - 1.4	T50 - 0.7	

(2) Thermocouples were placed in a beaker of hot water (~95°C) with the calibrated thermometer.

Temperatures are recorded below.

Calibrated thermometer - 95°C

T1 - 94.6	T26 - 95.6	T51 - 94.6
T2 - 94.2	T27 - 94.0	T52 - 95.5
T3 - 94.3	T28 - 94.6	T53 - 95.3
T4 - 95.1	T29 - 94.7	T54 - 95.0
T5 - 95.8	T30 - 95.5	T55 - 94.6
T6 - 94.3	T31 - 95.4	T56 - 94.8
T7 - 94.3	T32 - 95.6	T57 - 94.5
T8 - 95.8	T33 - 95.9	T58 - 94.4
T9 - 95.1	T34 - 94.7	T59 - 93.8
T10 - 95.4	T35 - 95.4	T60 - 94.4
T11 - 95.0	T36 - 96.1	T61 - 94.8
T12 - 94.9	T37 - 96.2	T62 - 94.2
T13 - 95.6	T38 - 95.6	T63 - 94.3
T14 - 95.3	T39 - 95.6	T64 - 94.6
T15 - 95.6	T40 - 95.7	
T16 - 94.5	T41 - 95.5	
T17 - 95.3	T42 - 95.3	
T18 - 95.5	T43 - 96.3	
T19 - 95.6	T44 - 95.6	
T20 - 95.0	T45 - 95.9	
T21 - 94.9	T46 - 96.0	
T22 - 94.3	T47 - 96.0	
T23 - 95.6	T48 - 95.8	
T24 - 95.1	T49 - 95.7	
T25 - 94.6	T50 - 95.8	

5/15/00 JP

Construction and assembly of experimental apparatus to measure infiltration of a liquid finger into a boiling isotherm

Obj - Design + construct an apparatus to measure infiltration of a liquid finger of water into a boiling isotherm.

Method - infiltrate water at a known rate between two glass plates over which a horizontal heat gradient has been imposed.

Equipment + Materials.
- Two 12"x15"x3/8" glass plates. One side of each plate has been sandblasted to create a rough ~~texture~~.
- Two 15 1/4" x 15 1/4" x 1" plate of lexan plastic.
- Steel bolts - 4 inch long, with nuts + washers
- 1/8" neoprene rubber, 1"x4" pieces
- 1/4" plexiglass, 1.5"x4" pieces
- C-clamps
- aluminum foil
- aluminum tape
- ~~Omega~~ MINCO 1"x15" Kapton strip heaters
- ~~Omega~~ MINCO 0.5"x2" Kapton strip heaters JP 5/15/00

- Epsco Model D-612T power supplies (5)
- Banana clips, wire, and electrical caps as needed.
- Hewlett Packard 34970A Data acquisition system with 40 channel multiplexer cards.
- Omega Precision fine wire thermocouples with 72" inch leads.
- Statco variable transformers (120V) (4)
- Glas-Col variable transformers (120V) (3)
- HP Benchlink Data logger software.
- Wood and steel frame (as shown in following photographs).
- Manostat cassette pump
- tubing
- DI water.
- Kelvar insulation
- 1/16 inch aluminum sheets (12"x15").
- Quizix SP 5200 pump system
- Canon ZR digital video camcorder
- WinTV software

Assembly

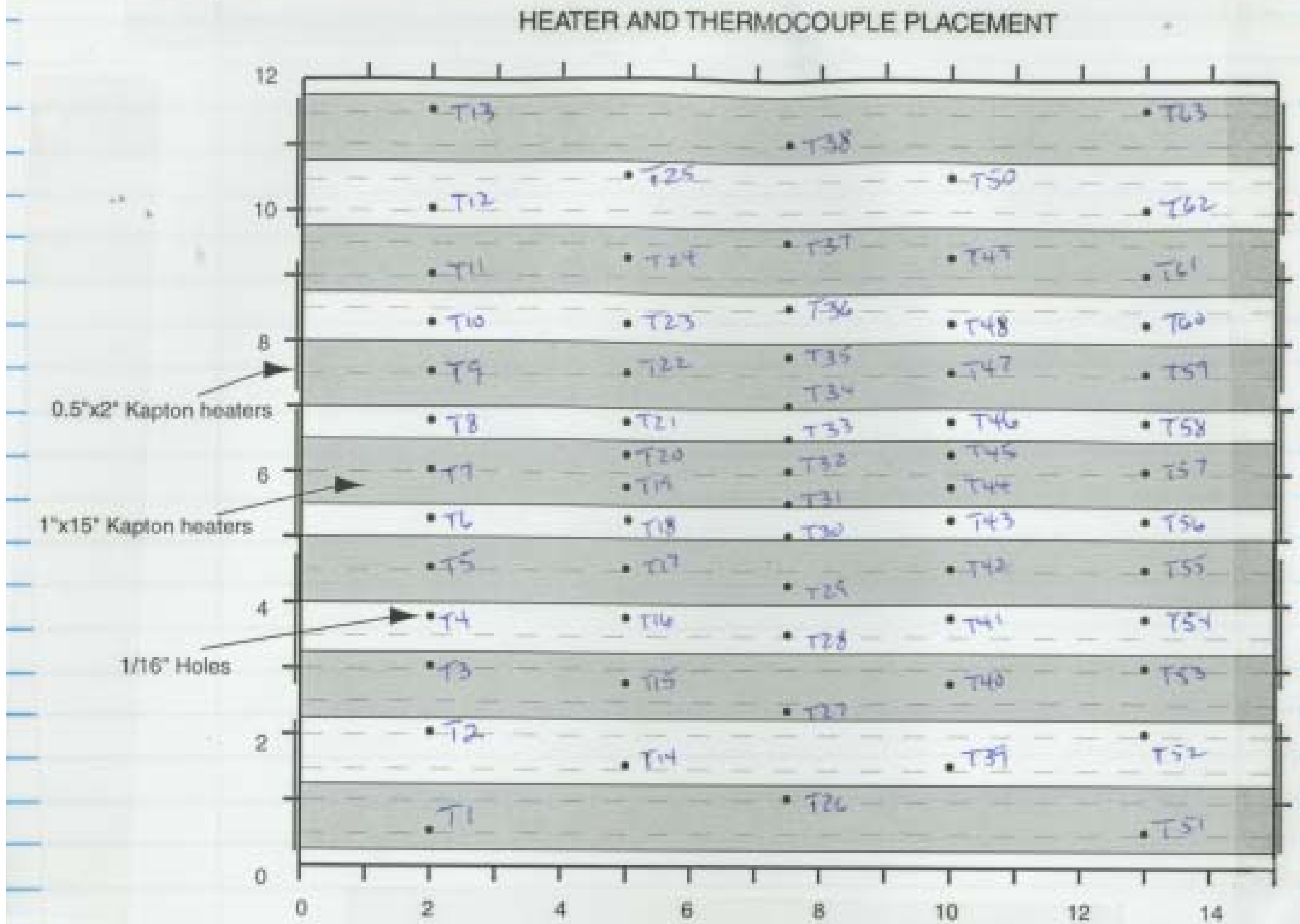
1. Glass plates were placed together evenly with sandblasted sides touching or facing inward.

2. Three evenly spaced holes were drilled on opposite sides of each of the lexan plastic sheets. The holes were drilled ~1" from the edge of the plastic. The holes were drilled to accomodate the steel bolts.

3. The glass plates were sandwiched between the lexan sheets with drill holes exposed.

4. The 1"x15" strip heaters (7) were placed between the glass & lexan, lengthwise. The diagram on the next page shows the placement of the heater strips with respect to the glass plates.

5. On the opposite lexan sheet, 1/16" holes were drilled for placement of thermocouples. The diagram on the next page shows the placement of the holes/thermocouples. A total of 63 thermocouples labeled T1 thru T63 were placed.



5/16/00 JJ The diagram aboves shows placement of heaters and thermocouples. Diagram shows placement with respect to 12"x15" glass plates. The 1"x15" heaters were placed horizontally as shown and were labeled 1 thru 7 from ~~top~~ JJ 5/16/00 bottom to top. The 0.5"x12" heaters were placed vertically on the sides of the glass plates. Holes were drilled thru the lexan sheet opposite the 1"x15" heaters as shown above. The holes will accomodate thermocouples and were labeled as shown.

5/16/00 JJ ⑥ Five pairs of 0.5"x2" Kapton heaters were placed vertically on the sides of the glass plates to control temperature at the boundaries. Placement of these heaters is shown on the previous page.

⑦ The glass plates and lexan were then bolted together using 4" steel bolts. Spacers consisting of plexiglass + neoprene rubber were placed between the bolts to avoid damaging the lexan. 85 ft lb of pressure applied with a Torque wrench was applied to each bolt. C-clamps were placed on the right + left sides of the assembly to apply pressure to the center & avoid bowing. The assembly was placed in a steel and wood frame.

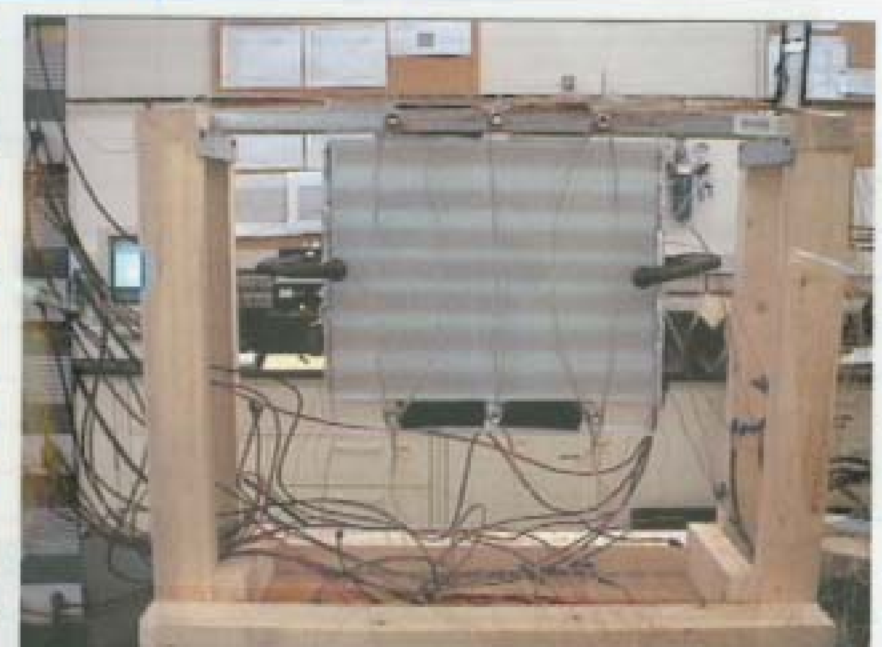


Photo showing glass plate/lexan assembly mounted in wood and steel frame.

(8) To monitor ~~the~~ temperature, thermocouples were placed in the holes drilled in the lexan sheet. Five wire thermocouples were placed in each hole and attached to an HP 34970A data logger. The thermocouples were inserted so that they would be touching the glass plate opposite the 1"x15" heaters. Temperature data was captured electronically using HP Benchlink data logger software. Each thermocouple was attached to a 40 channel HP multiplexer cartridge.

Thermocouples and their channel designations are listed below.

Channel	Thermocouple	Channel	Thermocouple
101	T1	116	T16
102	T2	117	T17
103	T3	118	T18
104	T4	119	T19
105	T5	120	T20
106	T6	121	T21
107	T7	122	T22
108	T8	123	T23
109	T9	124	T24
110	T10	125	T25
111	T11	126	T26
112	T12	127	T27
113	T13	128	T28
114	T14	129	T29
115	T15	130	T30

Channel	Thermocouple	Channel	Thermocouple
131	T31	206	T46
132	T32	207	T47
133	T33	208	T48
134	T34	209	T49
135	T35	210	T50
136	T36	211	T51
137	T37	212	T52
138	T38	213	T53
139	T39	214	T54
140	T40	215	T55
201	T41	216	T56
202	T42	217	T57
203	T43	218	T58
204	T44	219	T59
205	T45	220	T60
		221	T61
		222	T62
		223	T63

(9) The 1"x15" Kapton heaters were attached to the Staco or Glas-Col variable transformers. The 0.5"x2" Kapton heaters were attached to the Epsco power supplies.

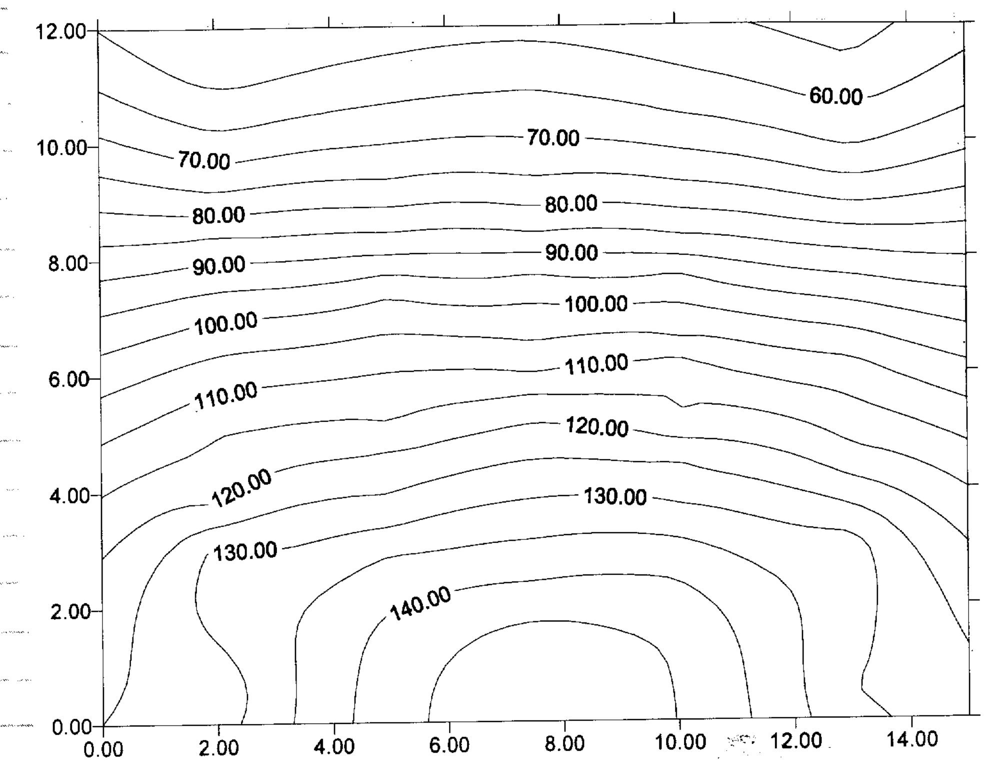
(10) The 0.5"x2" heaters were covered with a layer of aluminum foil held in place with aluminum tape. This allowed insulation and an even temperature distribution along the sides of the assembly.

(11) An initial test (Test 1) was conducted to determine the approximate settings required to impose a temperature gradient in the assembly.
The amount of power supplied to the 1" x 15" strip heaters was increased incrementally until the temperature of the bottom heater was about 140°C in the center and the temperature of the top heater was about 50°C in the center. At the conclusion of the test the variable transformers and power supplies had the following settings.

Strip heater #	Transformer setting	
7	65	Statco
6	55	"
5	45	"
4	35	"
3	20	Glas-Col
2	15	"
1	10	"

Side heater #s	Power supply setting
5	20V
4	15V
3	10V
2	5V
1	2.5V

Using these settings the temperature field shown in the below plot was imposed.

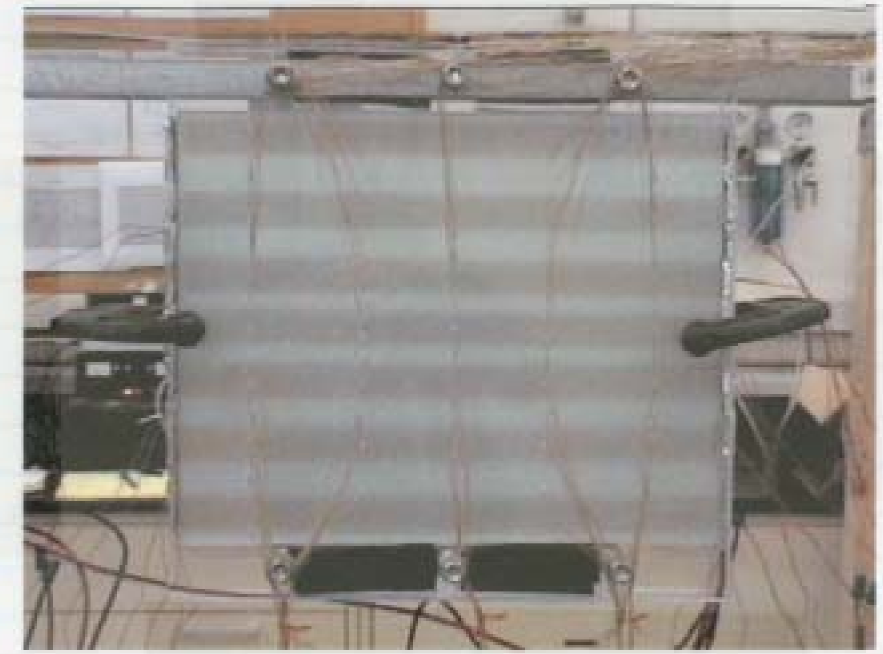


5/17/00 JP Results of the test indicated that an adequate temperature field could be imposed. However, cracks developed in the glass plates as high temperatures were imposed on the assembly. The cracks developed at points of pressure along the bottom of the assembly were bolts were used to tighten the assembly. Cracks did not develop along the top of the assembly where steel bar where placed along the length of the assembly to mount the assembly into the wood frame. Apparently the steel bars allowed pressure to be applied evenly along the top.

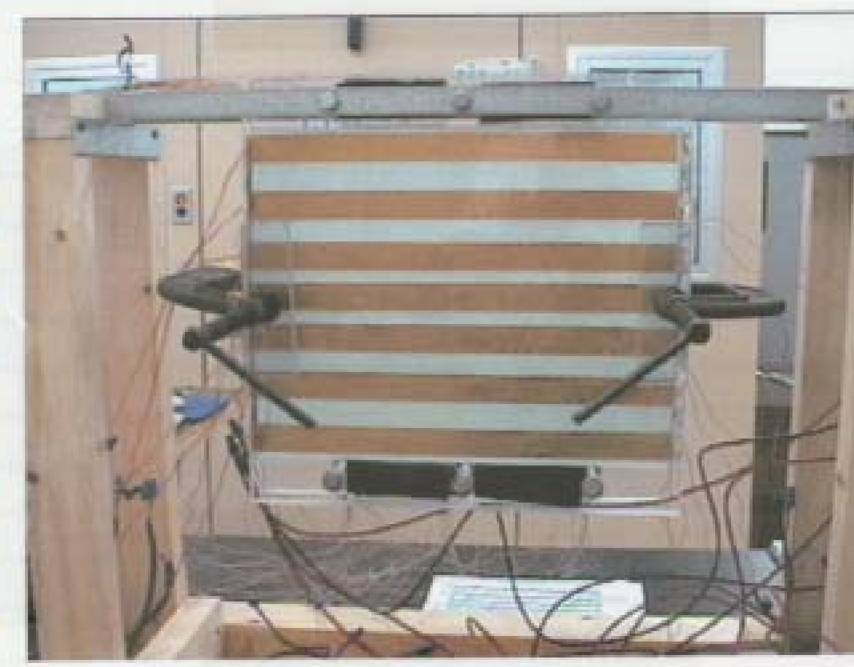
Photos of the assembly used in test 1 are the initial test are shown on the following pages.

Overview of equipment and assembly.

Front of assembly



Back of assembly showing 1"x15" strip heaters.



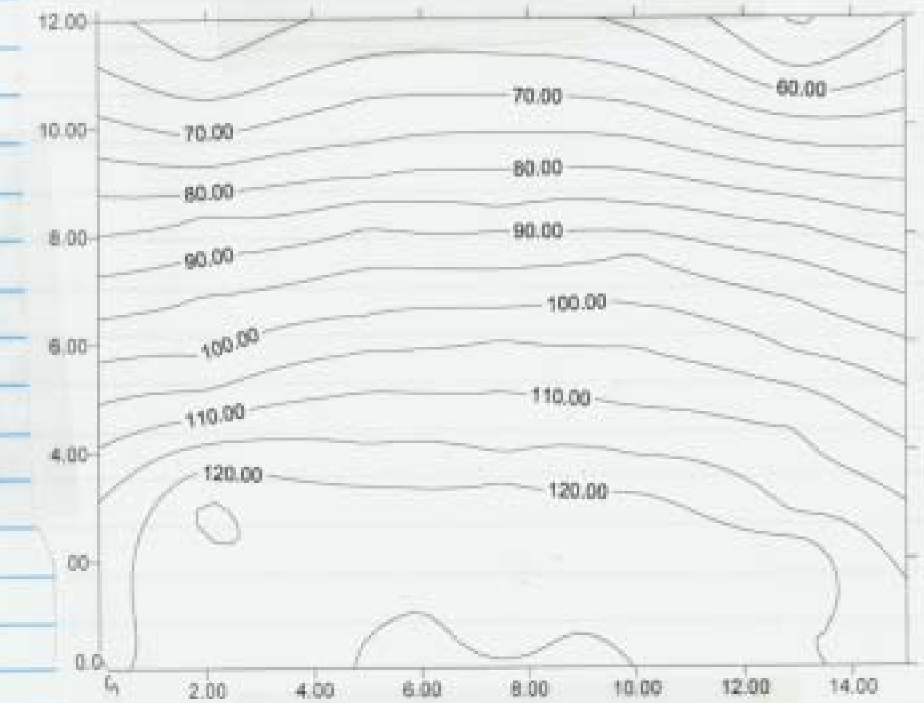
5/17/00 gp

(12) The experimental apparatus was disassembled and a new test (Test 2) was initiated. In this test steel bars were placed lengthwise along the bottom of the assembly to evenly distribute pressure at this location and avoid cracking of the glass plates.

The apparatus was assembled as before (steps 1 thru 10) using new glass plates. Also in step 10 the ~~the~~ aluminum foil insulation was replaced by 1/8" kevlar insulation.

A photo of the test 2 assembly is shown below.

Again a temperature field was established. The field at the end of the test is shown below.



The above temperature field was established using the variable transformers + power supply settings listed below.

Strip heater #	Transformer setting
7	58 Staco
6	49 "
5	39 "
4	29 "
3	15 Glas Col
2	10 "
1	3 "

Side heater #'s	Power Supply Setting
5	20V
4	15V
3	10V
2	5V
1	2.5V

Cracking of the glass plates did not occur at the bottom of the assembly as in Test 1. However, two cracks developed in the middle of the front glass plate and emanated from a point where pressure was applied using C-clamps. The cracks are shown in the photo below.

5/26/00

ing finger experiment

Subject: infiltrating finger experiment
Date: Sat, 27 May 2000 05:24:57 -0500
From: Melissa Hill <mehill@swri.edu>
Organization: CNWRA
To: "Debra Hughson (dhughson)" <dhughson@gargol.cnwra.swri.edu>,
"Ronald Green (rgreen)" <rgreen@swri.edu>,
"James Prikryl (jprikryl)" <jprikryl@swri.edu>,
"Troy Maxwell (tmaxwell)" <tmaxwell@swri.edu>

Debra, Ron, Jim and Troy

The 3rd attempt at heating the plates failed as did the earlier trials. A crack developed after 6 hrs of heating. I can across a paper by Kneafsey and Pruess. Like us they used lexan, however they used a different liquid. Pentane which has a boiling point of 36 °C was used. We have acetone on campus which has a boiling point of 56 °C. I suggest we use acetone as our liquid. If 56 °C is still too high we can resort to pentane. I am leaning more towards using acetone in lieu of pentane as I have used acetone before. Troy is ordering 5 more sets of plates which cost ~$30.00 a sheet. Ron suggested that we keep searching for some heat tempered glass while we start the acetone experiments. I like this suggestion because we will have something to report should we never succeed with the current design. My intentions at this point are to proceed ahead using acetone as the liquid. While those experiments are running we can continue modifying the current setup using water as the liquid. However, I am open to suggestions, please let me know of any that you may have.

Thanks,
Melissa

M Hill 5/26/00

M Hill 5/26/00

5/31/00

Picked up two sheets of 12" × 15" glass, 3/8" inch thick. The plates were sand-blasted at 80 in with EX-FINE grit.

T.M. 5/31/00

5/31/00 gp

A 3rd attempt - referred to here as Test 3 - was conducted during the week of May 22nd. The apparatus was assembled as before except that 12" x 1.5" x ½" strips of plexiglass were placed at the left and right edges of the assembly at both the front + back and clamped in place. This was done to apply an even pressure along the sides of the apparatus to avoid cracking of the glass plates.

The results of Test 3 were encouraging. A temperature field appropriate for the purpose of the experiment was established. Water was introduced at the top of the glass plates. As the water moved downward thru the glass plates it was observed to boil off when it reached the zone of boiling temperature. However, a crack again developed after about 6 hours of heating.

Cracking is probably caused by bowing + movement of the lexan plates as it encounters temperature above 100°C. Most bowing is observed on the back lexan sheet which is in contact with the Kapton heater.

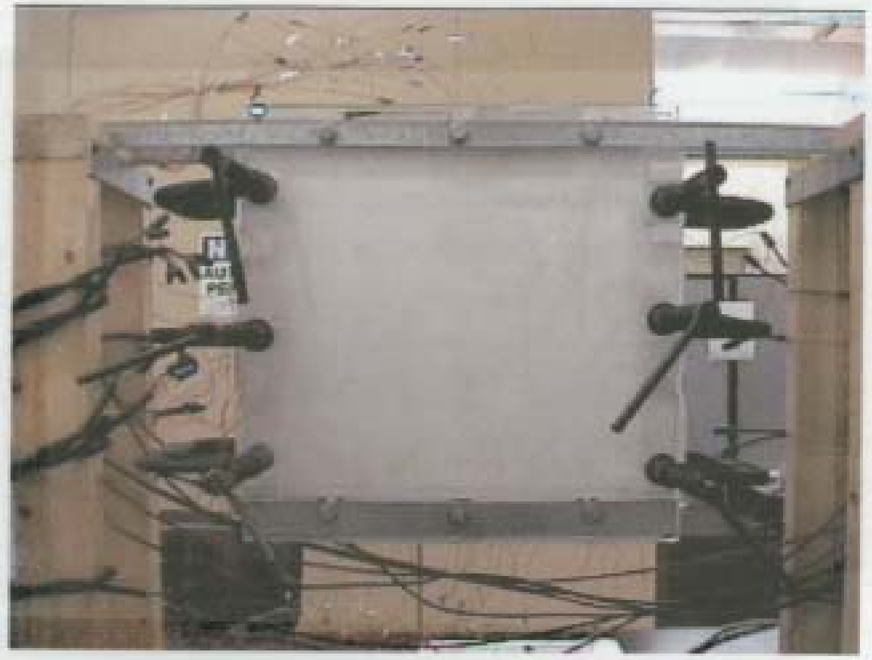
5/31/00 gp

A 4th test was assembled - referred here as Test 4 - with the following modification. A sheet of 12" x 15" x 1/32" aluminum and a sheet of 12" x 15" x 1/14" kelvar insulation was placed between the heater and back lexan sheet. This was done to reduce the temperature of the back lexan sheet.

6/1/00 gp

Photos of the modified assembled apparatus are shown below

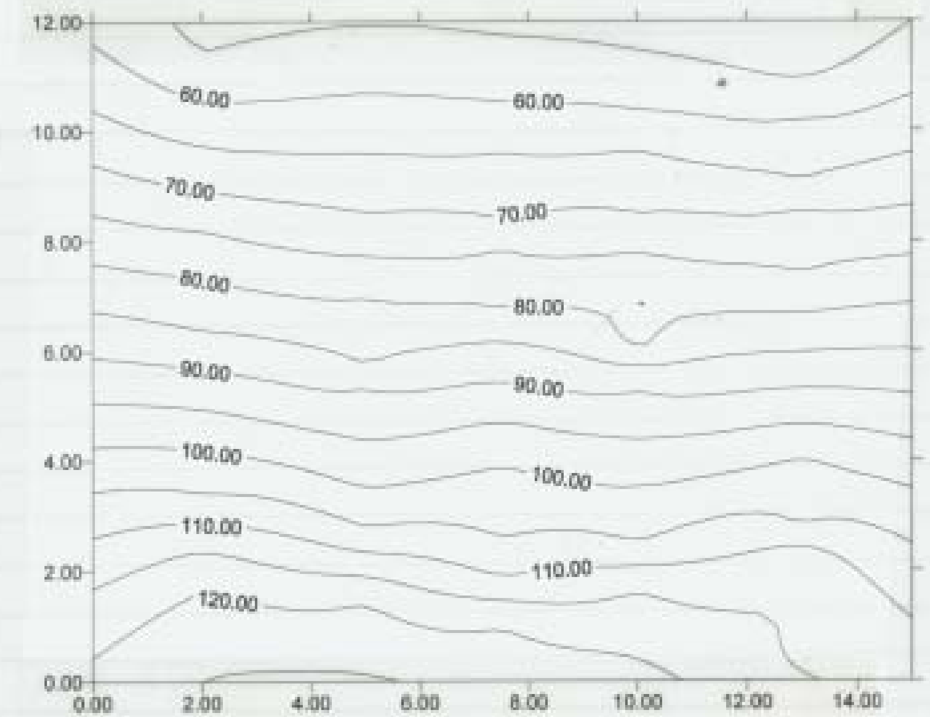
Front view



Back view

6/2/00 gp

The temperature field established in Test 4 is shown below



This temperature field was established using the variable transformer & power supply settings listed below.

Strip heater #	Transformer setting	
7	70	Staco
6	60	
5	50	
4	25	
3	5	Glas-Col
2	0	
1	0	

Side heater #	Power Supply setting
5	20V
4	15V
3	10V
2	5V
1	2.5V

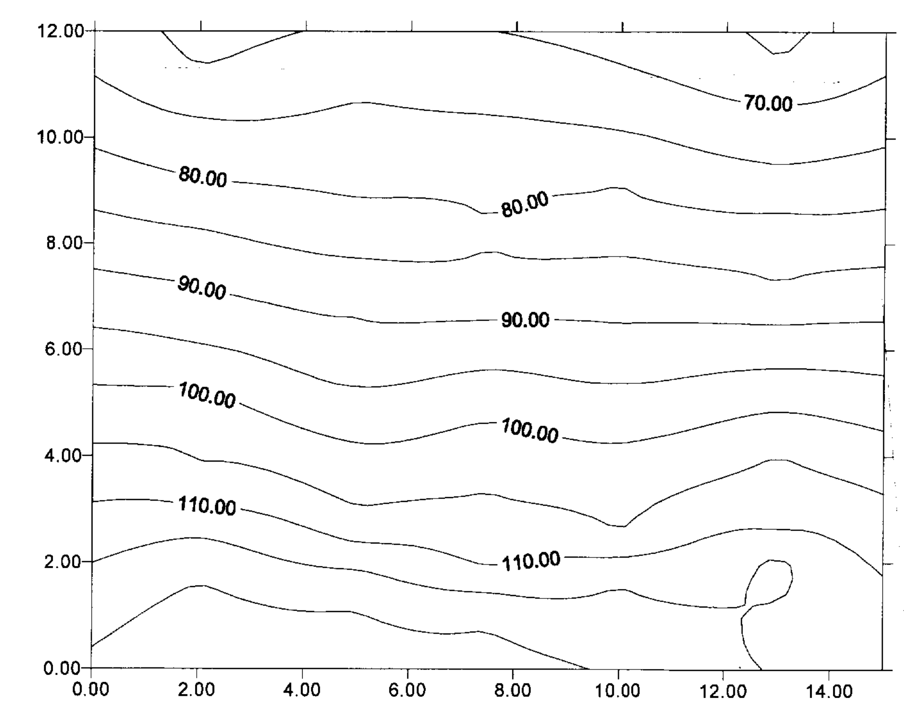
6/5/00 JP

Experiment Finger_run_1.

This is the initial attempt at recording data and video while infiltrating water at the top of the glass plate assembly.

A steady-state temperature field was established using the variable transformers & power supply settings recorded on the previous 2 pages (p 23+24).

The temperature field is shown below



Temperature readings of the thermocouples were taken every 30 seconds. These data are stored in an EXCEL file named Finger-run-1.xls

DI water was introduced at the top middle of the assembly at a rate of 0.3 ml/min using the QUIZIX pump system. The water was introduced as a point source using a syringe needle.

A video of the experiment showing the infiltration of water between the glass plates was recorded using the Canon ZR digital video camcorder. The experiment was recorded for approximately 60 min onto a digital videocassette that was labeled Finger-run-1 video. The video can be viewed using WinTV software on a PC.

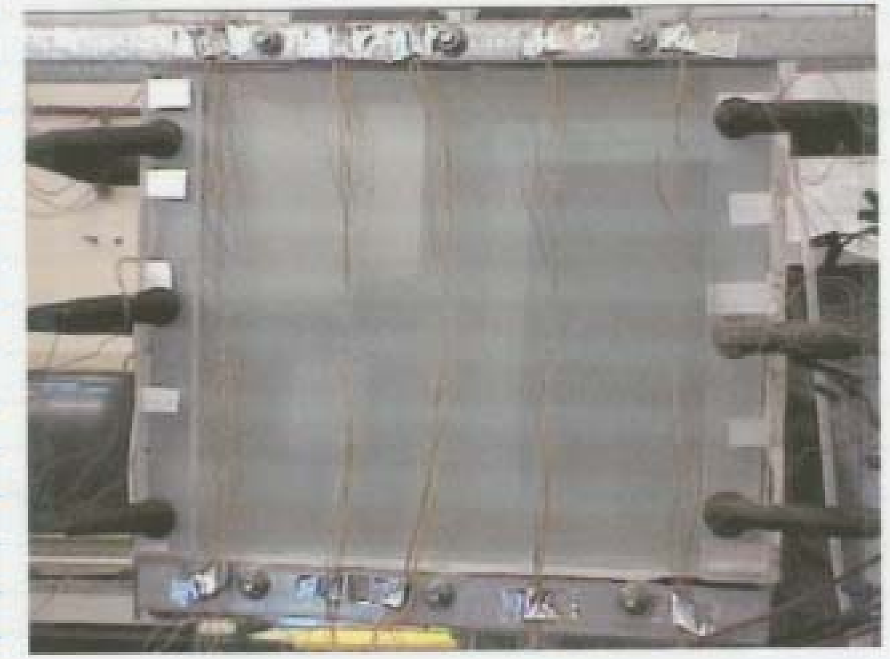
An infrared image of the temperature field was also recorded in real time. However, the infrared camera system was only able to focus on the front surface of the assembly (i.e., the front of the 1-inch thick Lexan plate). These temperatures are much lower than those between the glass plates. The infrared video was recorded onto a VHS videocassette labeled Finger-run-1. infrared.

6/6/00 JP

Results and observations

The photo below shows the assembly before water was introduced.

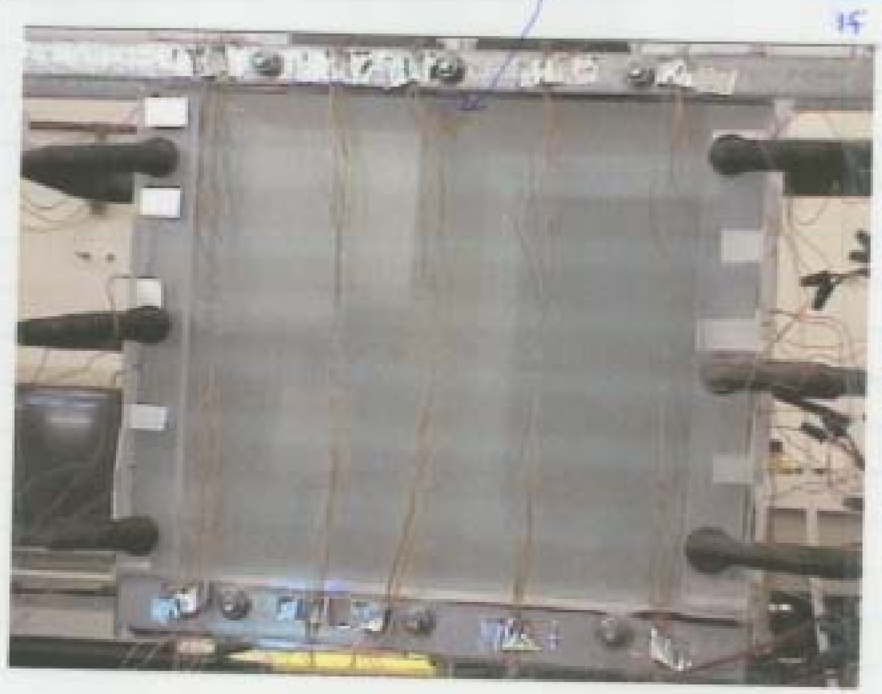
1e



Upon introduction of water a finger of water between the glass plates developed quickly (within 30 seconds). This finger is shown on the following photo.

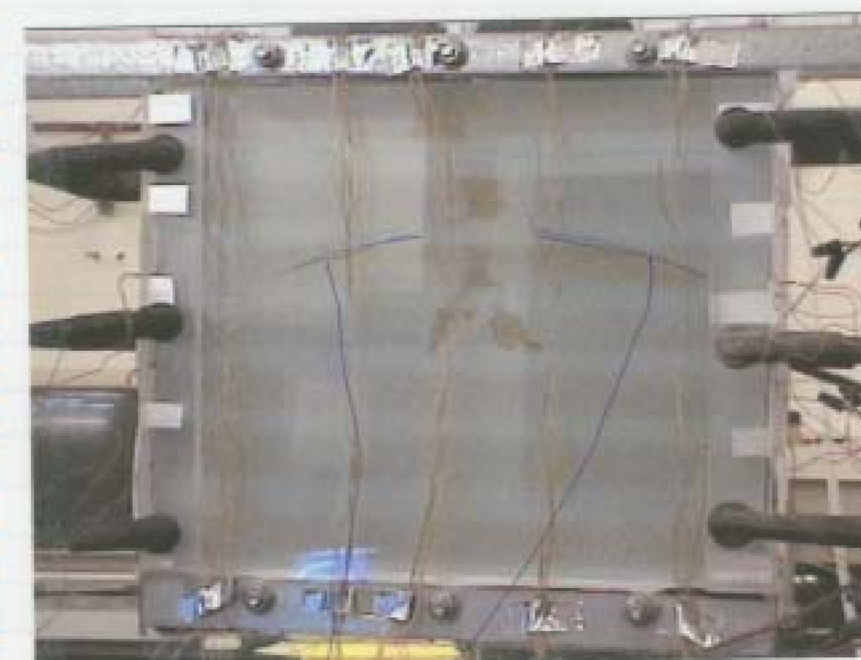
initial finger

15



This finger moved down quickly to the zone of boiling (about 1 min). Upon encountering boiling the water vaporized and a zone condensation starts to develop along the length of the assembly. This is shown in the photo below.

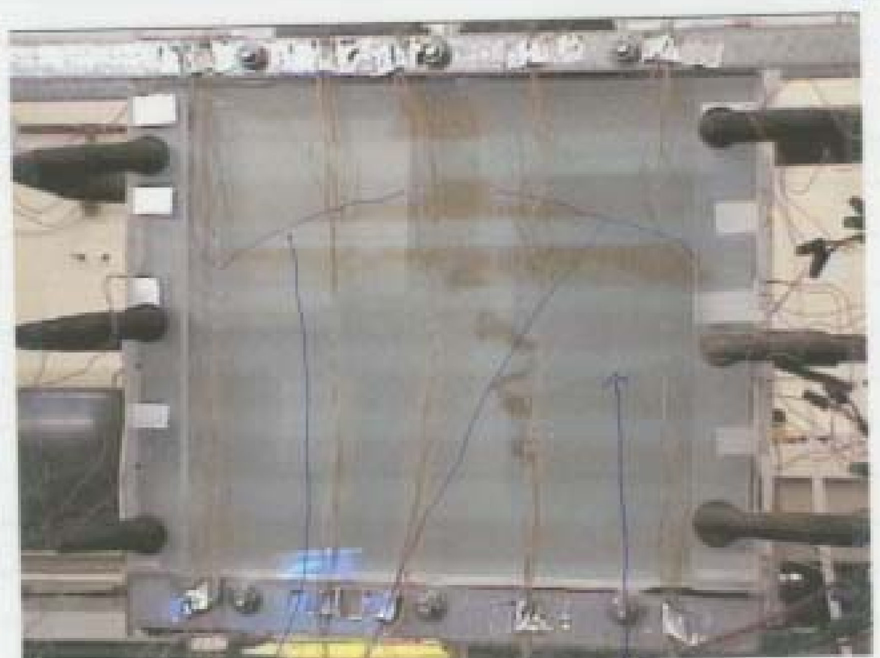
17



Zone of saturation resulting from vaporization of water.

The next photo shows penetration of the boiling isotherm by the finger of water. This photo was taken about 2 min + 30 secs after the initial formation of the water finger. The finger moves downward, vaporizes (recedes) and then advances again. The zone of saturation above the boiling isotherm grows as water vapor(?) condenses. A crack develops in the glass at this time.

1h

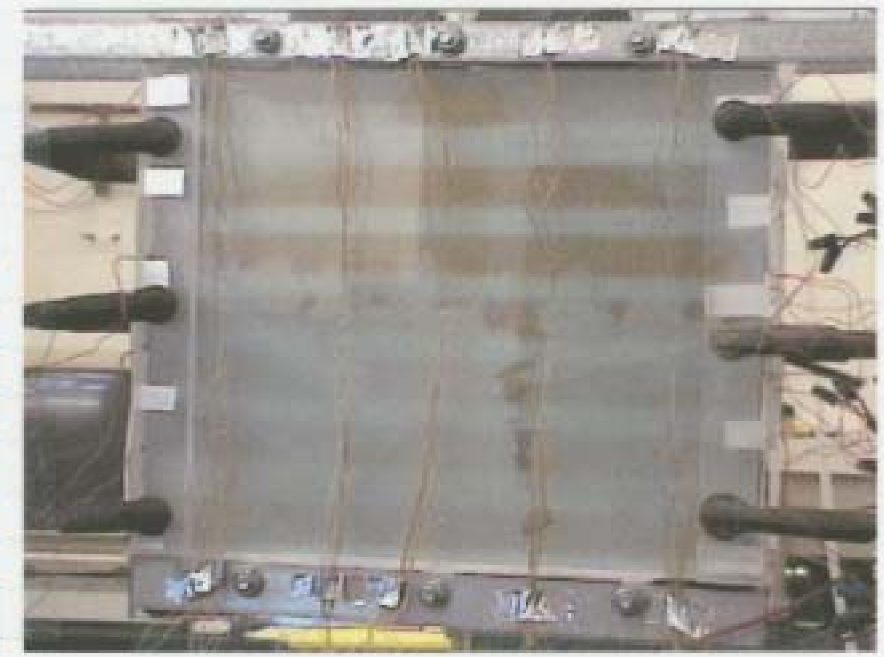


Zone of saturation

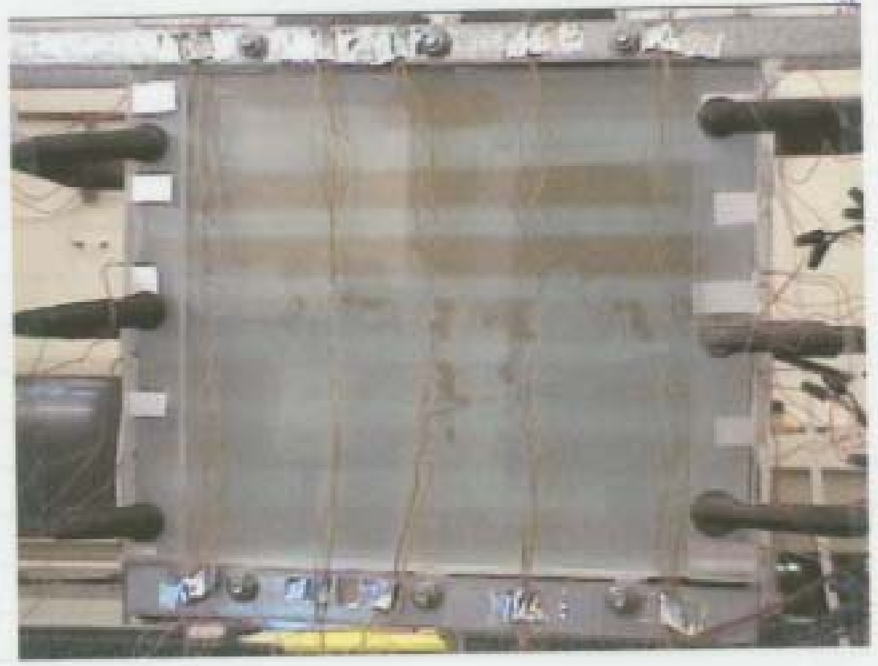
Crack in glass

The next photo was taken about 10 mins after initial formation of the finger. The finger continues to penetrate the isotherm of boiling and the zone of saturation continues to grow.

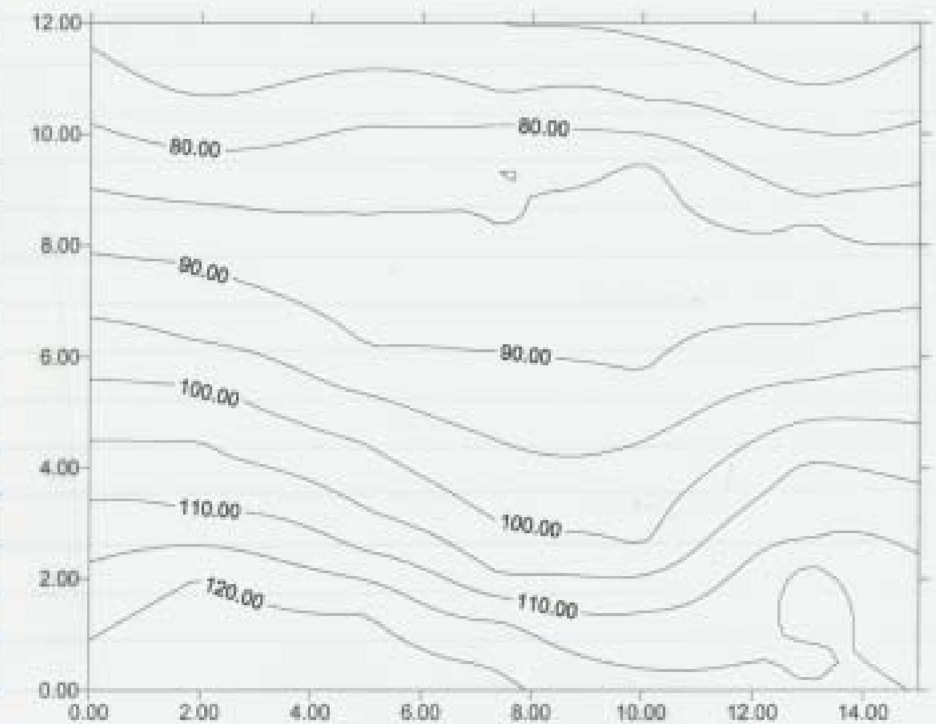
1i



The next photo was taken at about 13 min after initial formation of finger. The first finger recedes and a new finger develops to the right.



The graph below shows perturbation of the temperature field caused by the fingers of water and the formation of the saturated zone.



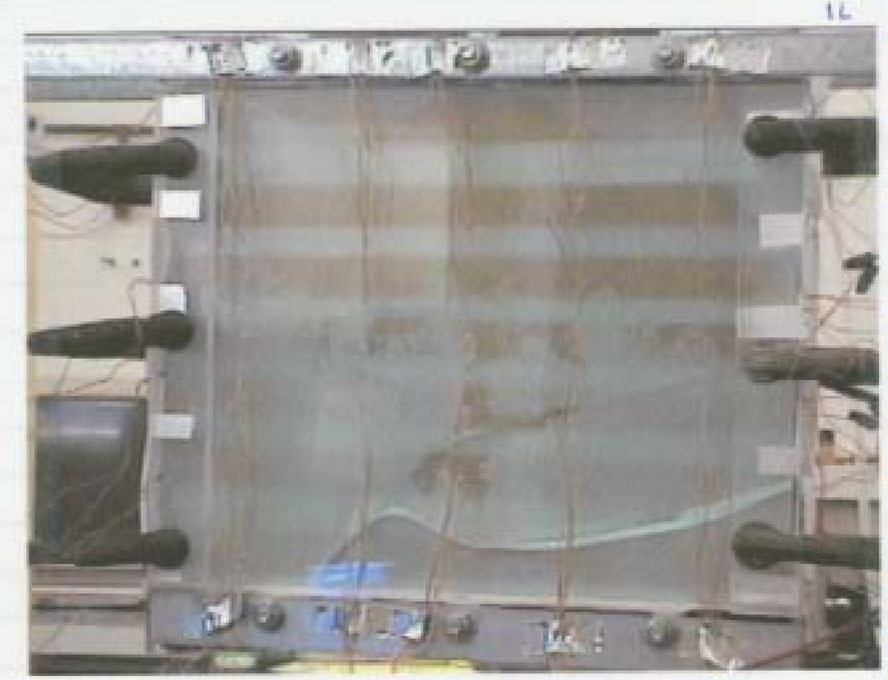
A second crack started to develop at the base of the second finger. This photo was taken at 17 min from the formation of the initial finger.

1k

second crack

This photo taken at about 30 min into test and shows fully developed second crack. Water started to follow first crack.

1k



Graph showing temperature field at about
30 min into test.

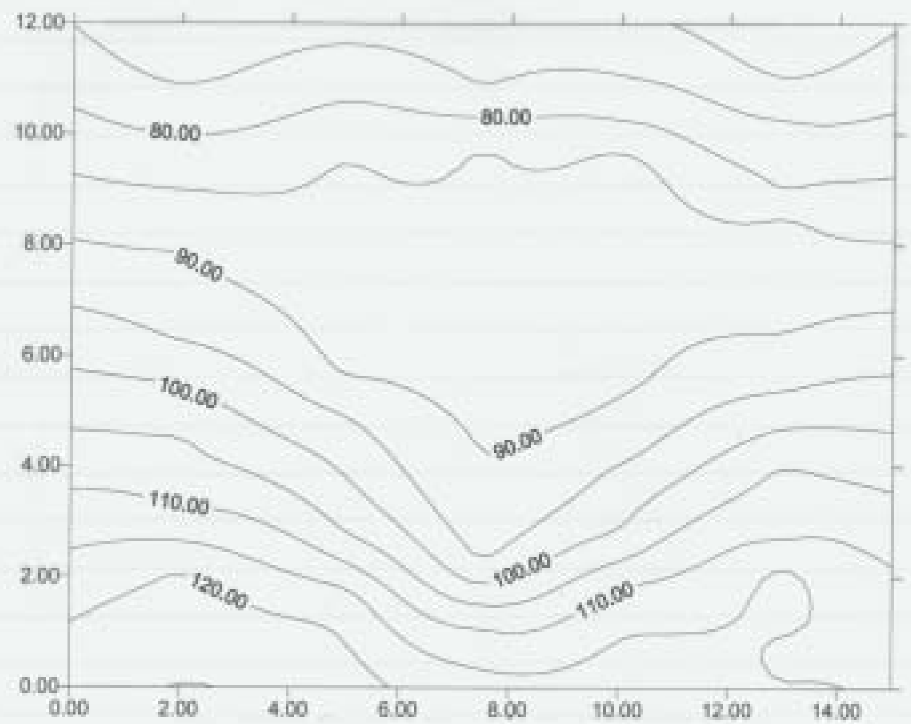


Photo of test assembly at about 42
min from formation of initial finger.

1m

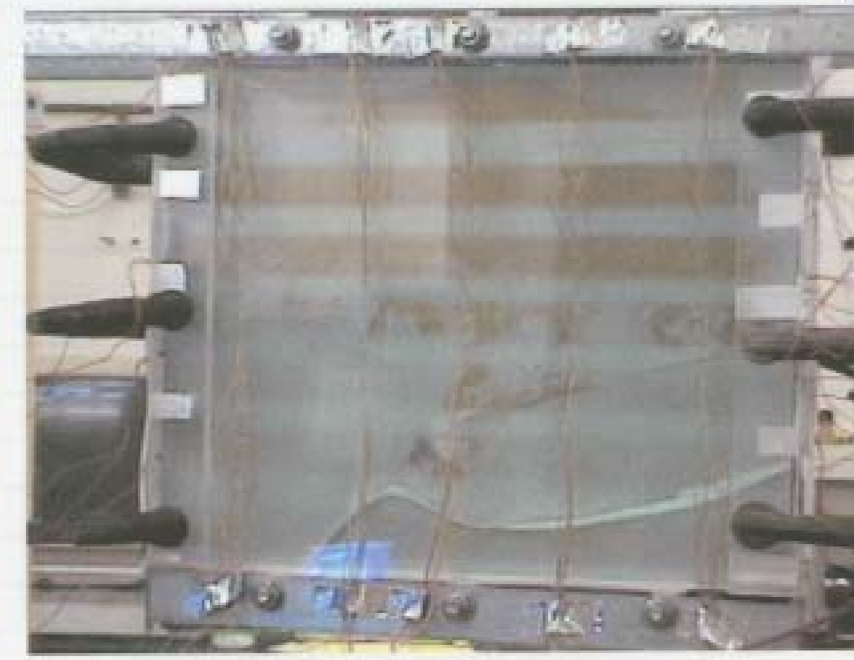
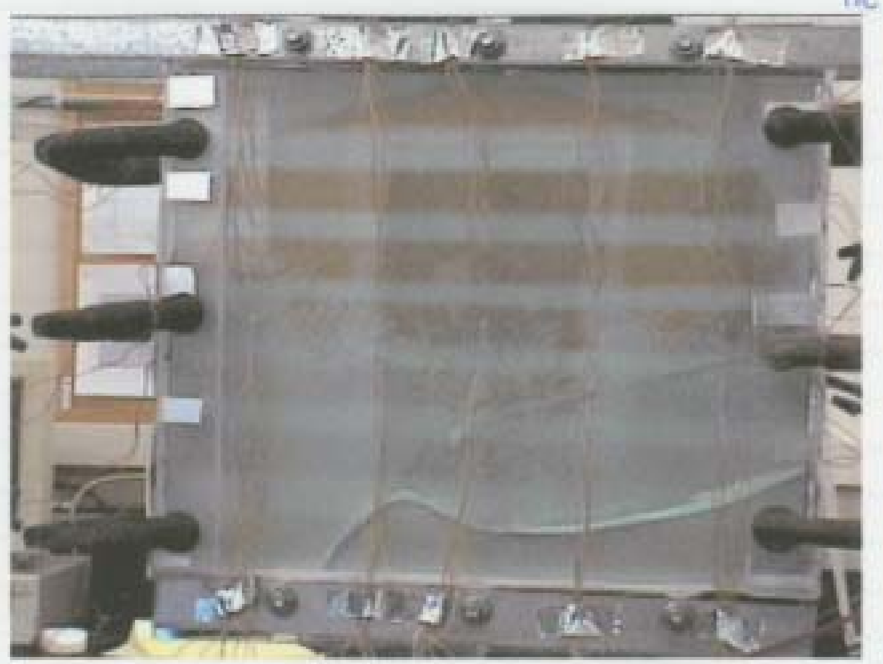
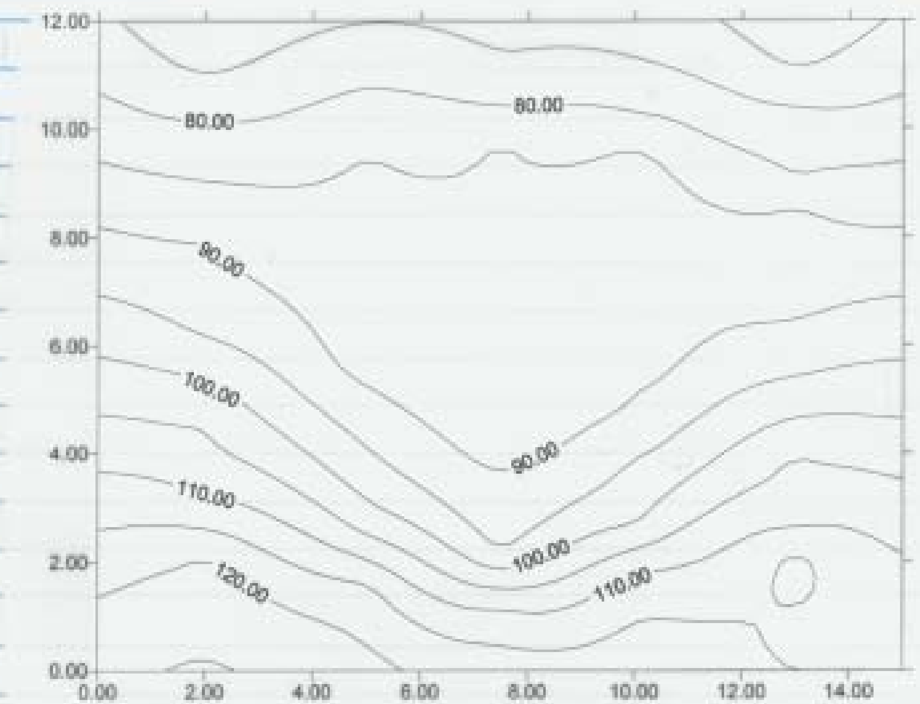


Photo of test assembly at conclusion of test (60 min)

1a



Graph of Temperature field at conclusion of test (60 min)



6/8/00 JJ

Experiment Finger-run-2.

Second experiment at collecting data and video while infiltrating water between the two glass plates.

The apparatus was assembled as before with the following modifications.

① Annealed glass plates (12"x15"x 3/8") were used. These plates were procured from Specialty Glass (Houston, TX). Annealing strengthens the glass by lowering its thermal expansion.

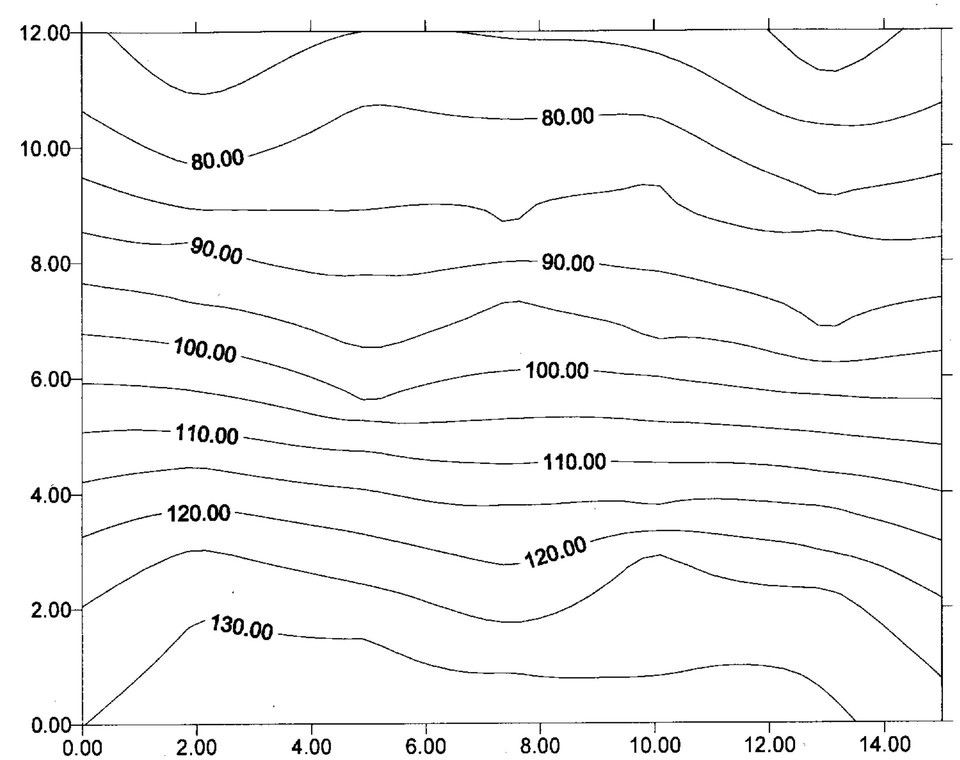
② 3 ft lb of pressure were applied to the steel bolts at the top + bottom of the assembly instead of 5 ft lb as in previous experiments.

A steady state temperature field was established using the following variable transformer + power supply settings for the strip heaters.

Strip heater #	Transformer setting
7	60
6	50
5	40
4	29
3	5
2	0
1	0

Side heater #	Power supply setting
5	20V
4	15V
3	10V
2	2.5V
1	1V

A plot of the initial temperature field is shown below.



Temperature readings of the Thermocouples were taken every 30 seconds. These data are stored in an MS Excel file named Finger_run_2.xls

D.I. water was introduced at the top of the assembly at a rate of 0.3 ml/min using the Quizix pump system. The water was introduced by a syringe needle placed between the glass plates.

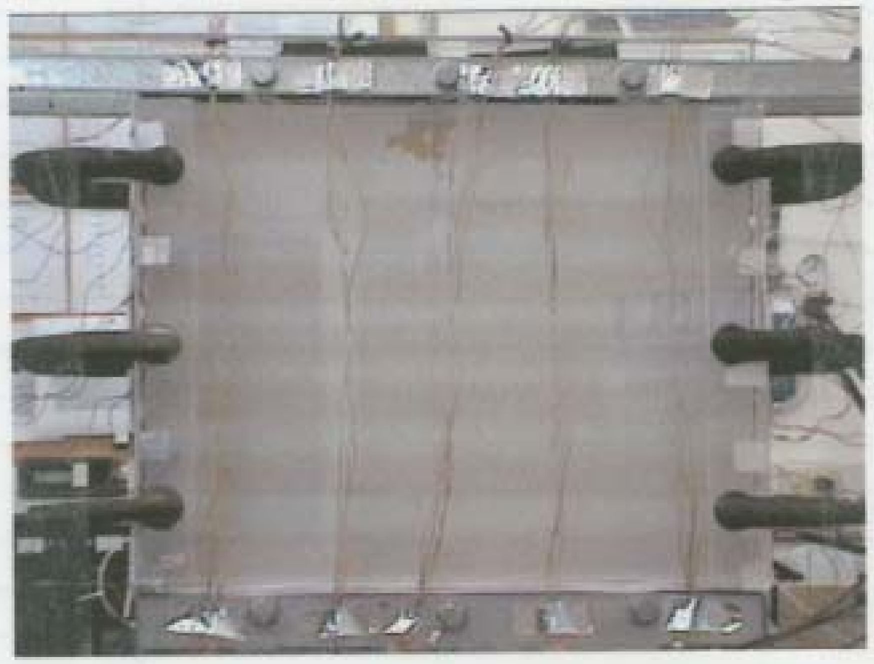
A video of the experiment was recorded using the Canon ZR digital video camcorder. The experiment was recorded for 91 minutes using two tapes. The first tape labeled Finger_run_2a_video contains the first 60 mins of the experiment. The second tape contains 31 min of the experiment and is labeled Finger_run_2b_video. A 4 min gap occurs between tape 1 and tape 2.

Temperature scans were started about 20 secs after the video started.

Heaters were cut off at 74 min into the test (10 min on second tape). However, water was allowed to continue to infiltrate. The test was run for 112 min.

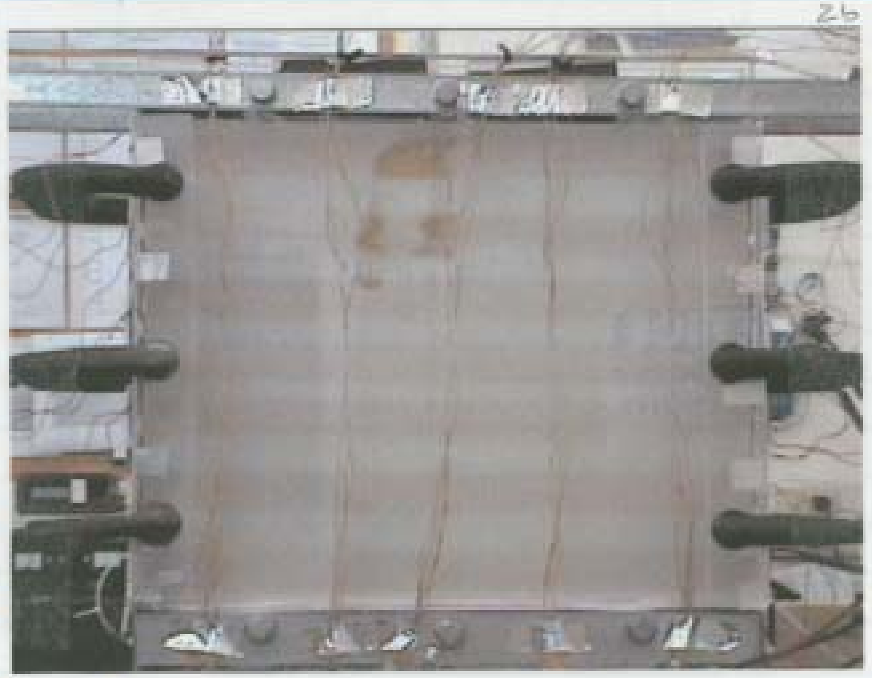
6/7/00 JP
Results & observations

2a



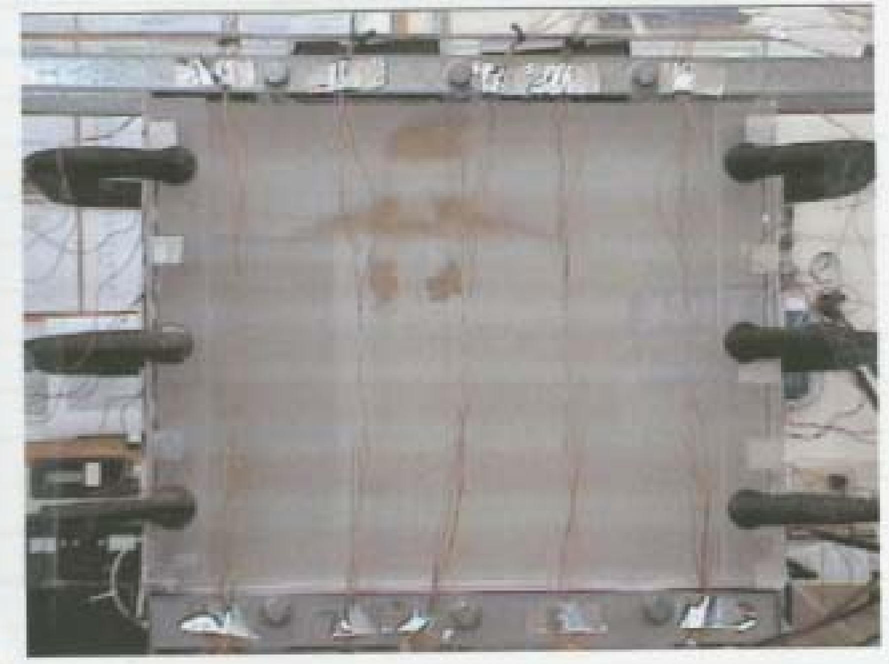
Initial finger forms at about 25 secs into test.

2b



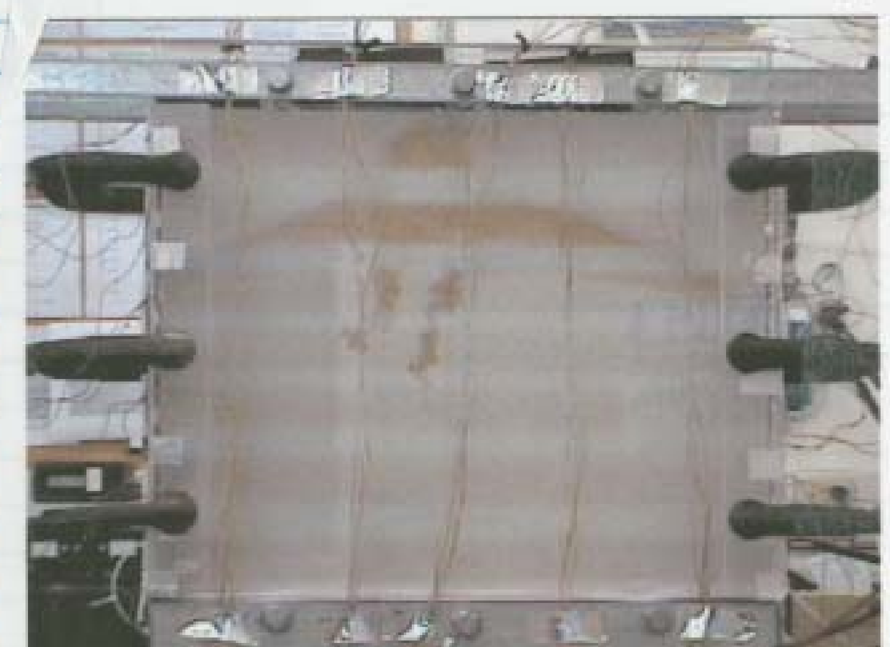
45 secs into test
Two fingers are present

2c



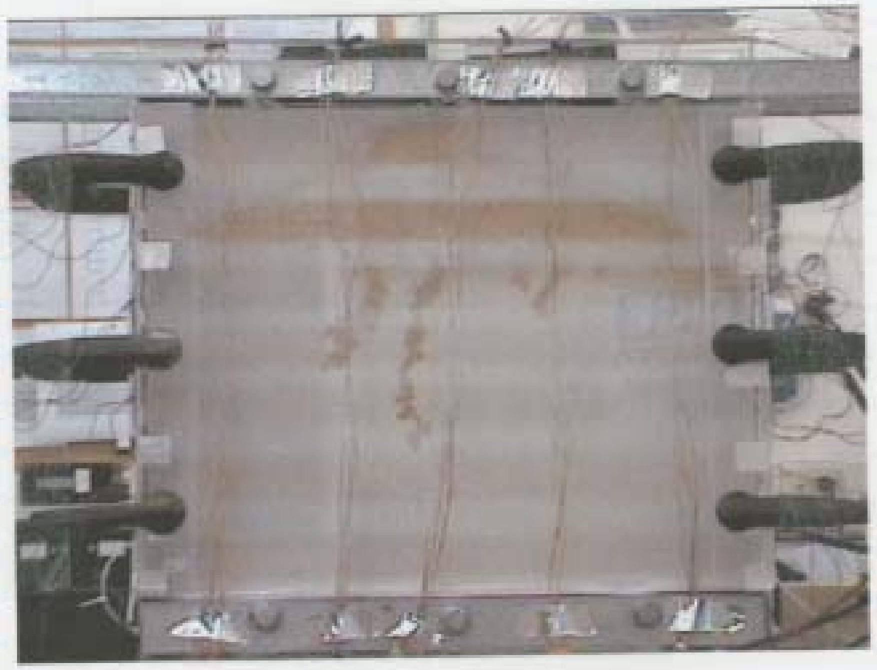
1:00 min into test
Fingers encounter boiling, vaporize, zone of saturations forms

2d

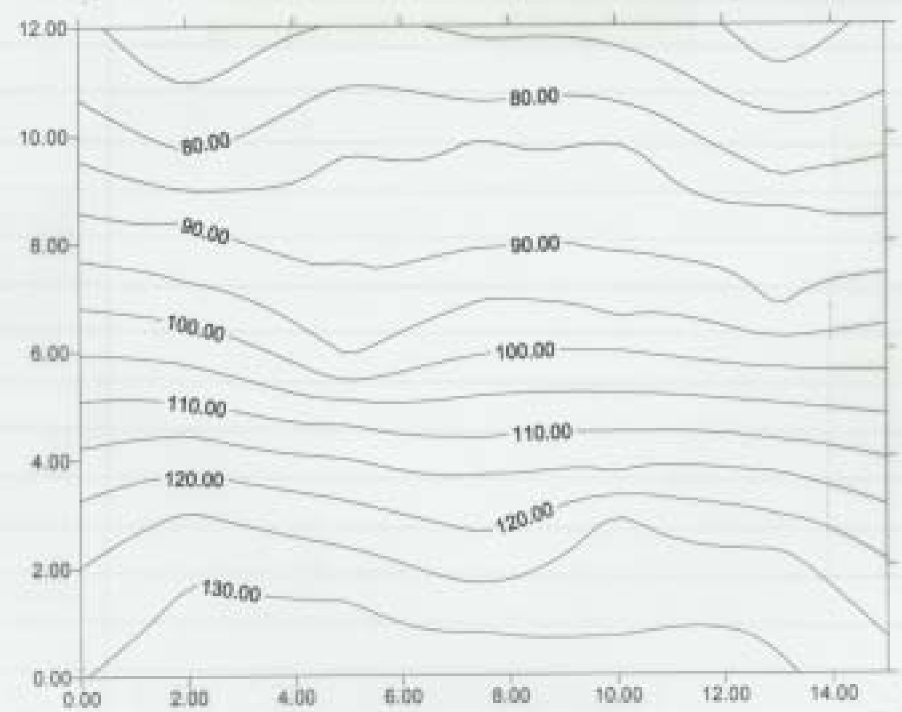


2:00 min into Test
Fingers continue to advance downward, zone of saturation grows.

2e



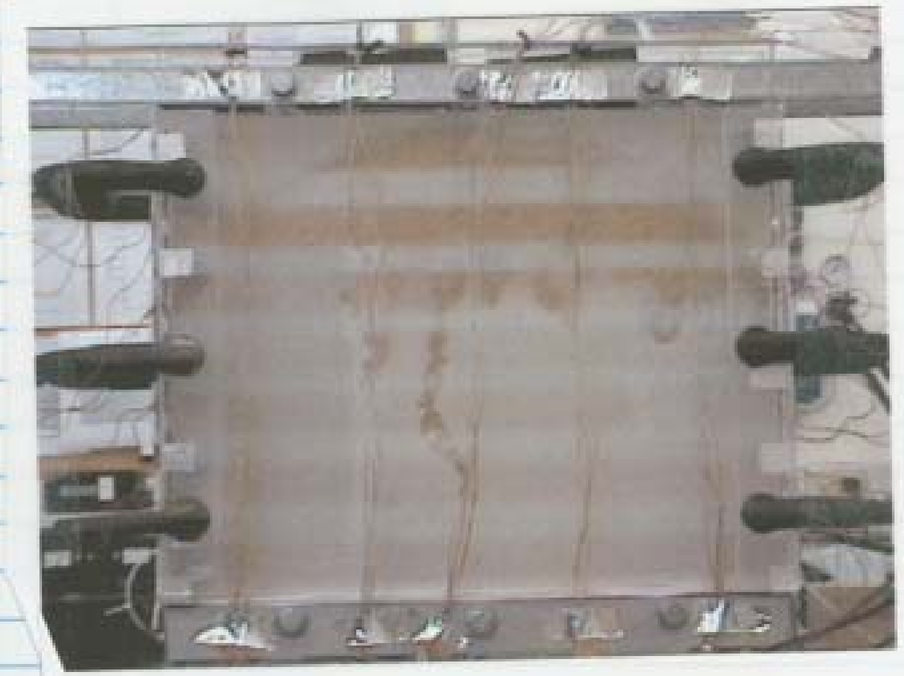
5 min into test
Middle finger
continues advance.
Finger to left
stalls



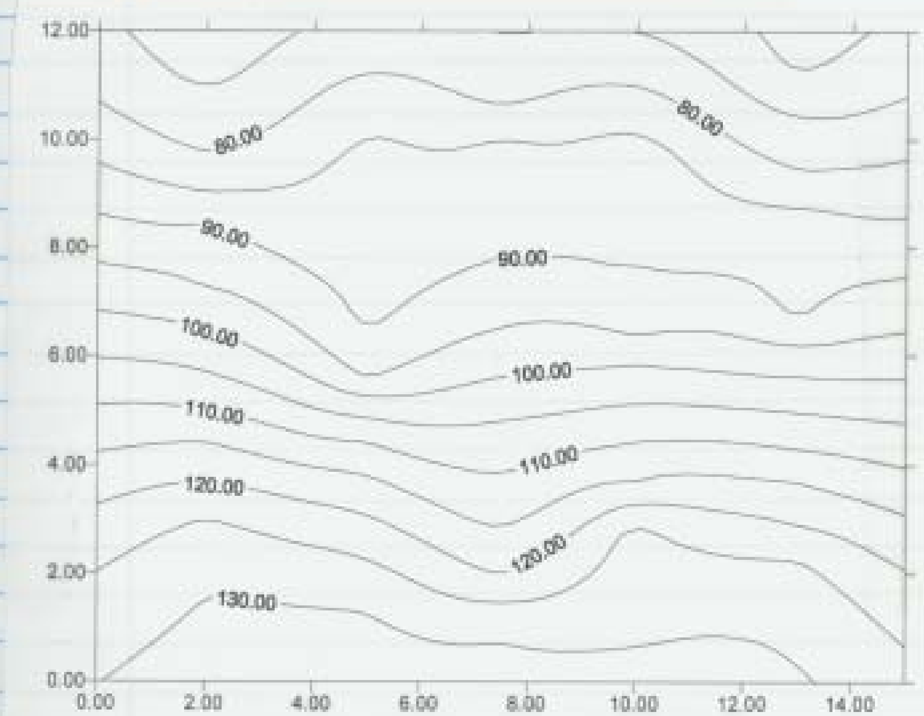
Graph of Temp
field at 500
min

2f

10 min into test



Middle finger
continues advance
Zone of saturation
grows.

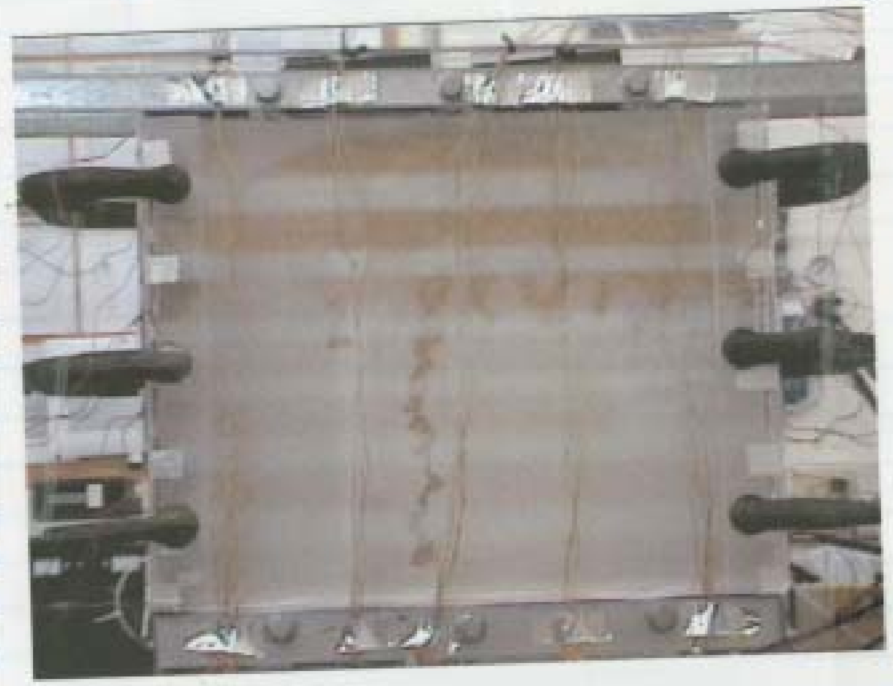


Plot of Temp
field at 10
min. In
zone of saturation
temperature
rise slightly
Boiling isotherm
is depressed
where fingers
have formed.

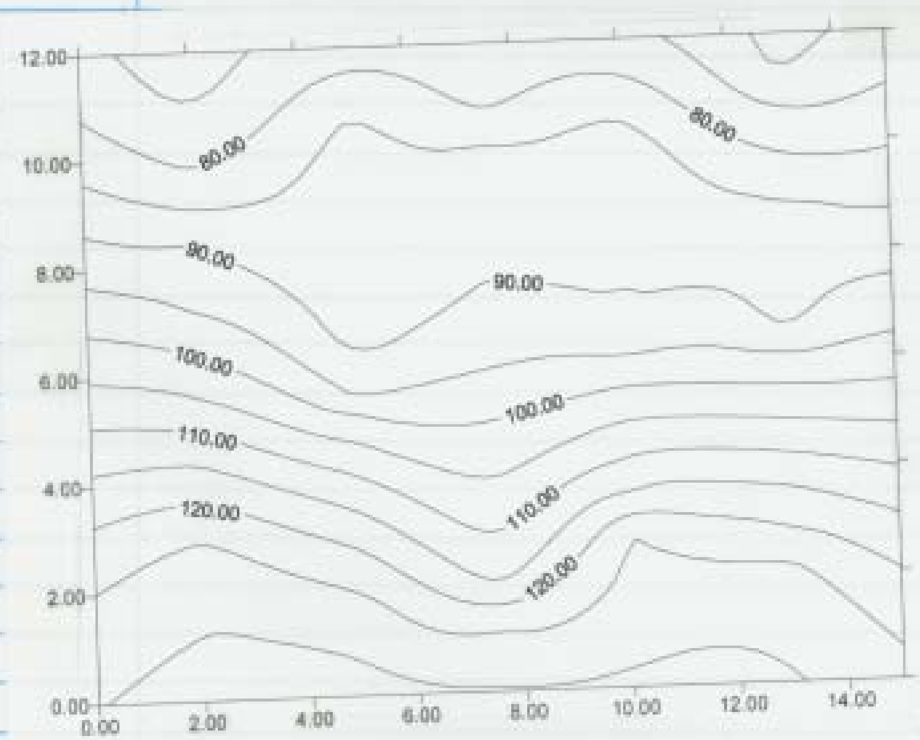
25

20 min into test

Middle fingers continue to advance.



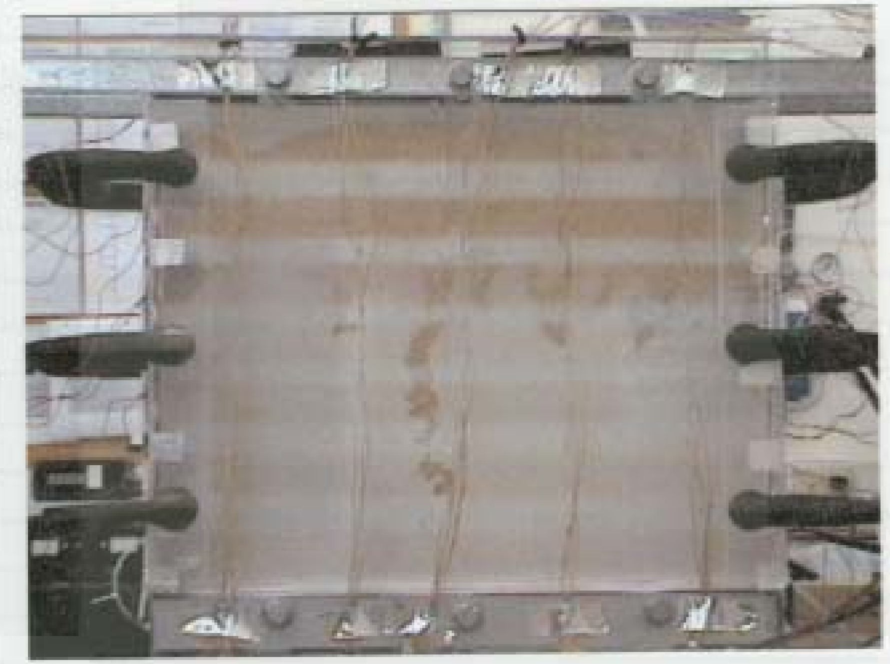
Plot of temp field at 20 min.



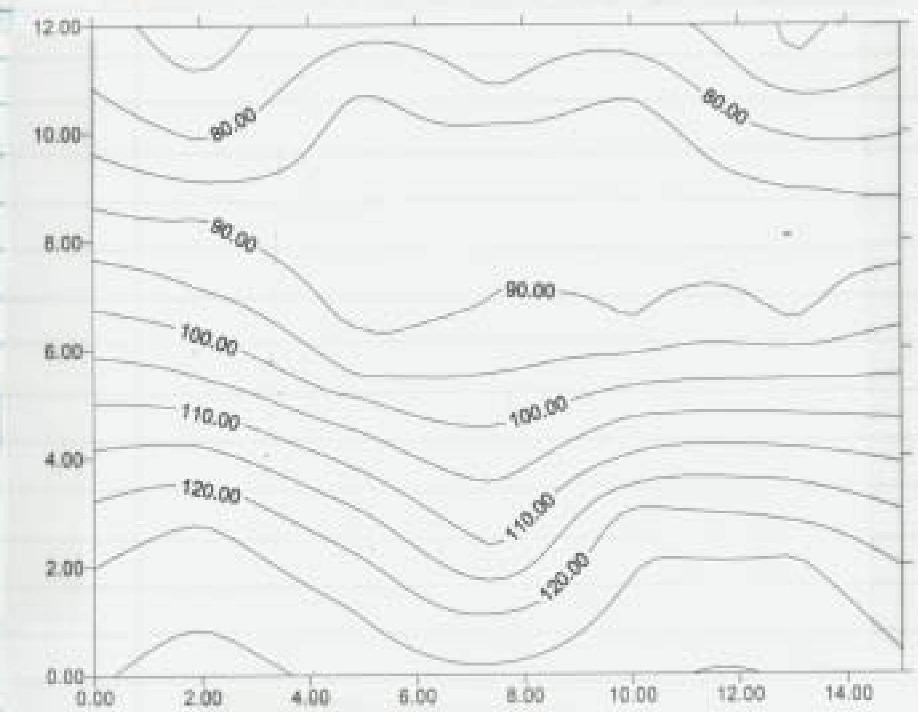
26

30 min into test

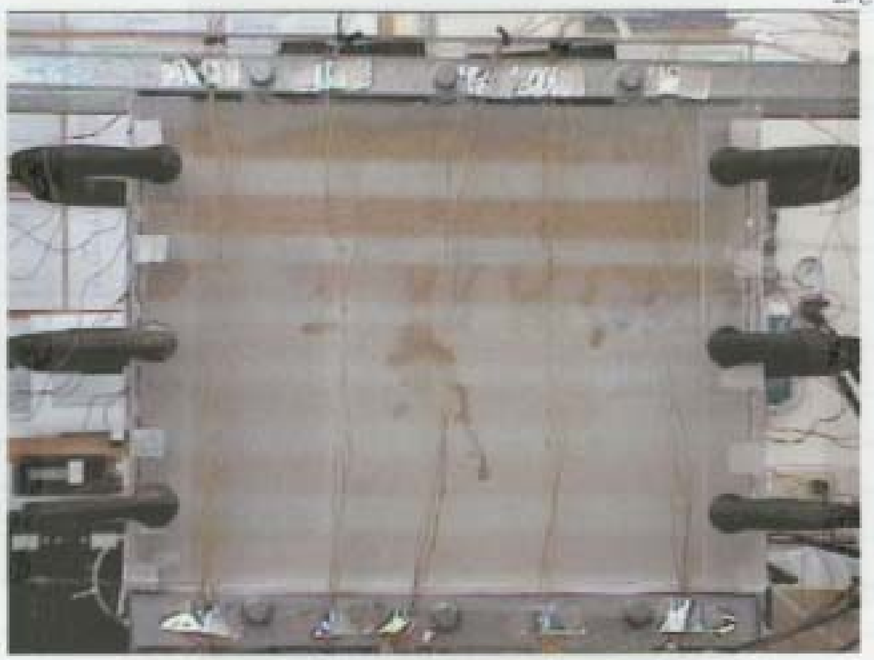
Zone of saturation grows. Middle finger recedes, advances, recedes...



Plot of temp field at 30 min.

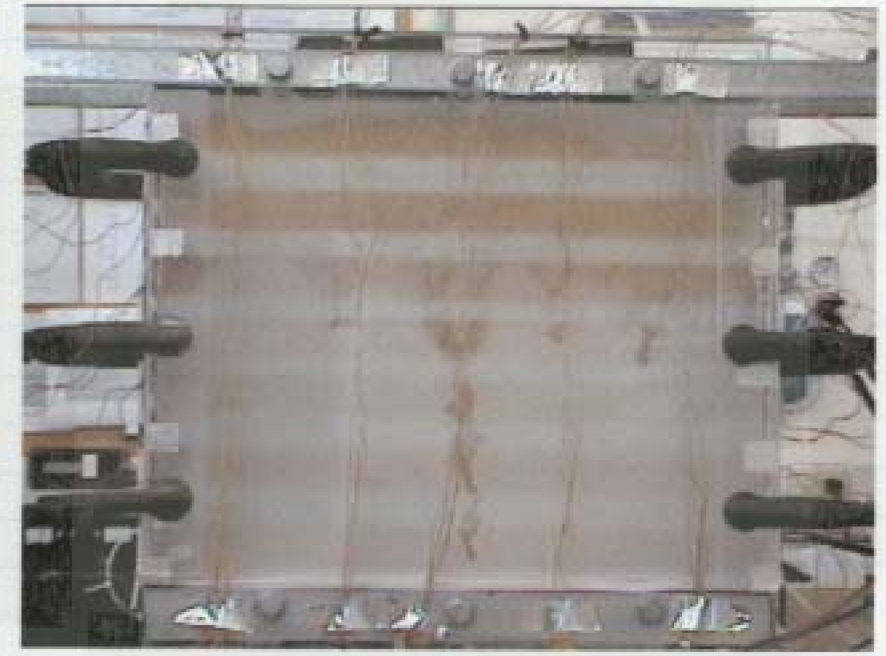


2i



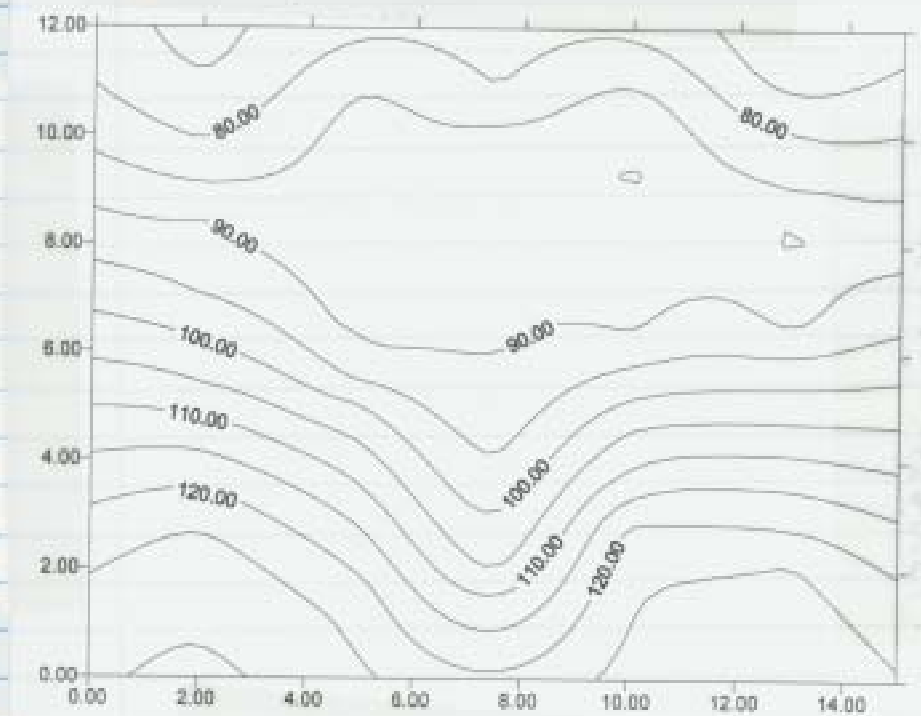
33 min into test. Middle finger diverts to the right.

2j



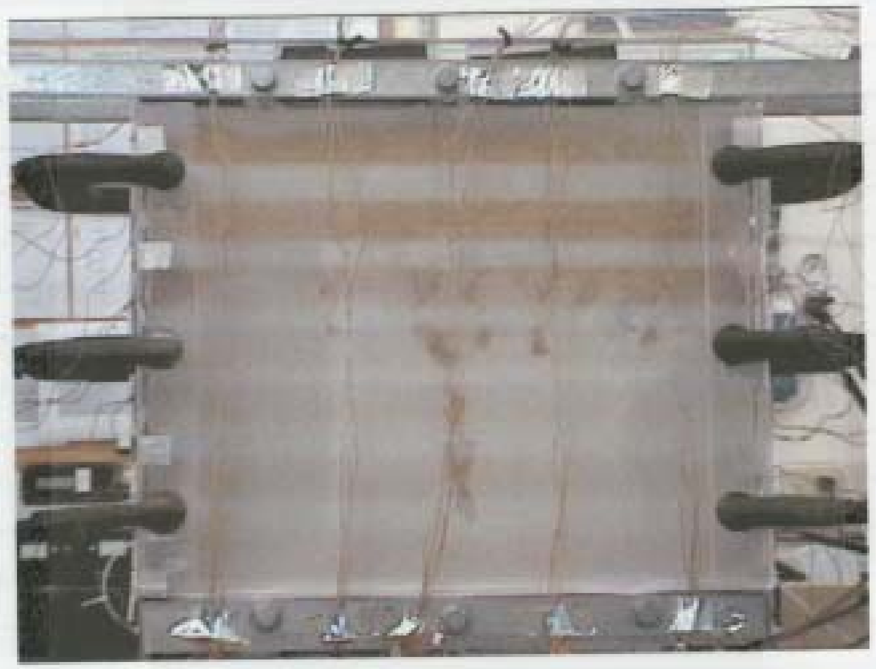
40 min into test

Middle finger continues to recede, advance, recede, etc...

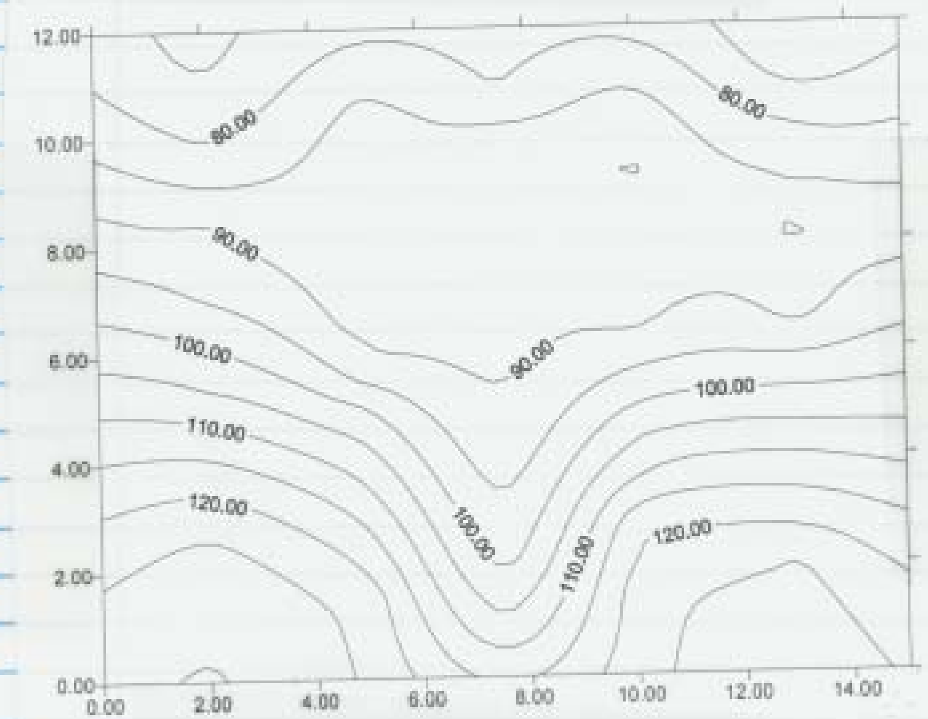


Plot of temp field at 40 min

2K

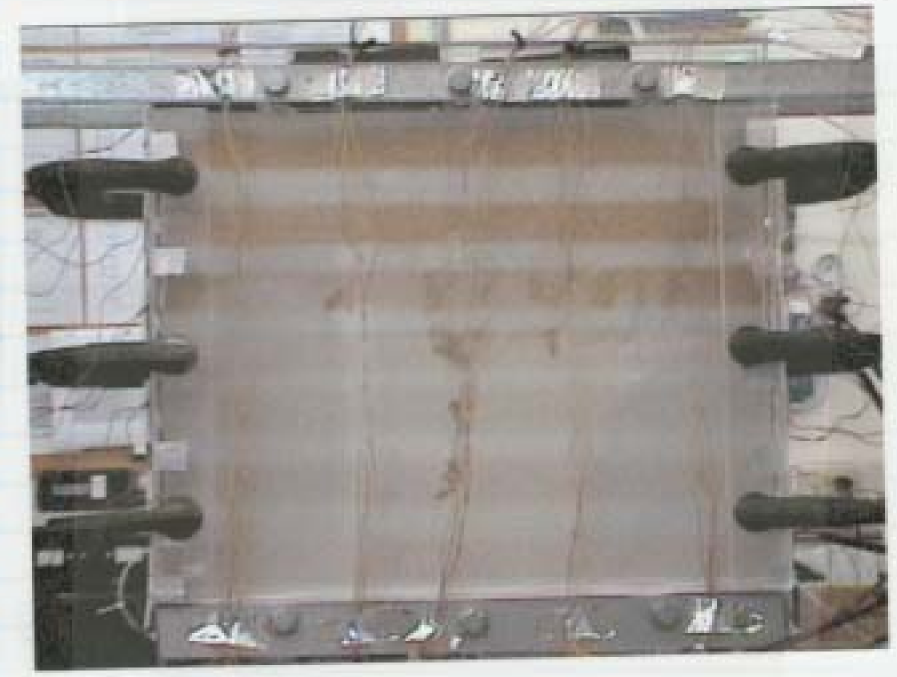


50 min into test

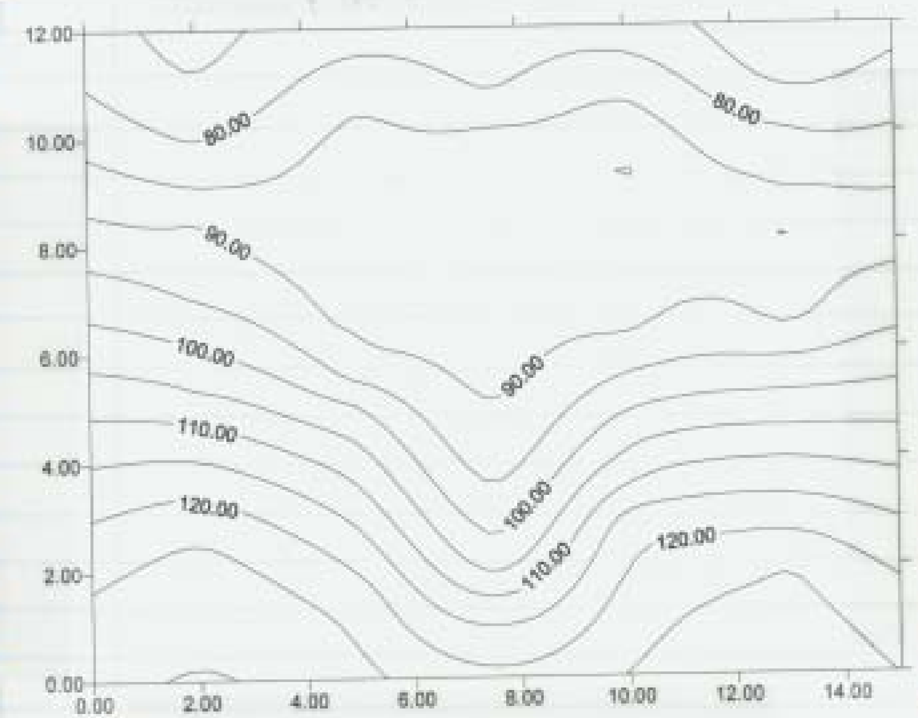


Plot of temp field at 50 min

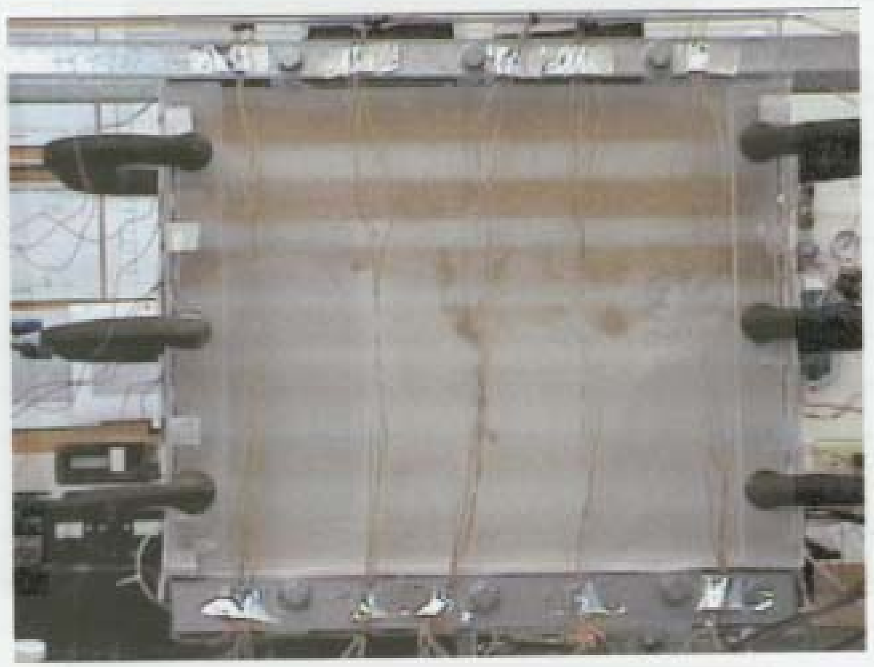
2L



60 min into test

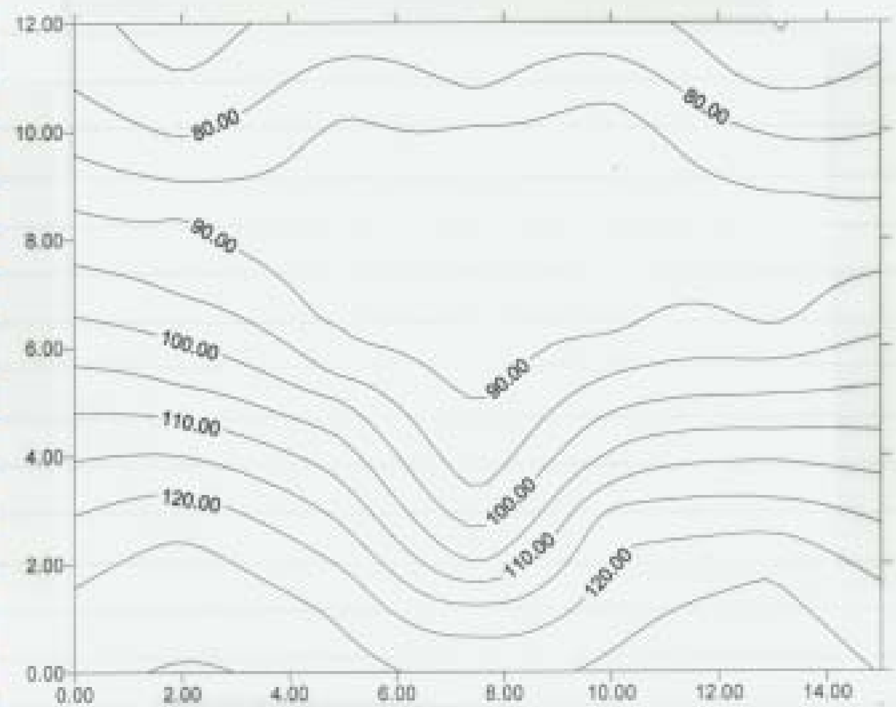


Plot of temp field at 60 min

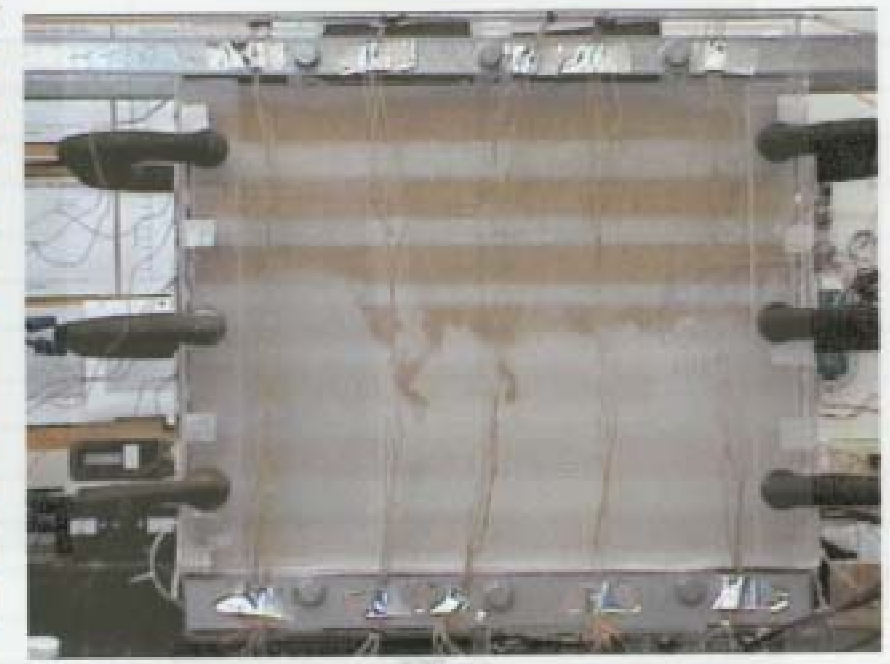


70 min into test.

System appears steady



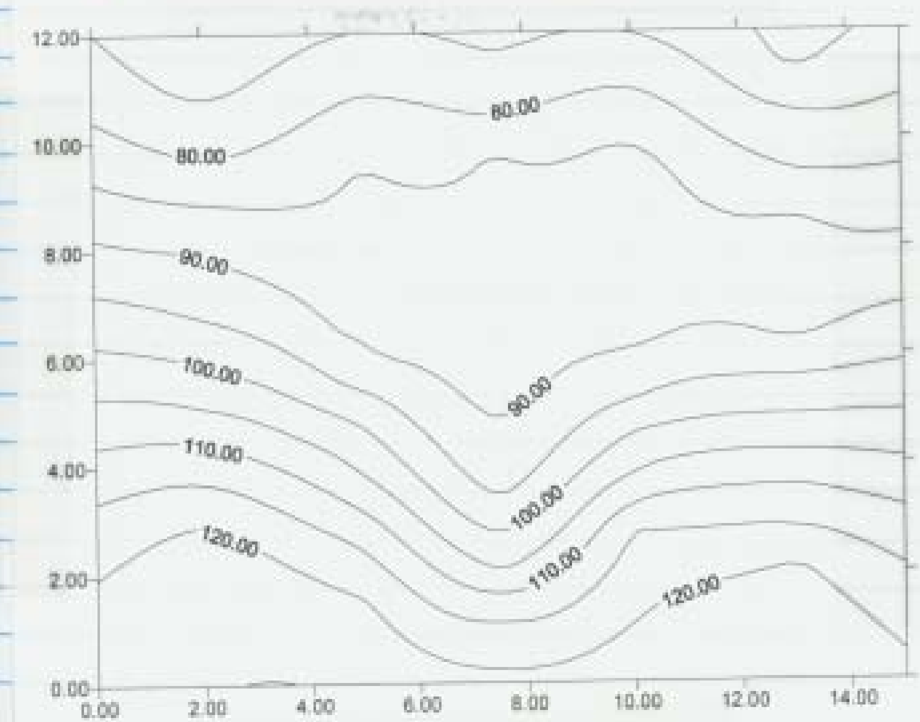
Plot of temp field at 70 min



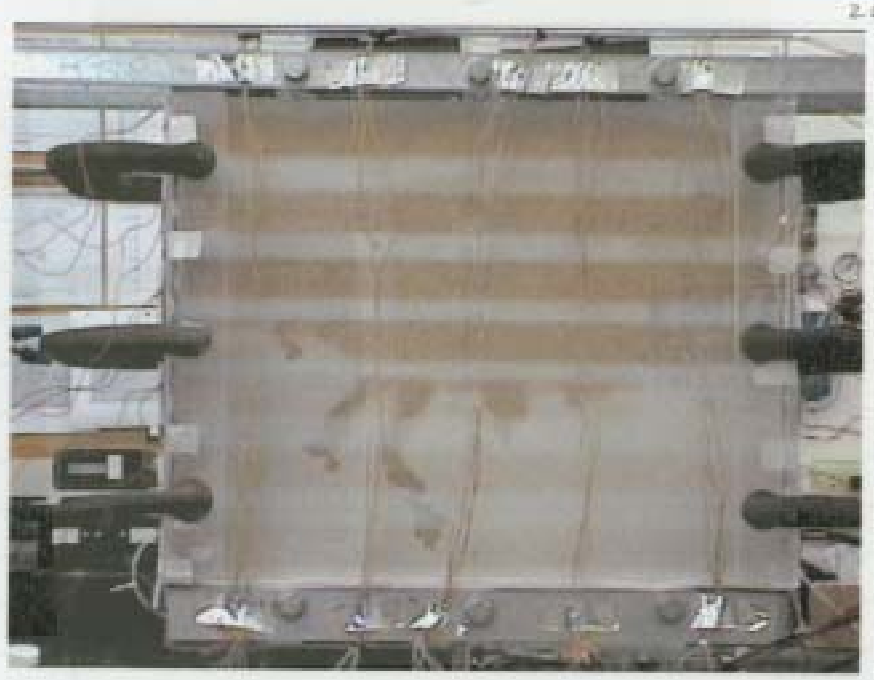
80 min into test.

Heat to the assembly was cut off at 74 min into test.

Zone of saturation grows.

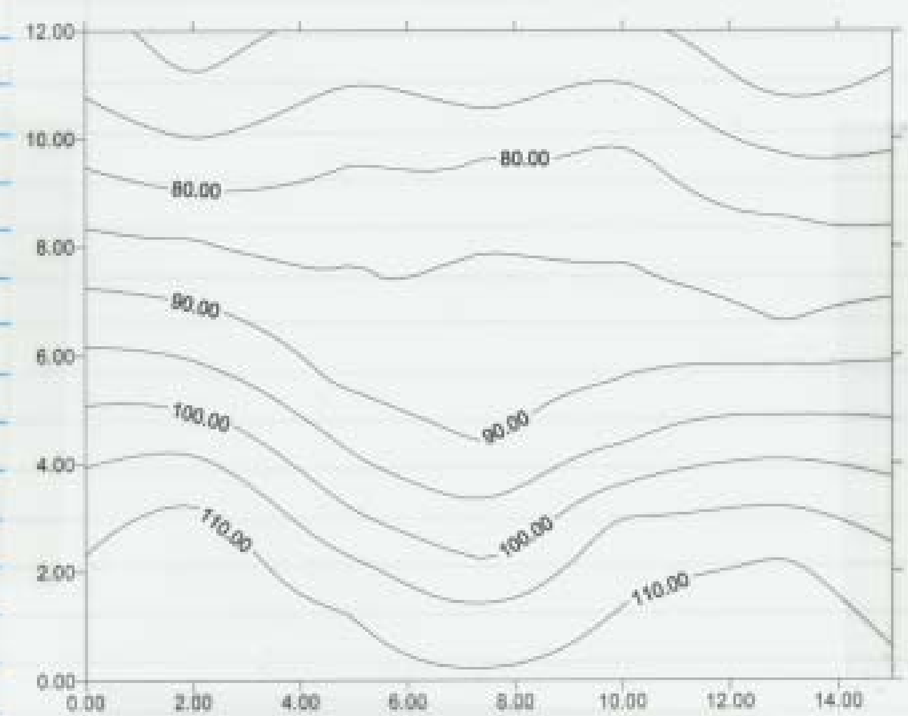


Plot of temp field at 80 min

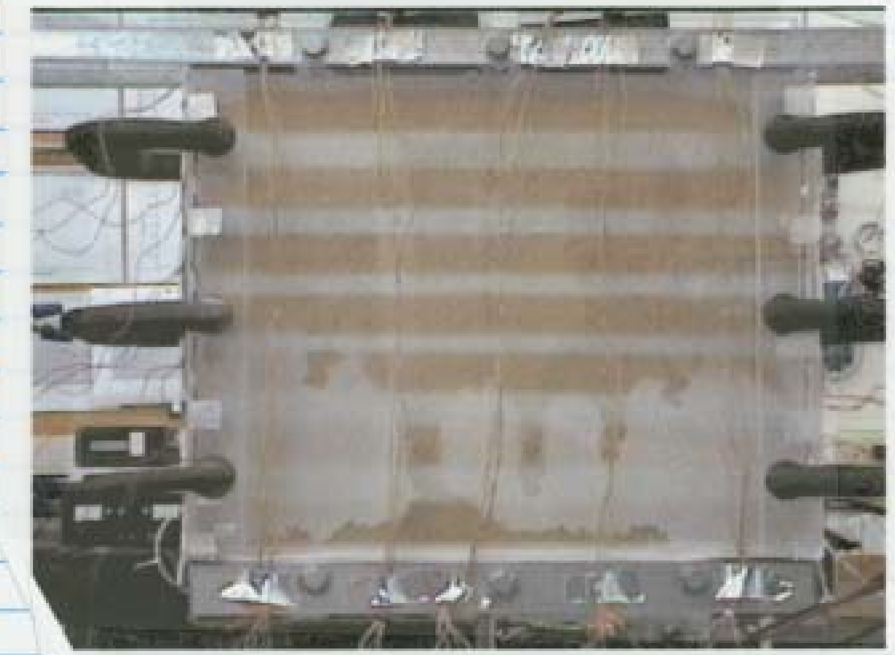


90 min into test.

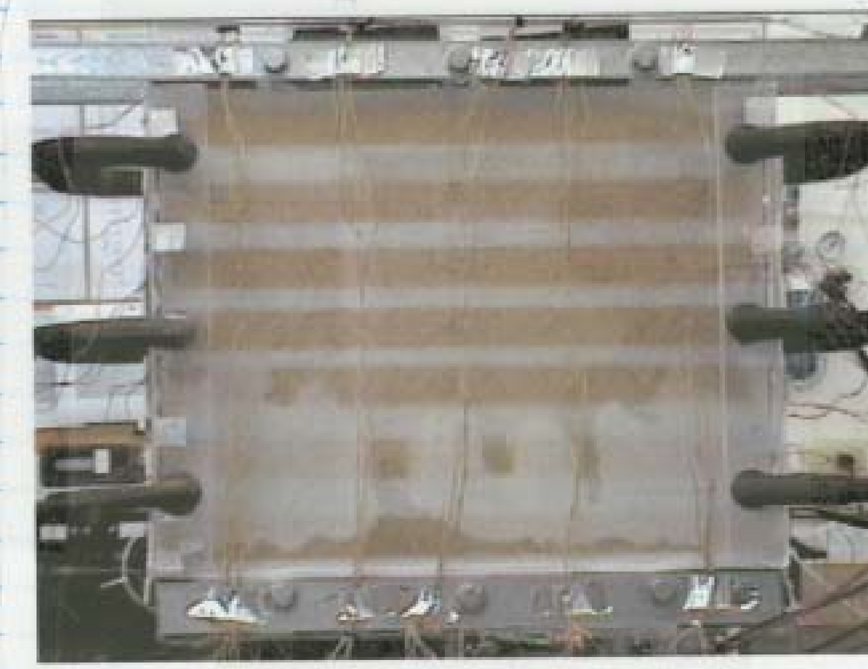
Zone of saturation continues to collapse.



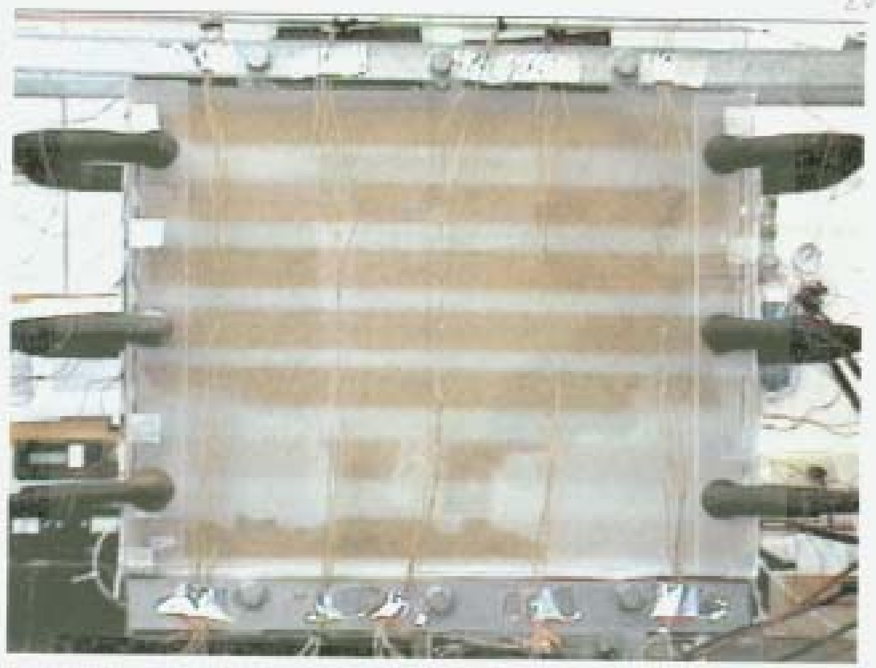
Temp plot at 90 min



95 min into test

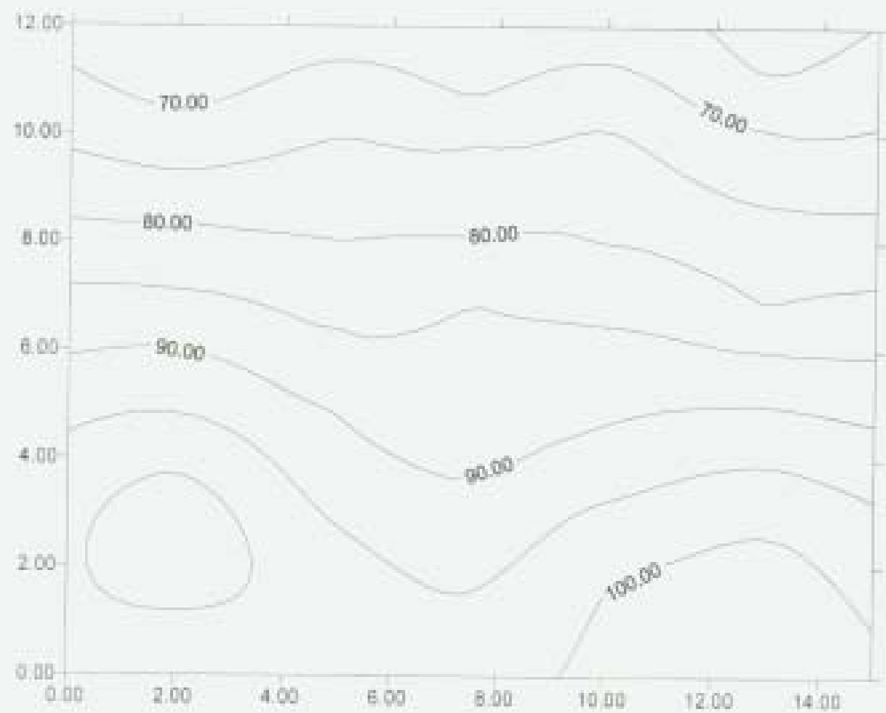


97 min into test.

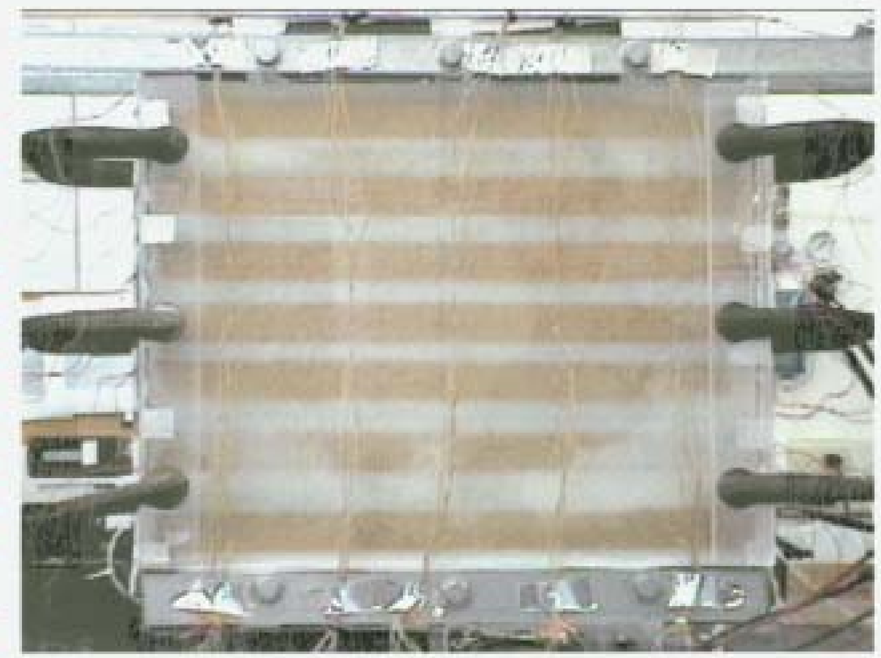


24

102 min into test

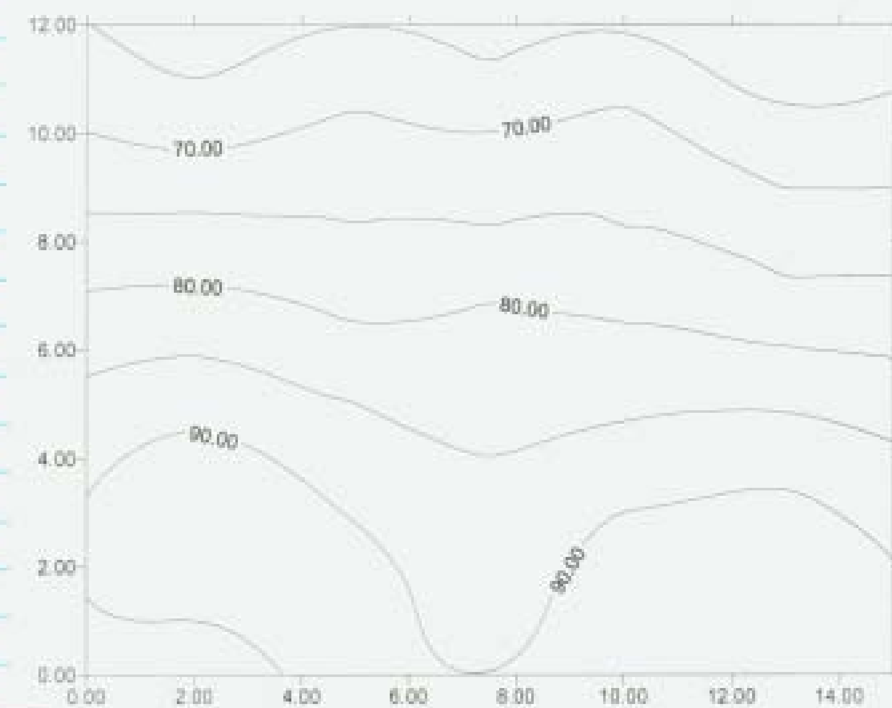


Plot of temp field at 100 min

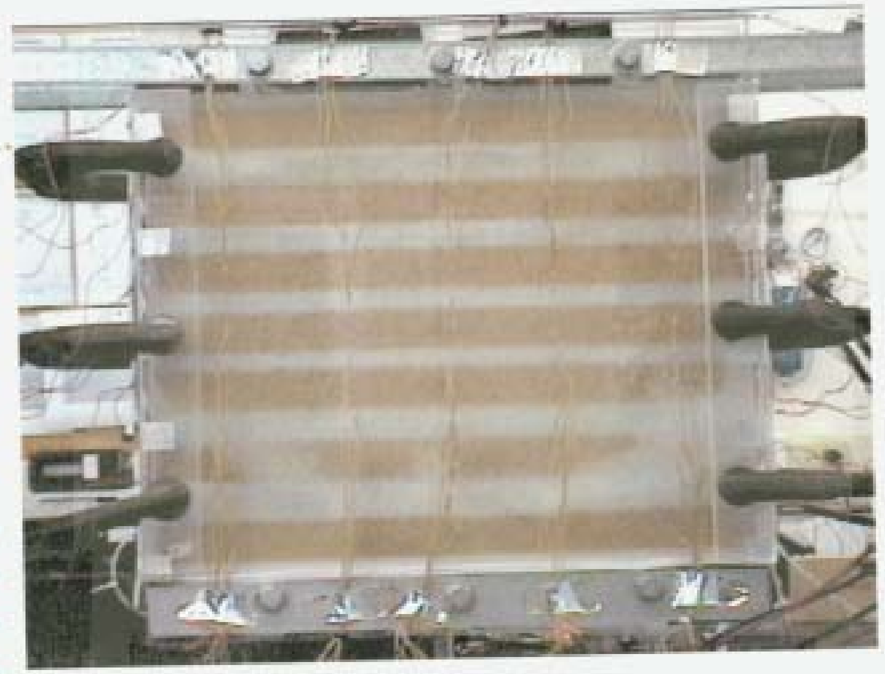


25

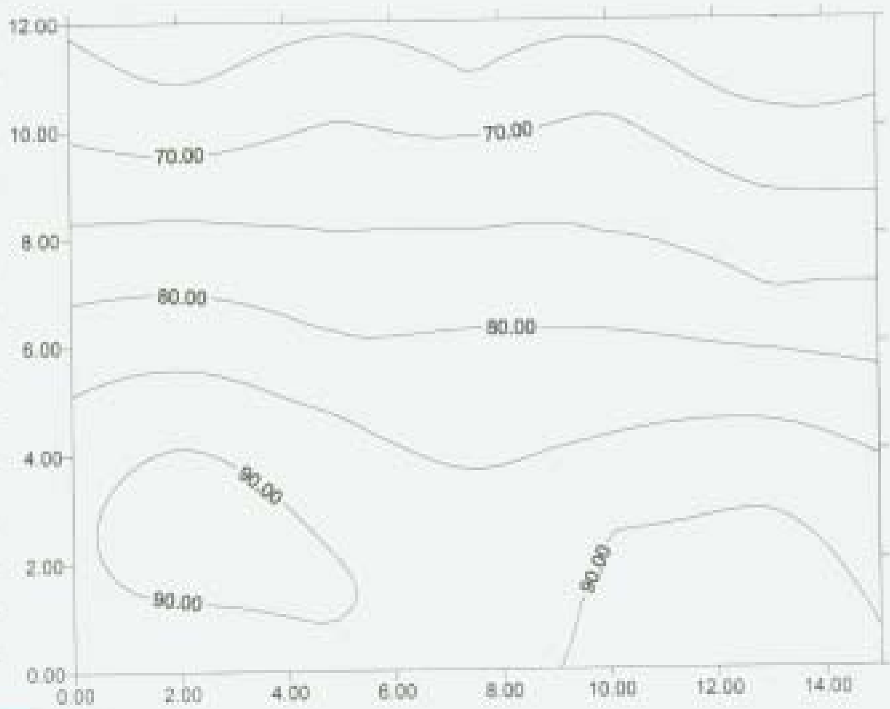
107 min into test



Plot of temp field at 110 min



2+ End of test
112 min



Plot of temp field at end of test 112 min.

11/2/00 JP

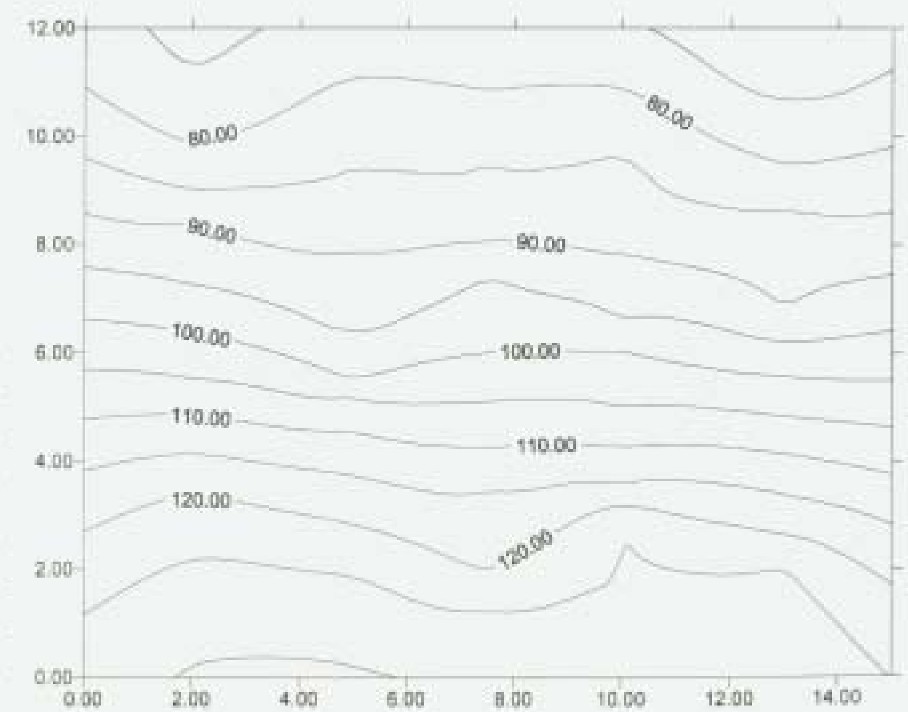
Experiment Finger run 3

Third experiment at collecting data + video while infiltrating water between two glass plates.

The apparatus was assembled as in the previous experiment.

A steady state temperature field was established using the setting shown on page 41.

A plot of the initial field is shown below



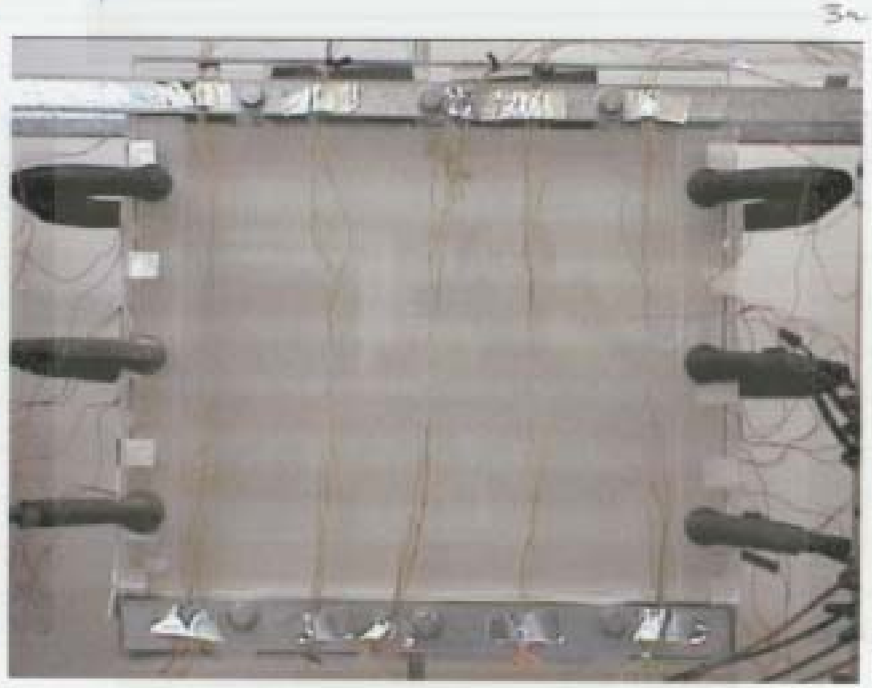
Temp readings of the thermocouples were taken every 30 seconds. Data was stored in an MS Excel file named Finger_run_3.xls.

DI water was introduced at top of the assembly at a rate of 0.2 ml/min.

A video of the experiment was recorded using the Canon ZR digital camcorder. The experiment was recorded for about 60 min. The tape is labeled Finger_run_3 video.

1/13/00 JP Results + observations

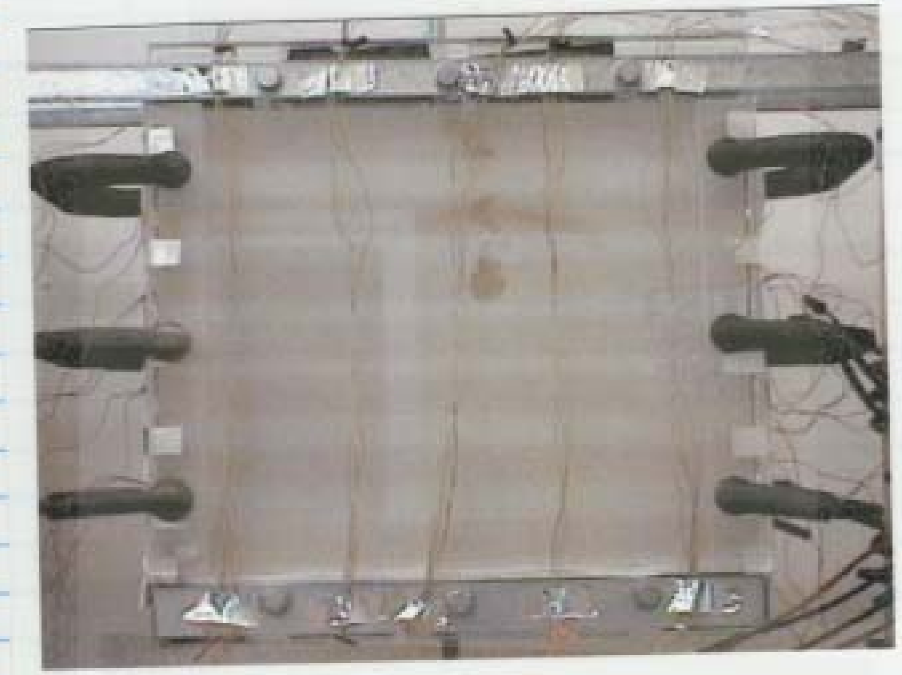
3a



15 secs into test

Initial finger forms.

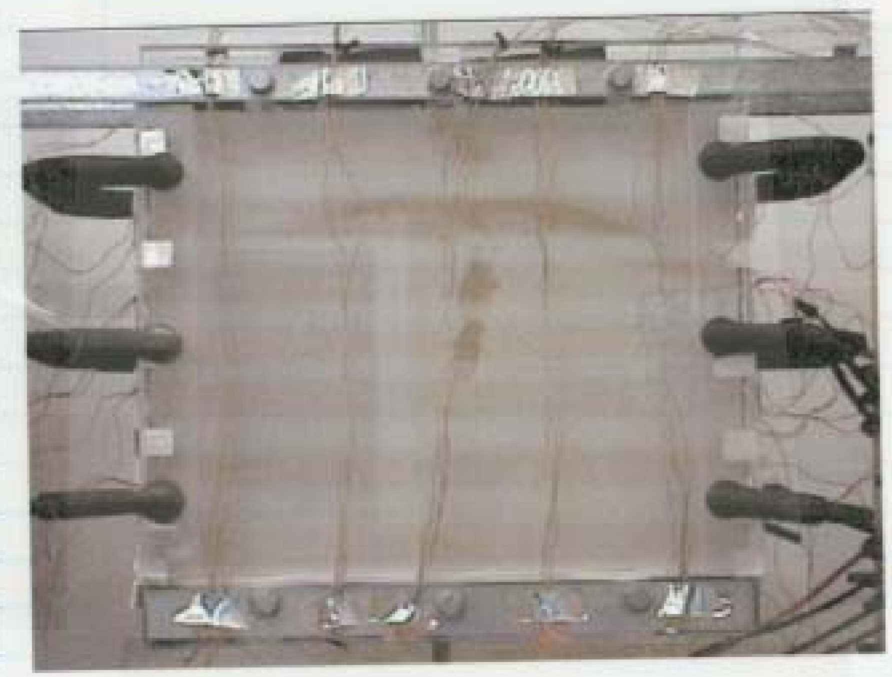
3b



45 secs

Finger encounters boiling isotherm, zone of saturation begins to form

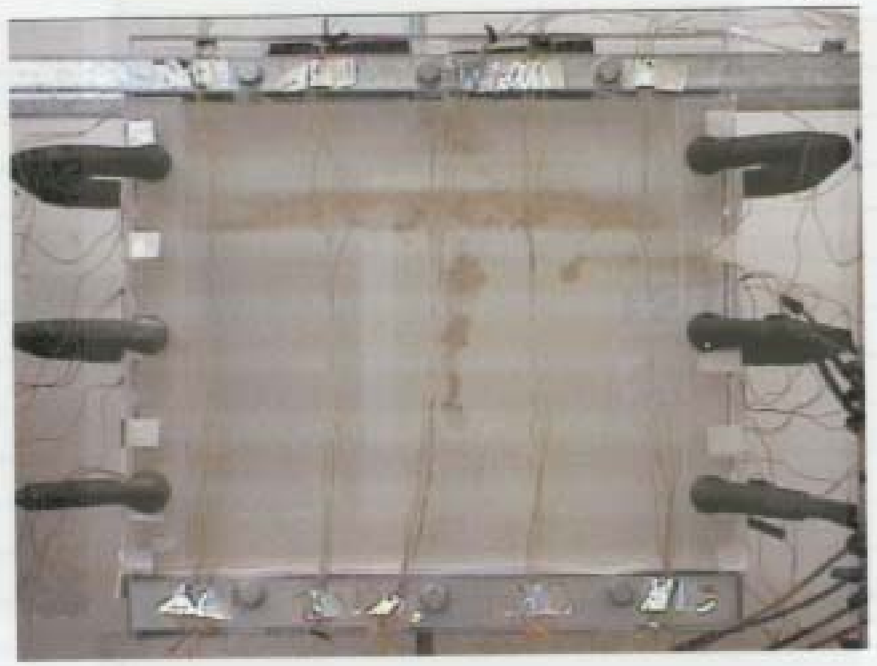
3c



2 min

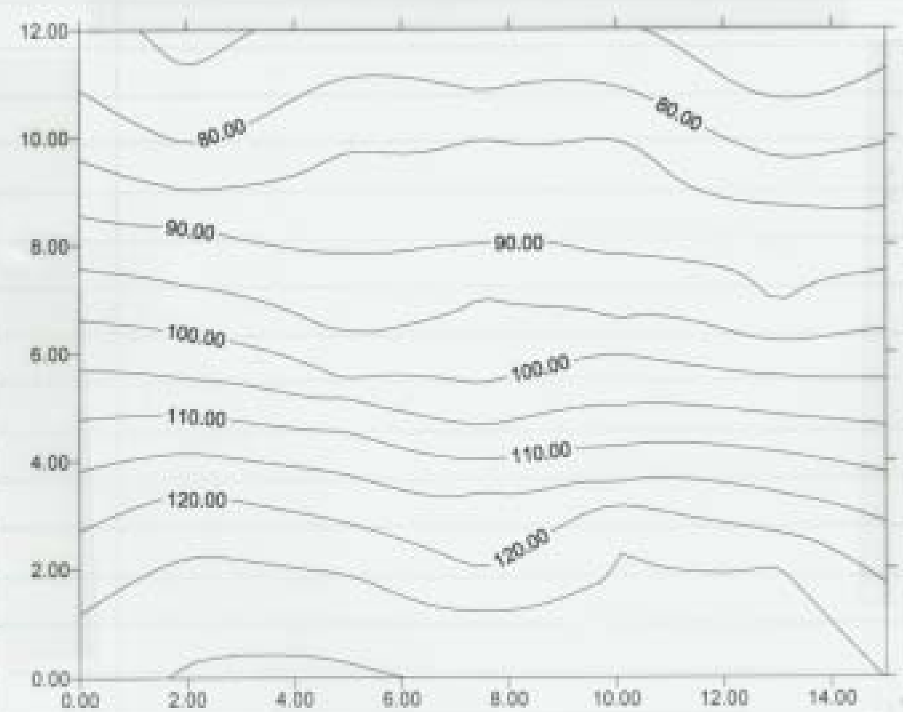
Finger continues downward advance, zone of saturation grows.

3a



5 min

Finger contour advance

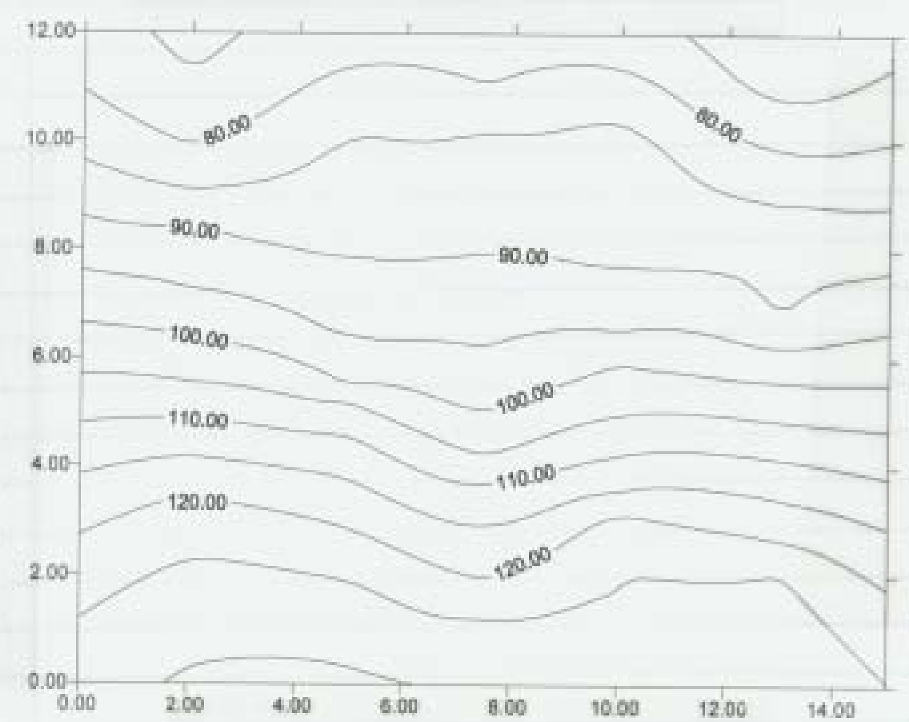


Plot of temp field at 5 min

3c

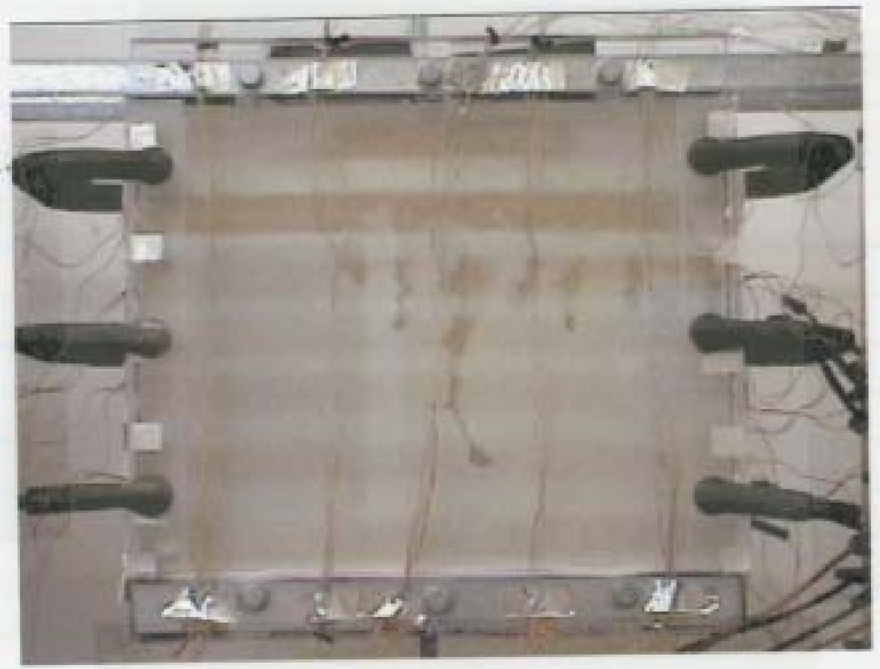
10 min

Finger contour downward advance



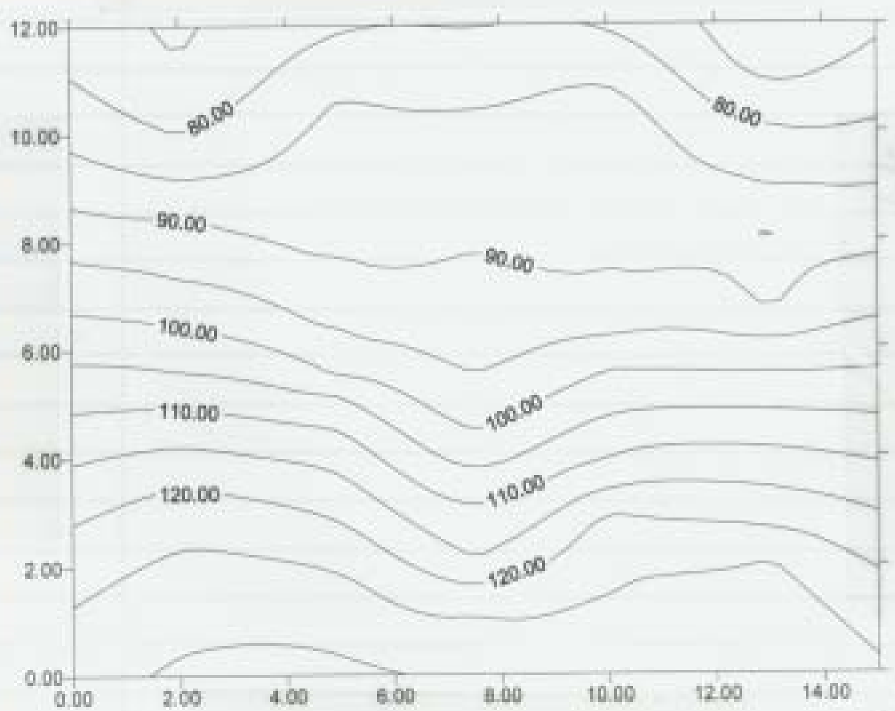
Plot of temp field at ~~20 min~~ 10 min

35



20 min

Fringe pattern developed

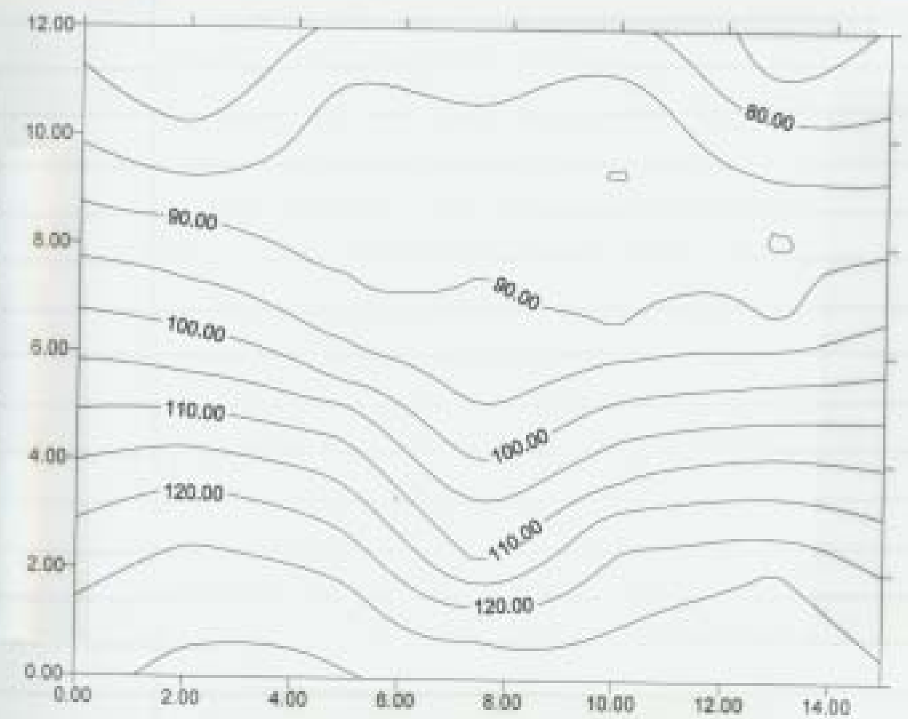


Plot of temp field at 20 min

36

40 min

Steady state reached.

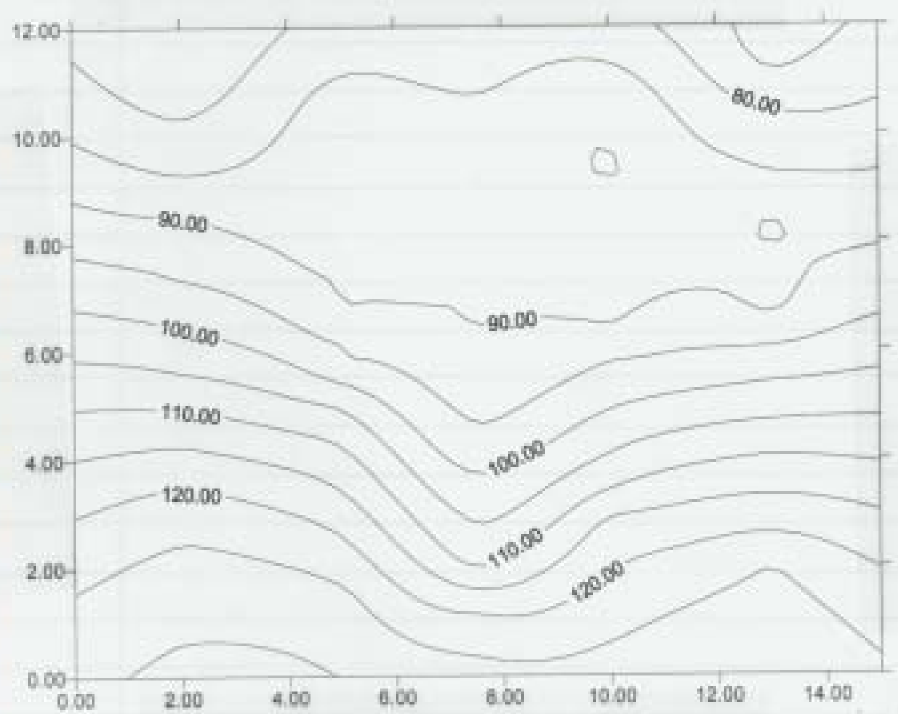


Plot of temp field at 40 min

3j

60 min

END of test



Plot of temp field at end of test (60 min).

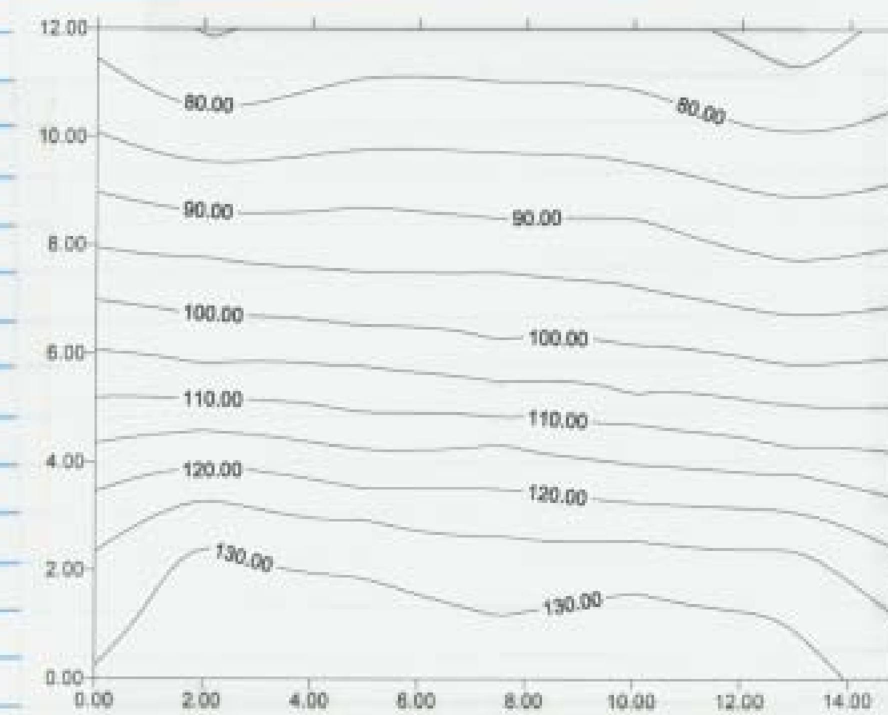
6/13/00 JP

Experiment Finger_run_4

Data + video were collected at a flow rate of 0.1 ml/min.
The apparatus was assembled as in the previous experiment

A steady-state temperature field was established using settings shown on page 41.

A plot of the initial temperature field is shown below.

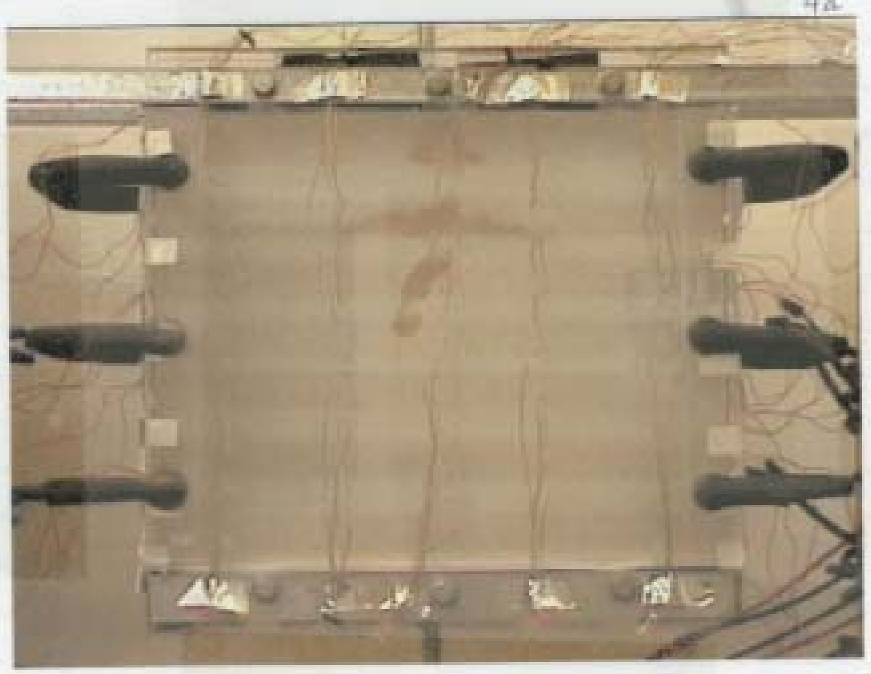


Temperature readings taken every 30 secs are stored in a MS Excel file named Finger_run_4.xls.

A digital videocassette of the experiment is labeled Finger_run_4 video. The experiment was recorded for 60min.

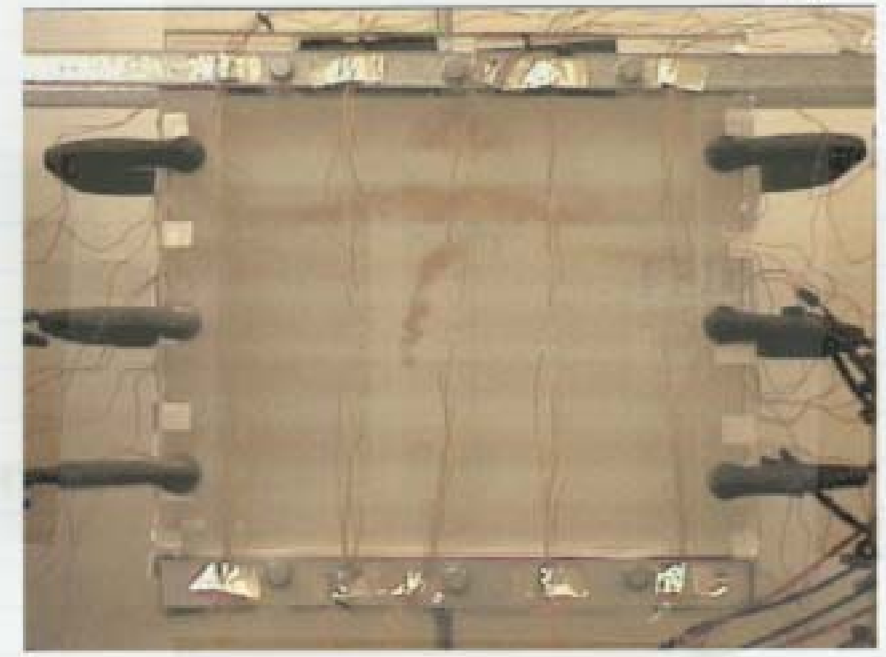
6/14/00 Results + observations

4a



3 min into test

4b



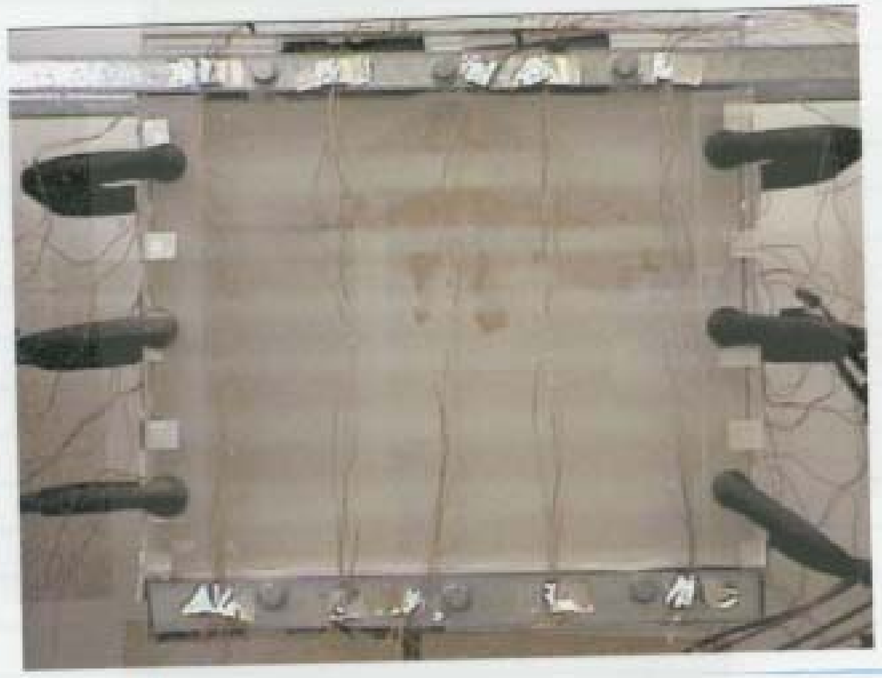
5 min into test

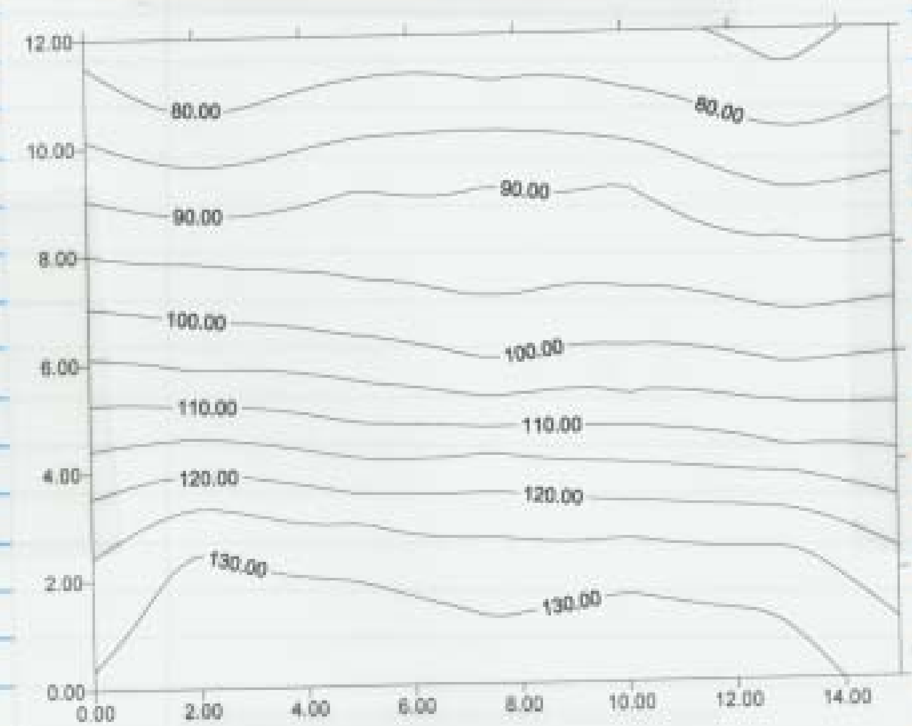
Finger continue to advance

Saturated zone grows.

4c

10 min into test

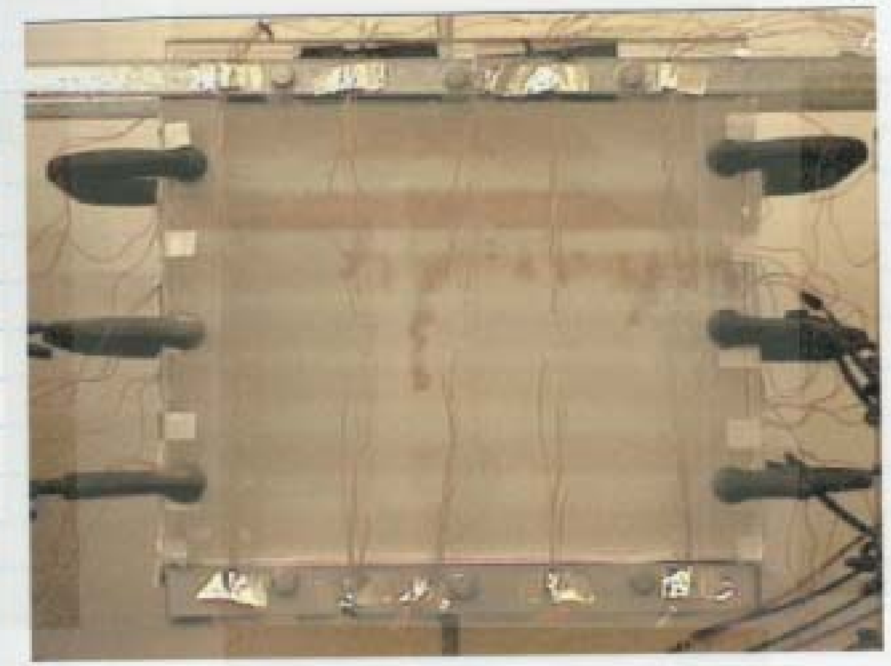


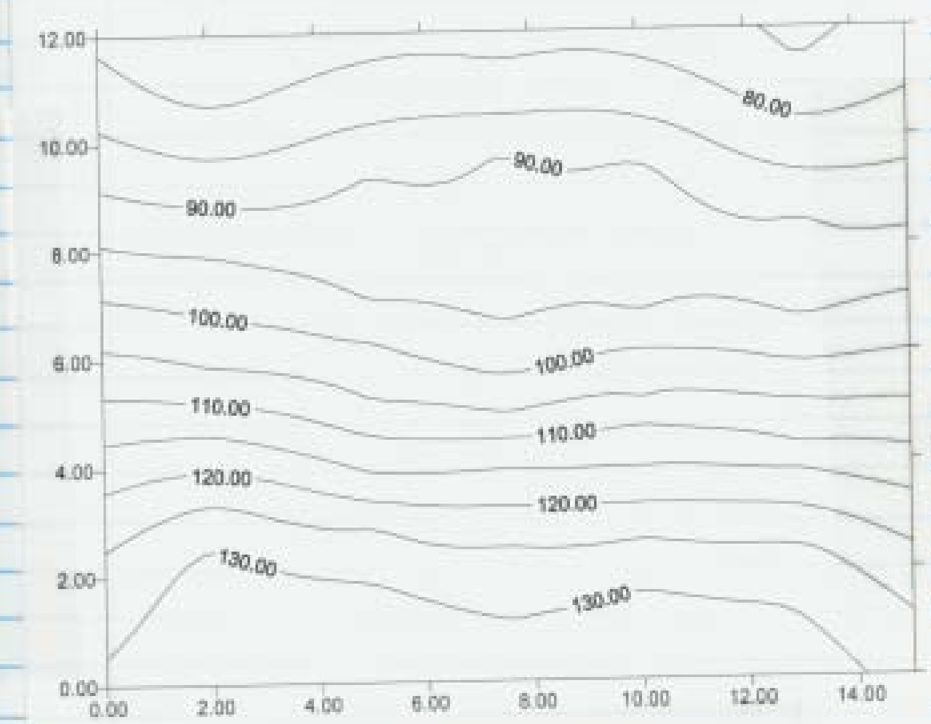


Plot of temp field at 10 min

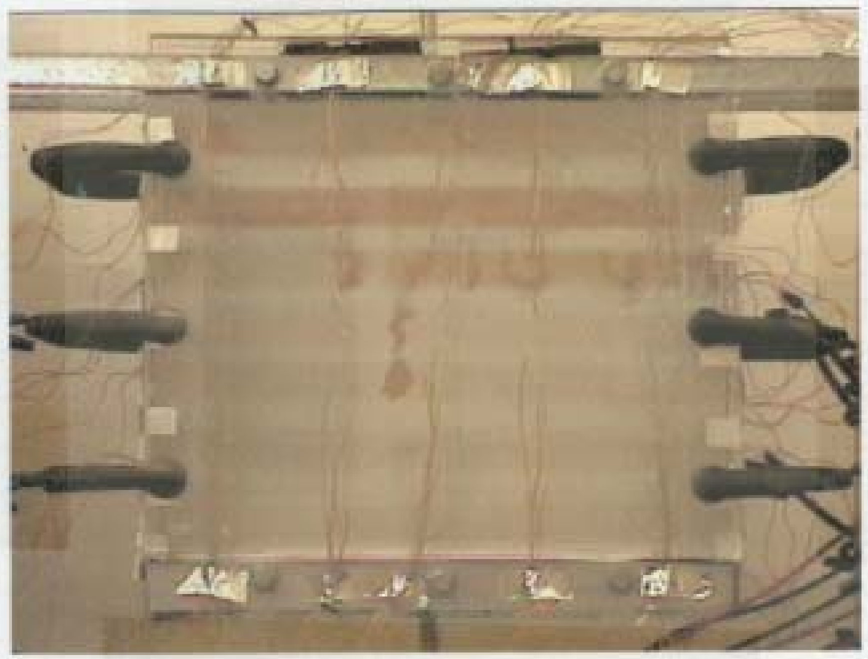
4d

20 min into test

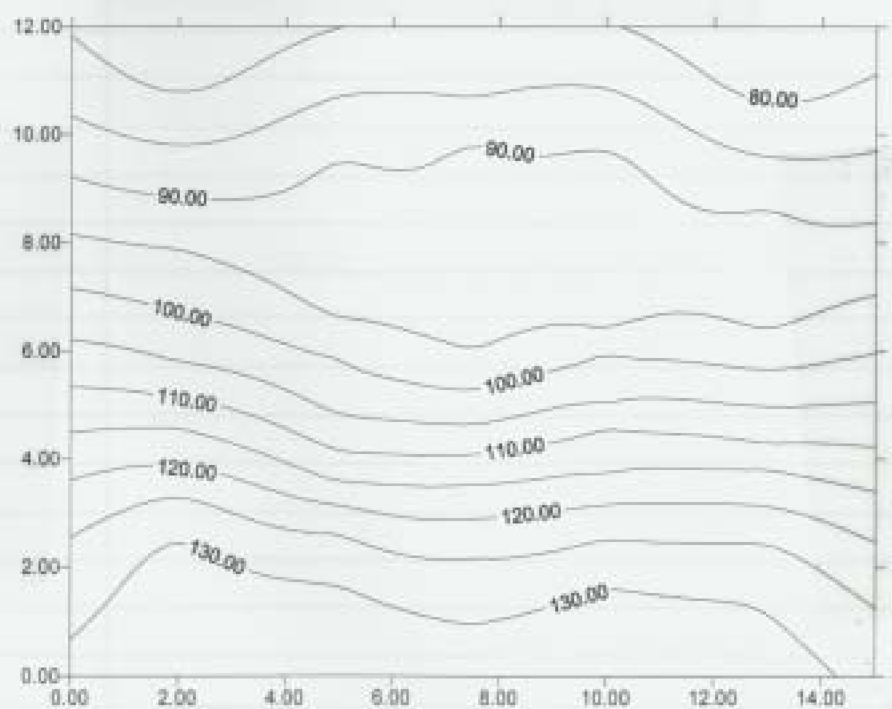




Plot of temp field at 20 min

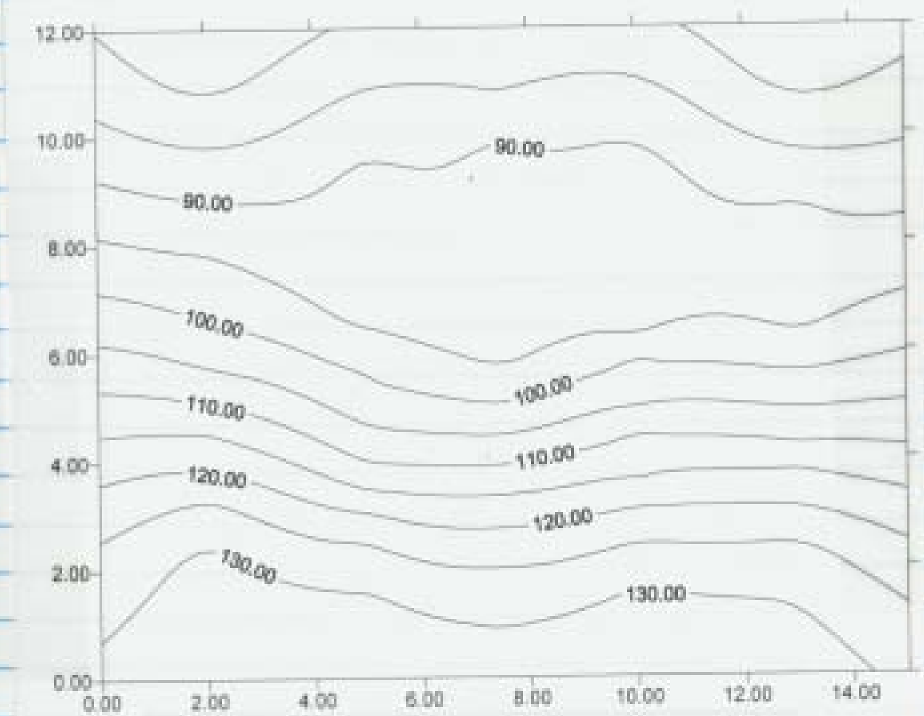


40 min into test



Plot of temp field at 40min

60 min into test



Plot of temp field @ 60min

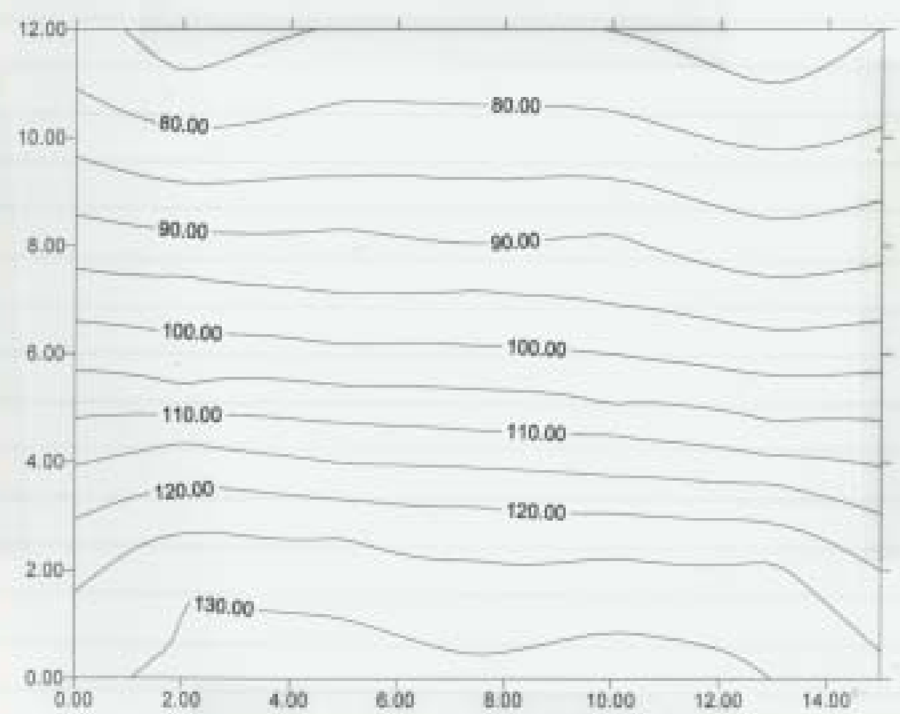
6/14/00 JP

Finger_run_5 Experiment

Data and video collected at a flow rate of 0.05 ml/min

Steady state temp field was established using settings on p 41.

A plot of the initial temp field is shown below



Temperature data is stored in a MS Excel file named Finger_run_5.xls

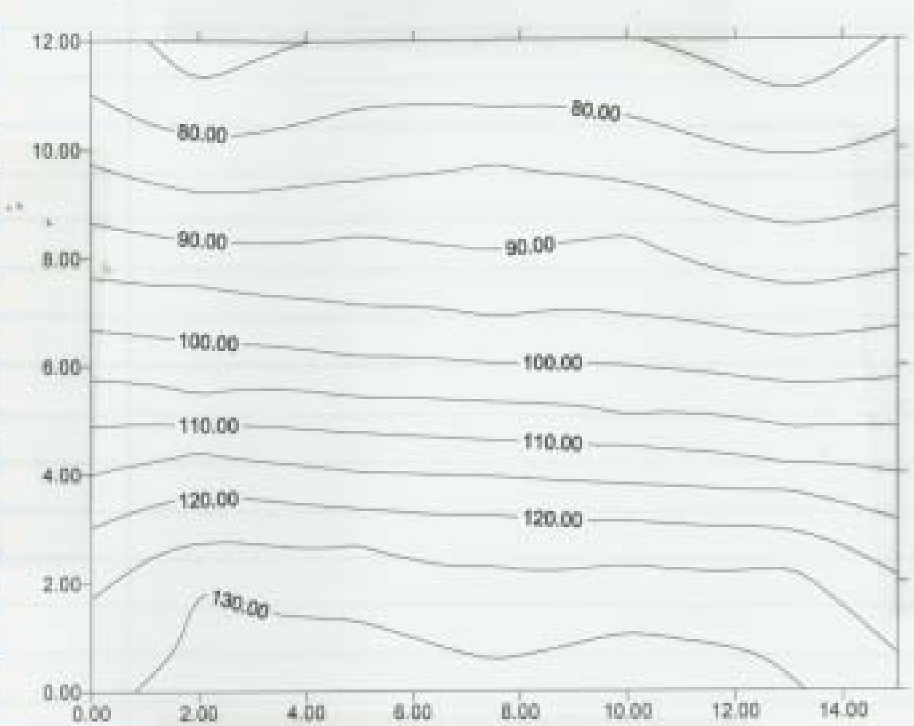
A digital videominute of the experiment is labeled Finger_run_5.video.

6/15/00 JP

Results + Observations

5a

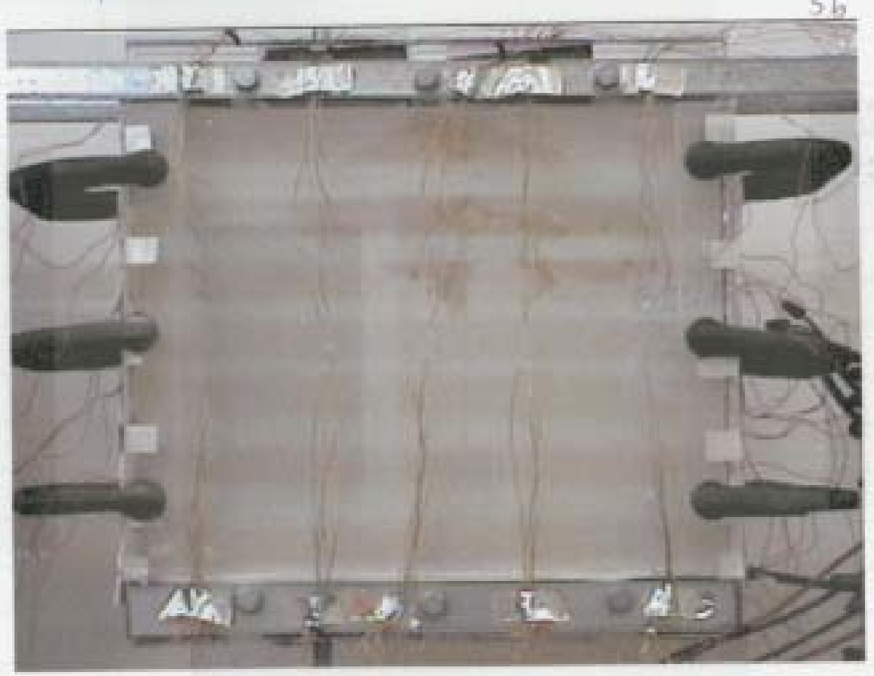
5 min into test.



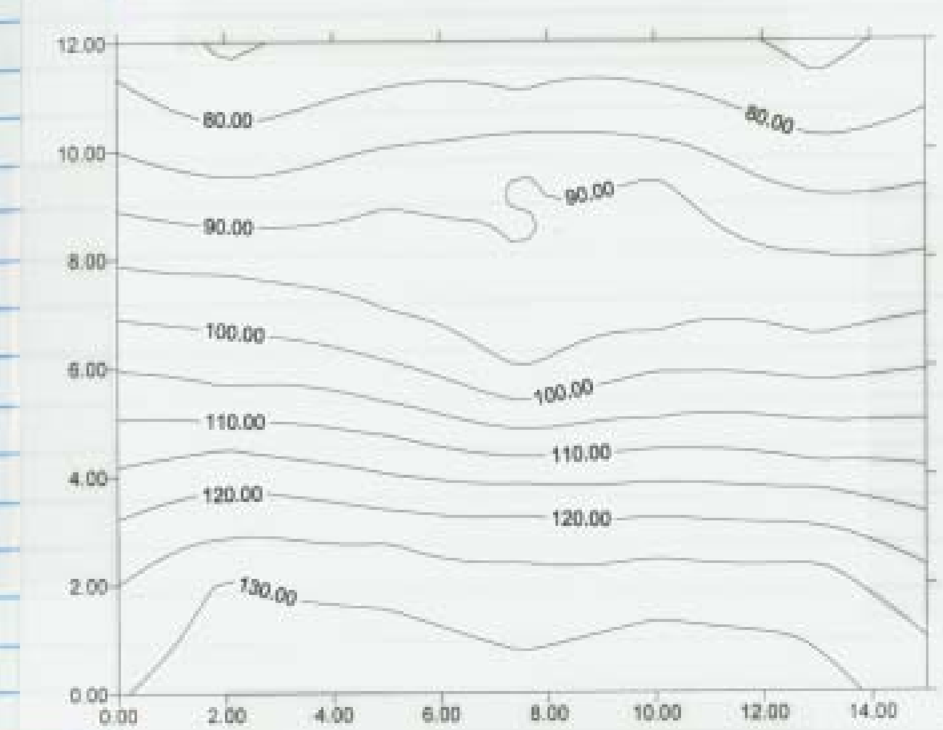
10 min into test

Plot of temp field

5b

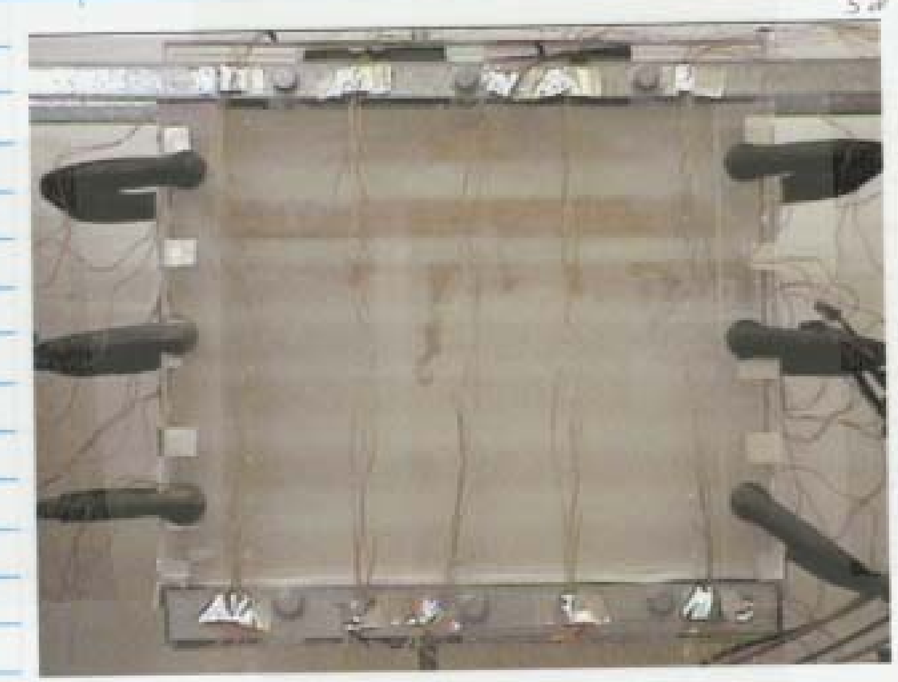


10 min into test



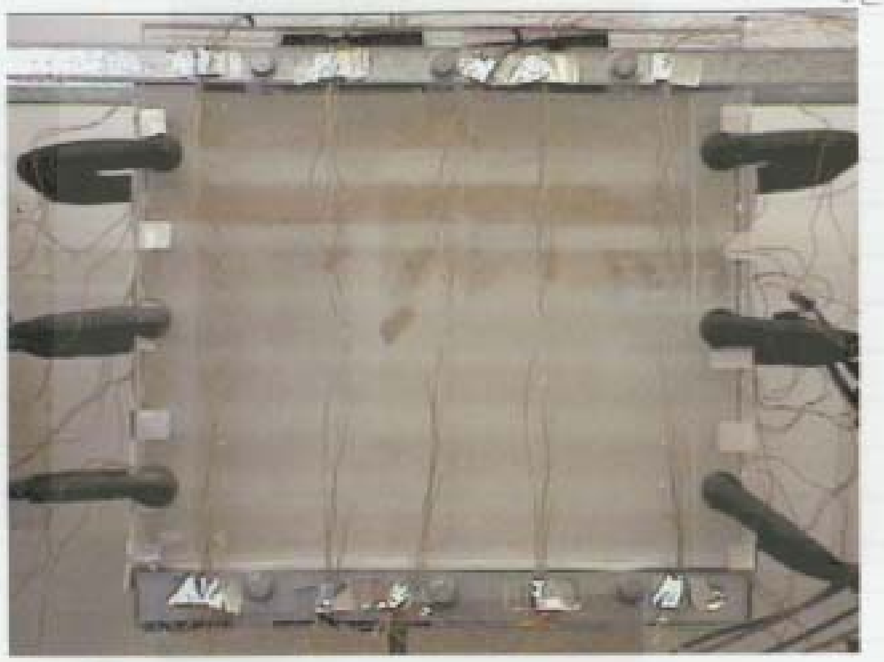
Plot of temp field at 40 min

5a

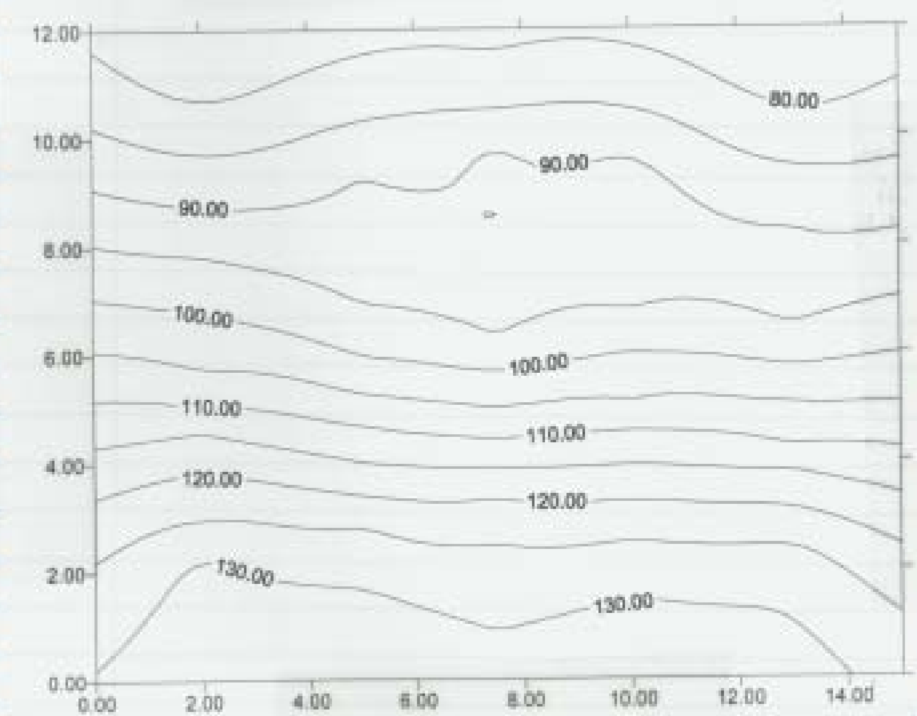


40 min into test

5c



60 min into test



Plot of temp field at 60 min

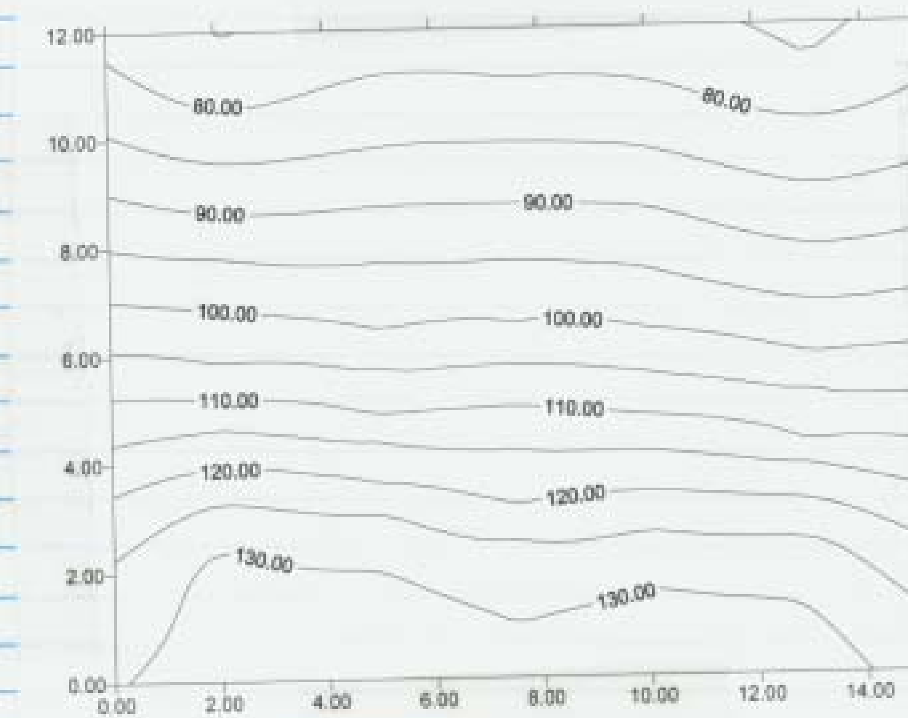
6/15/00 gp

Finger run 6

Data + video collected at a slow rate of 0.025 ml/min

Settings on p 41 were used to establish a steady-state temp field across the glass plate + lexan assembly.

A plot of the initial temp field is shown below.



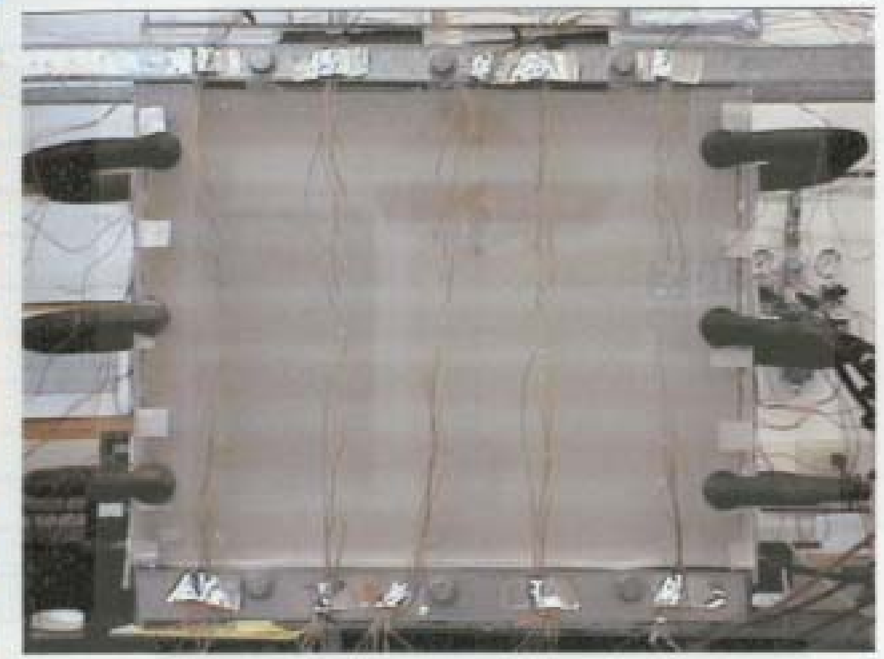
Temperature data is stored in a MS Excel file named [illegible]_run_6.xls

A digital videocassette of the experiment is labelled [illegible]_run_6. Video.

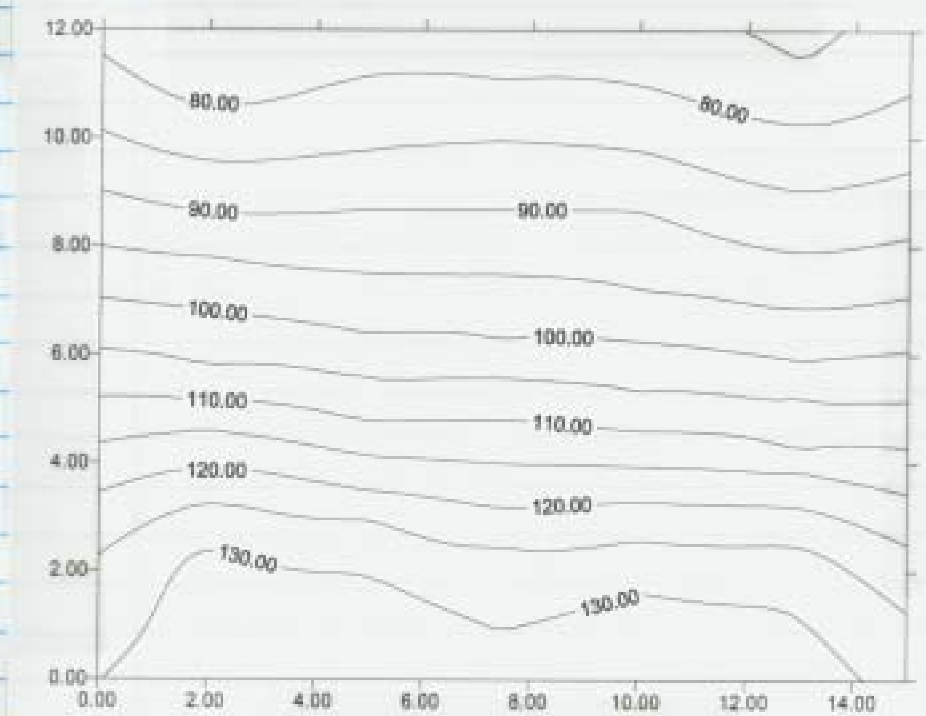
6/14/00 JP

Results & Observations.

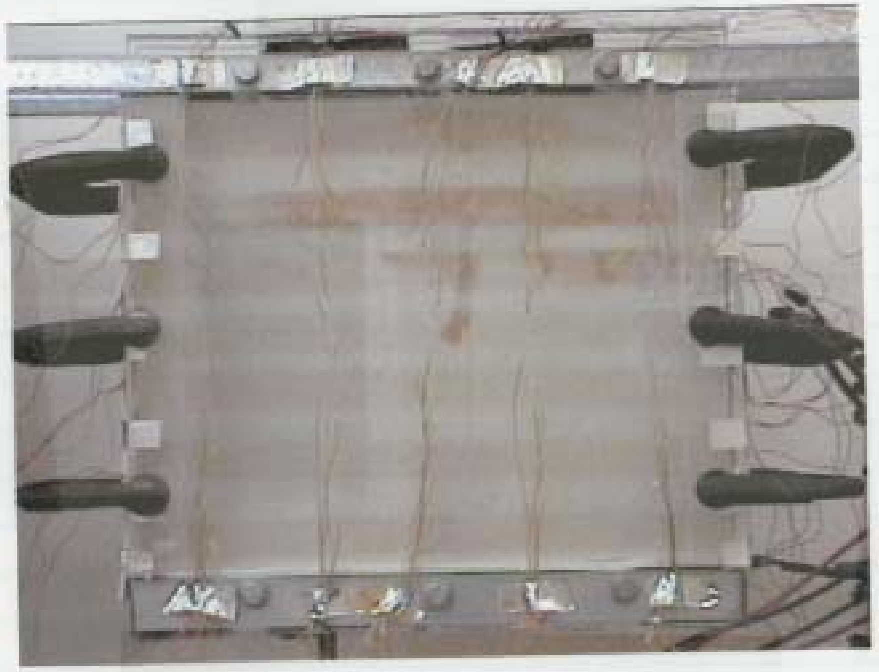
6a



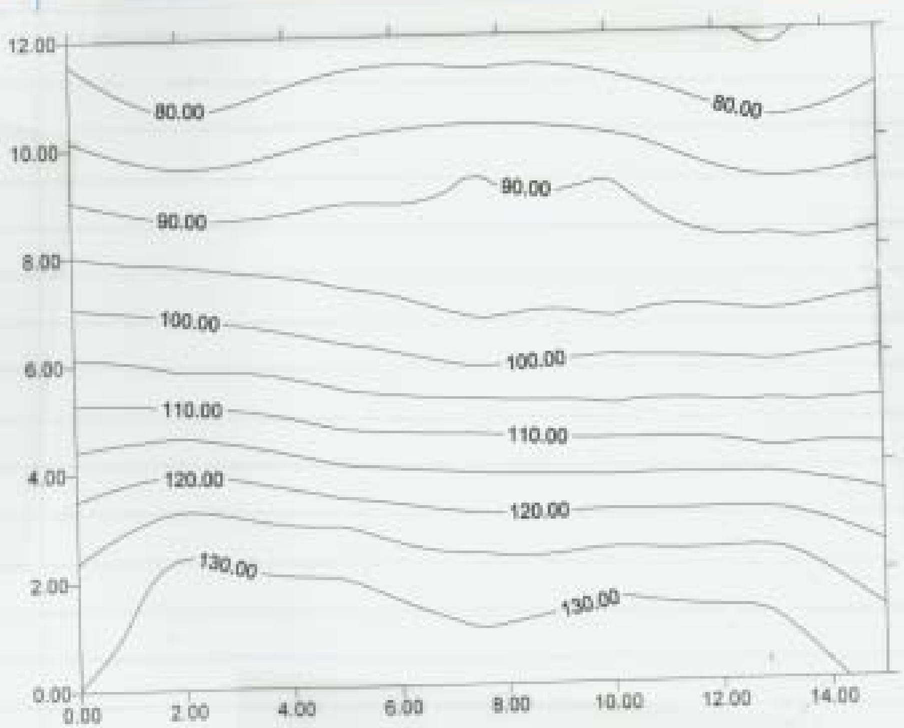
10 min into test



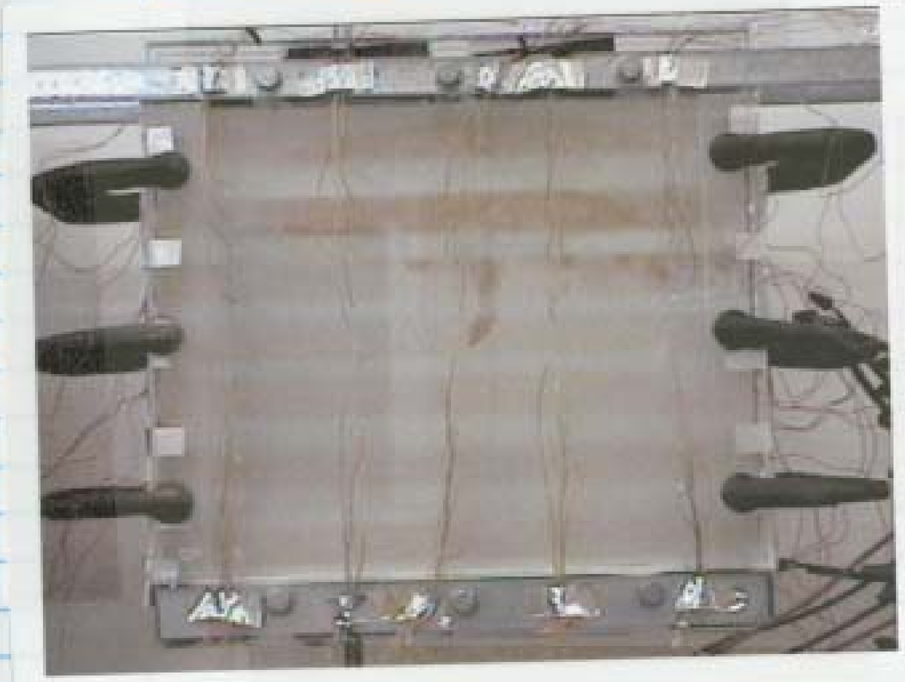
Plot of temp field at 10 min



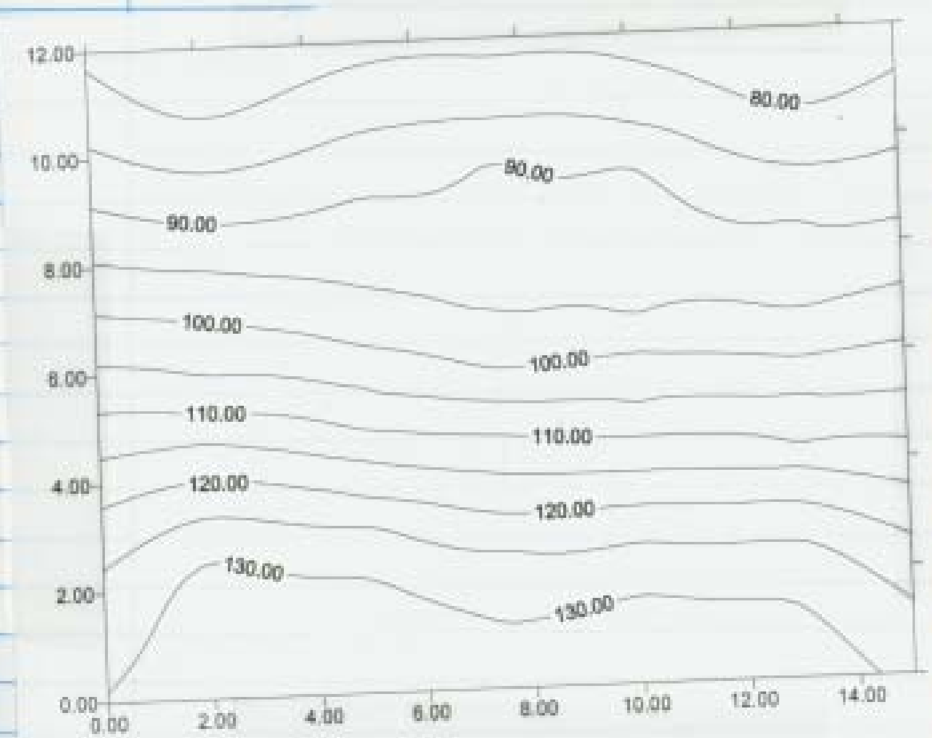
40 min into test



Plot of temp field at 40 min



60 min into test



Plot of temp field at 60 min

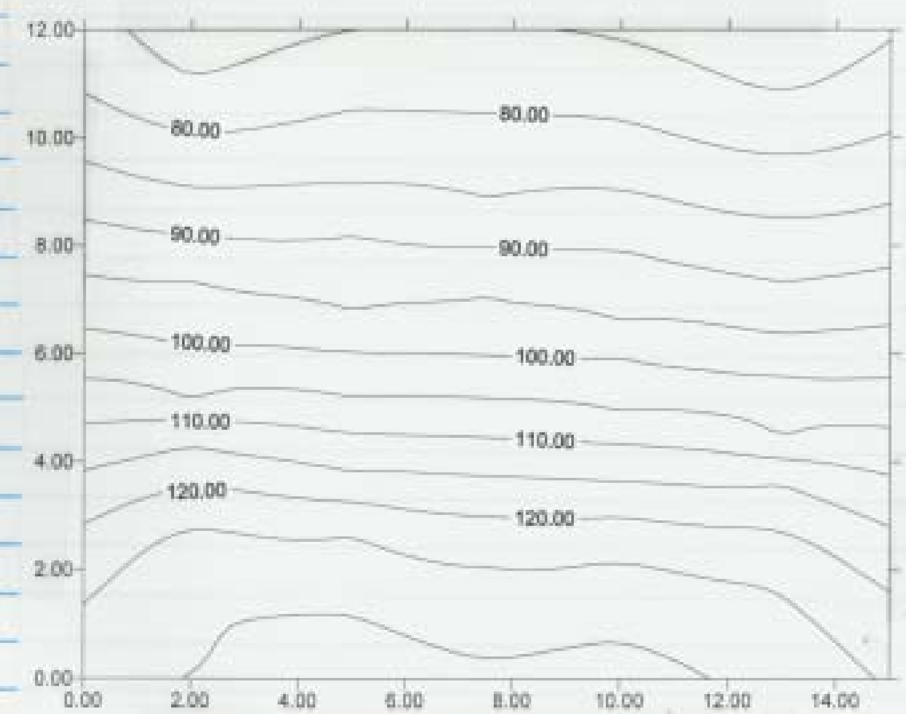
6/16/00 JP

Finger_run_7

Data + video collected at a slow rate of 0.01 ml/min.

Settings on p41 were used to establish a steady-state temperature field across the glass plate & lexan assembly.

A plot of the initial temp field is shown below



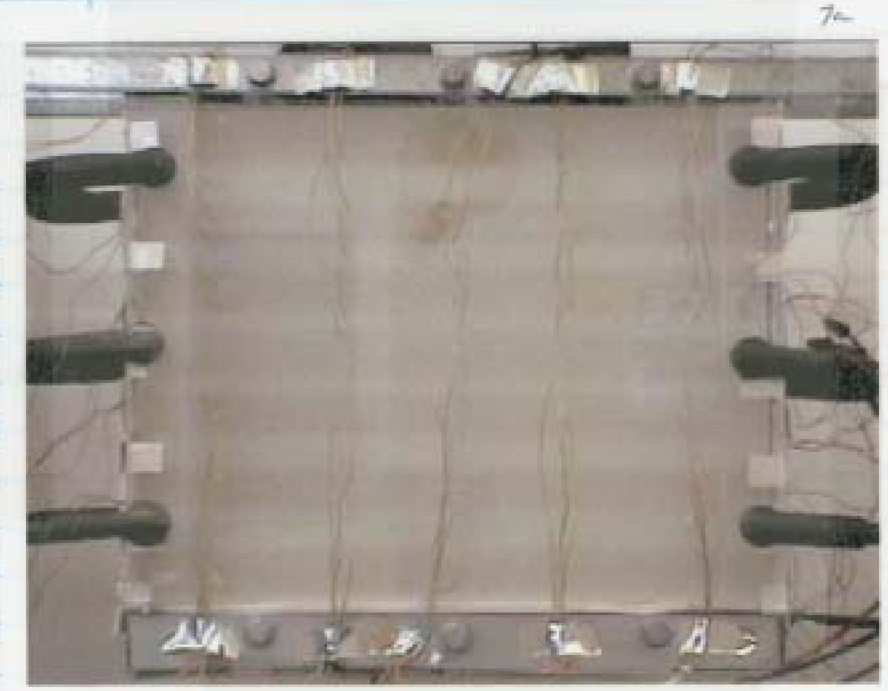
Temperature data is stored in a MS Excel file named finger_run_7.xls

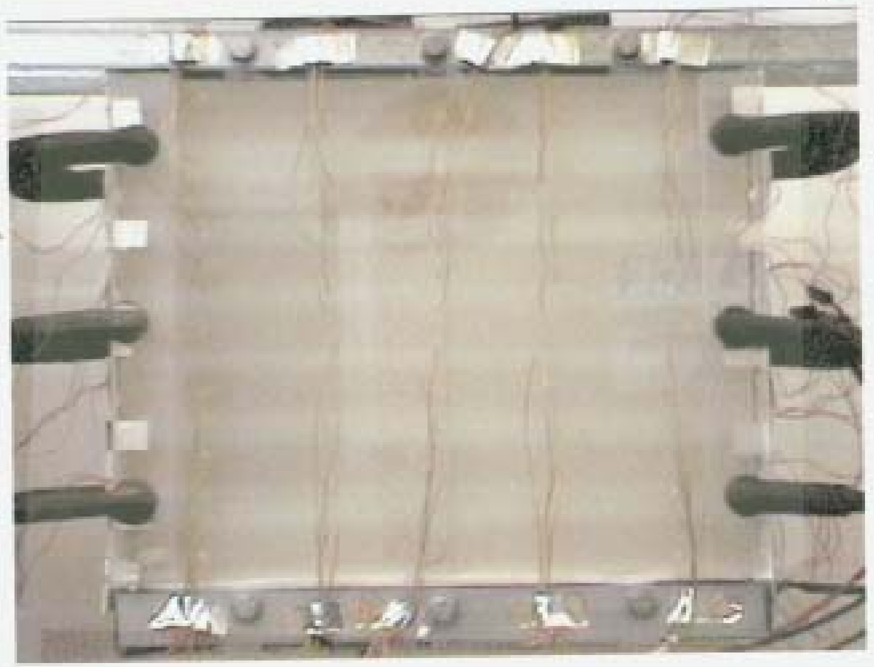
A digital videocassette of the experiment is labeled Finger_run_7 video.
This test ran approximately 93 min.
The videocassette contains the first 30 min of the test and the last 30 min of the test. The middle portion of the experiment (about 33 min) was not recorded.

6/19/00 JP

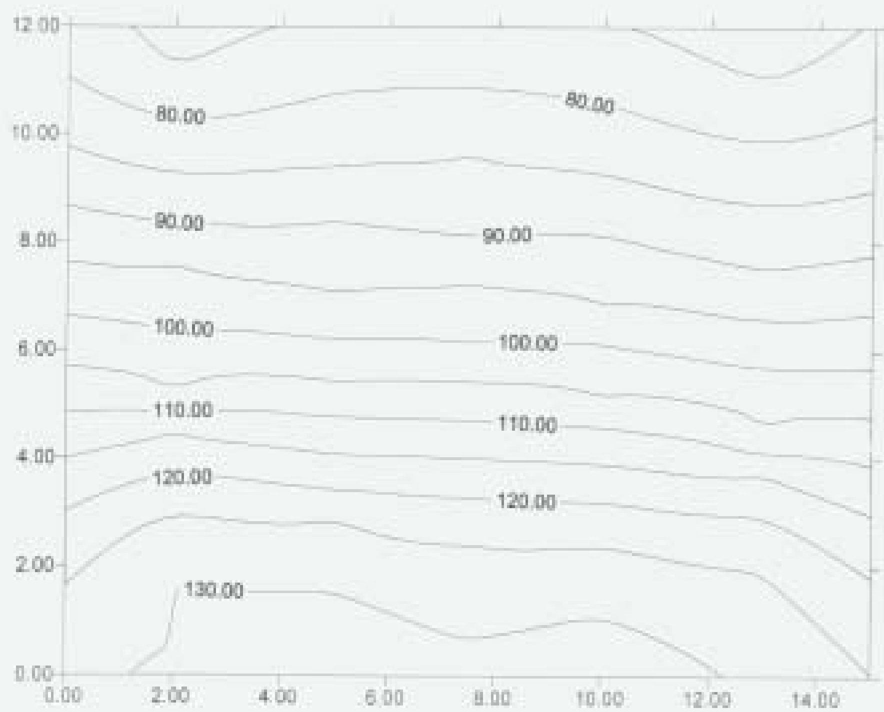
Results + observations.

7a 15 min into test

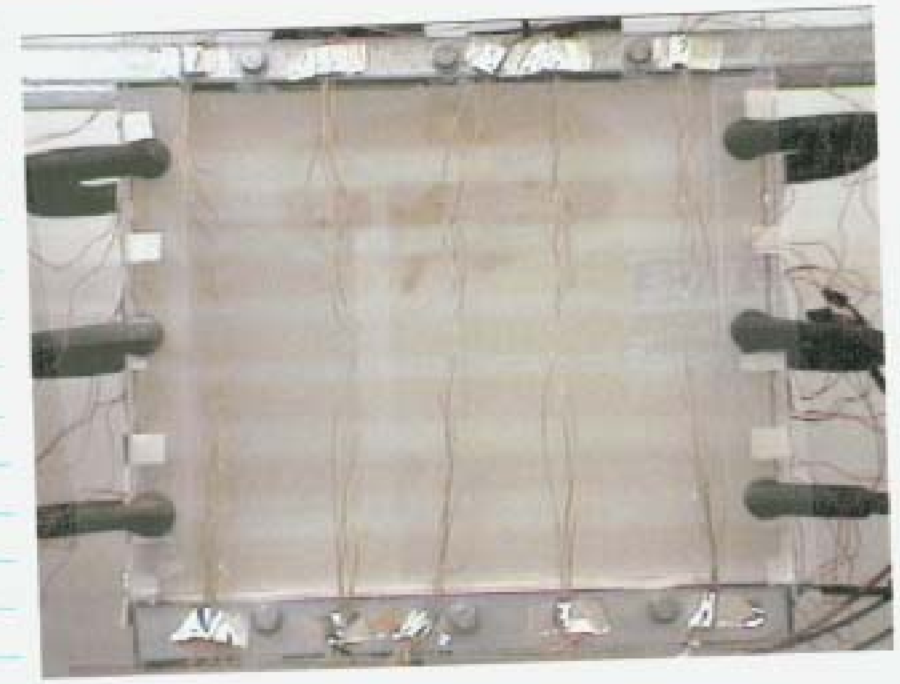




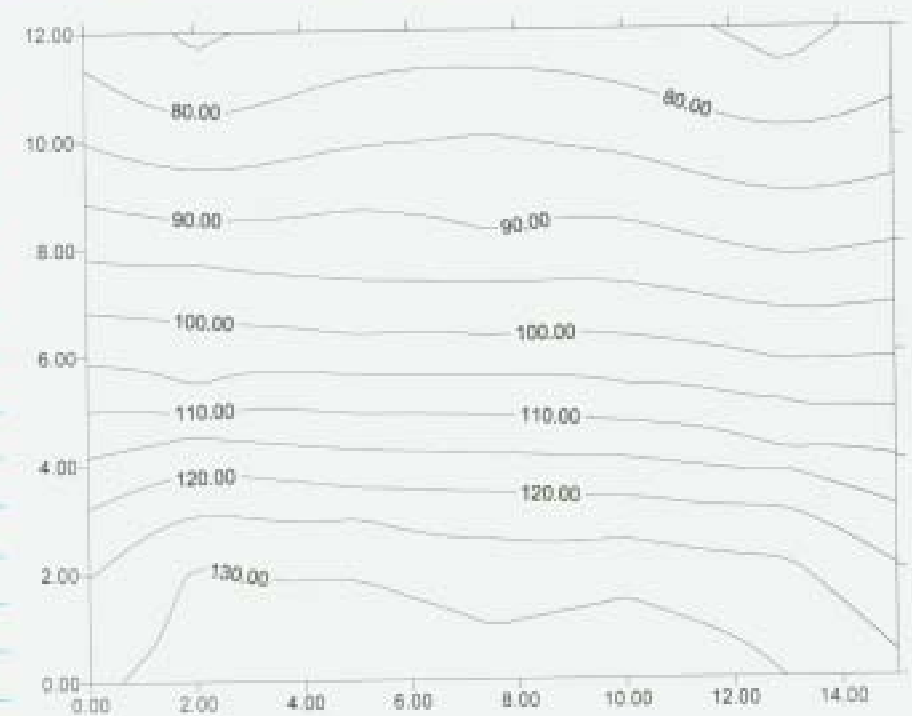
30 min into Test



Plot of temp
Side Out
30 min

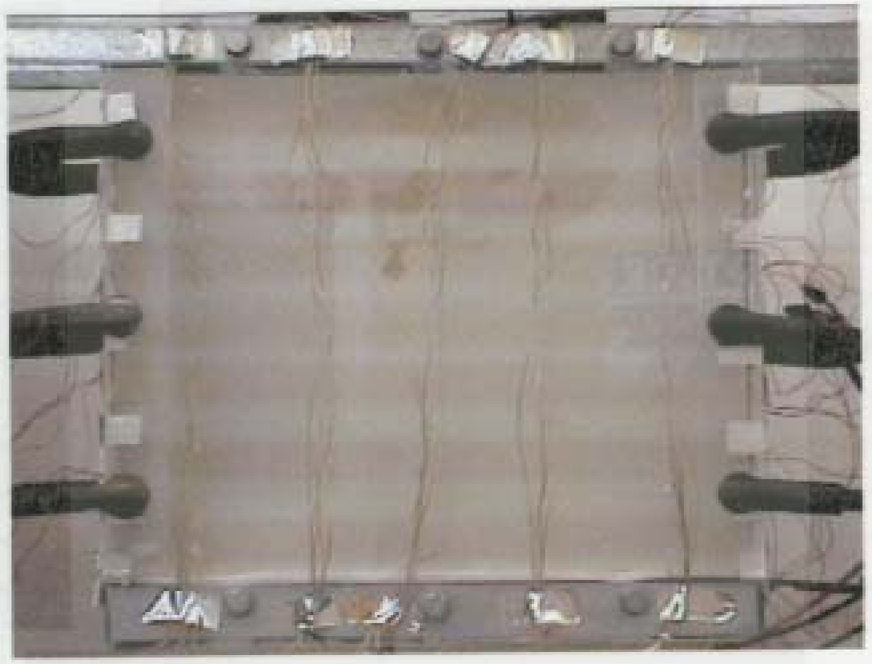


60 min into test

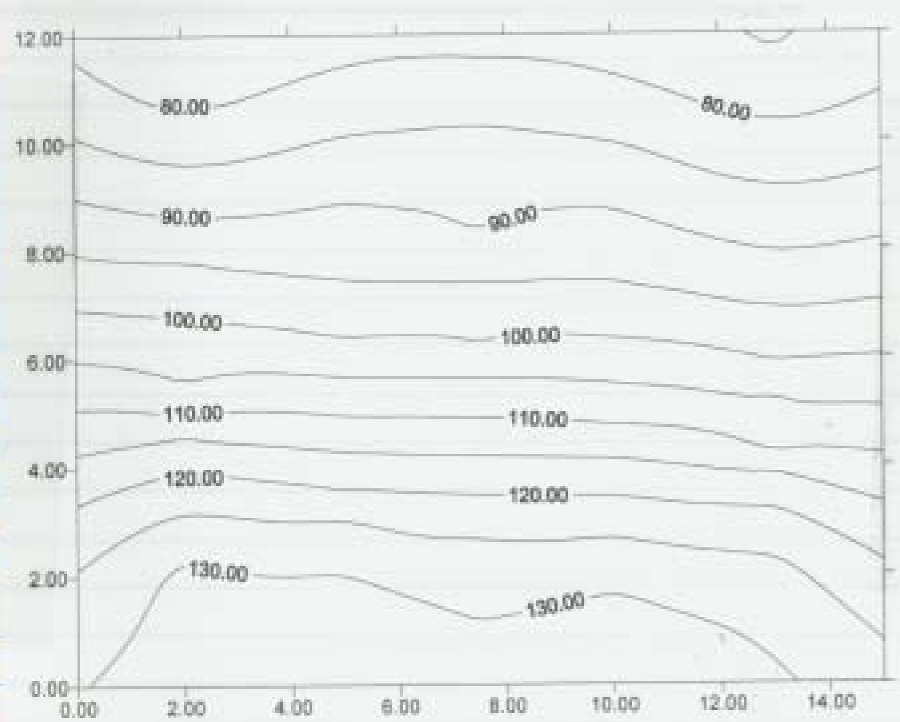


Plot of temp
Side Out
60 min

70



75 min into test.



Plot of temp field at 90 min

6/22/00 JP

Finger run 9

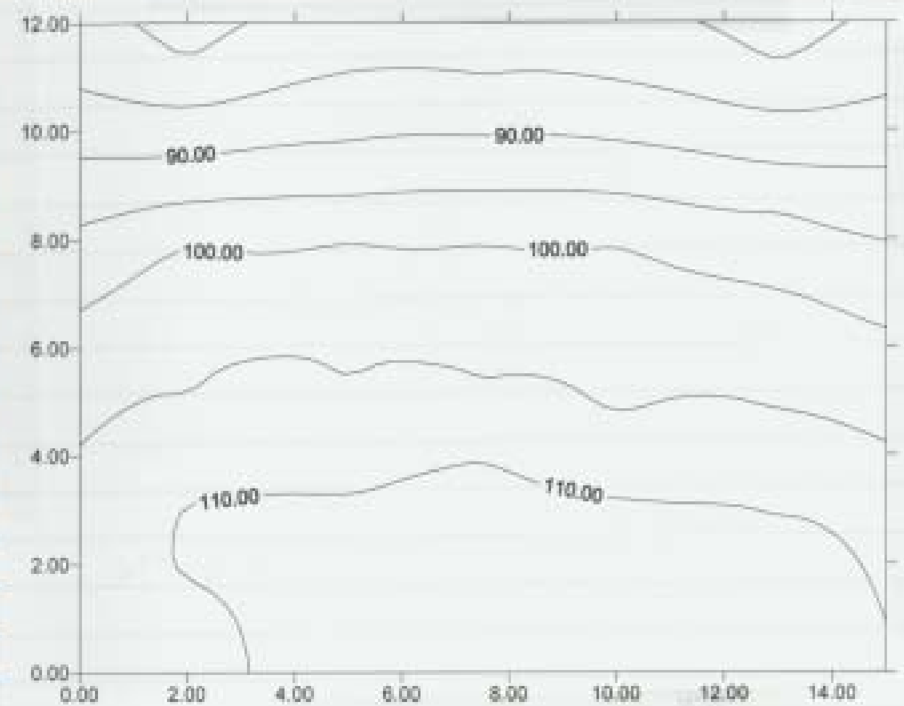
Data and video collected at a flow rate of 0.2 ml/min

Settings below were used to establish a steady state temperature field across the glass plate & lexan assembly.

Strip heater #	Transformer Setting
7	24
6	20
5	20
4	28
3	36
2	44
1	50

Side heater #	Power supply setting
5	10
4	10
3	12
2	17
1	20

A plot of the initial temperature field is shown below



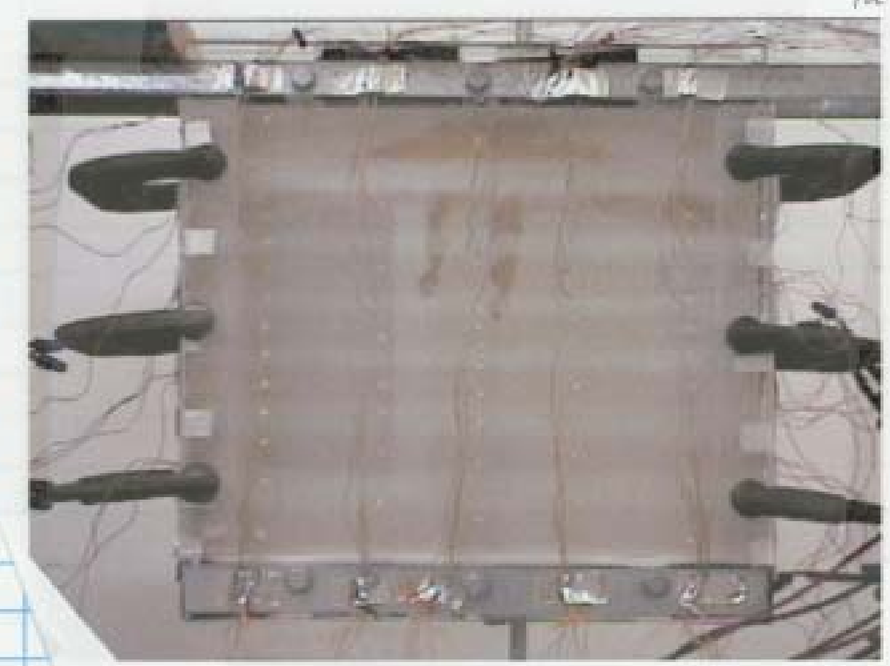
Temperature Data is stored in a MS Excel file named Single_run_9.xls

A digital videocassette of the experiment is labeled Single_run_9 video
This test ran ~ 60 min

6/23/00 JP

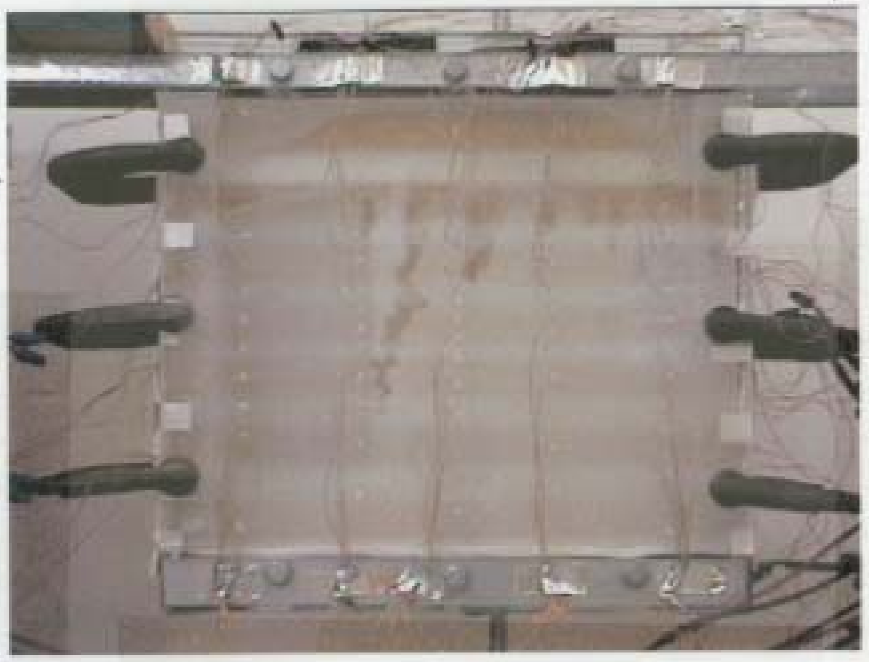
Results + observations.

9a

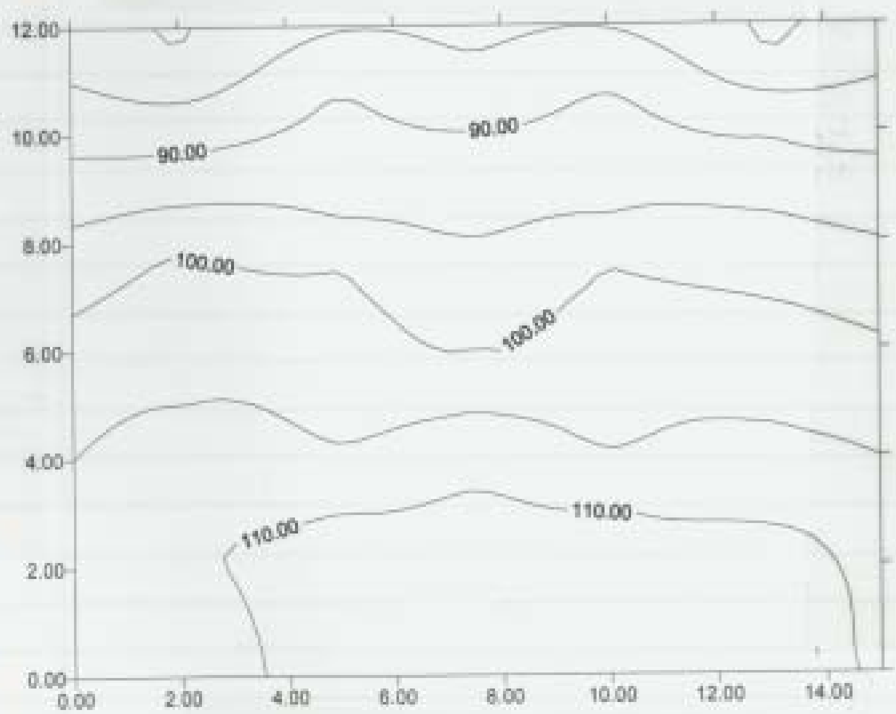


3 min into test

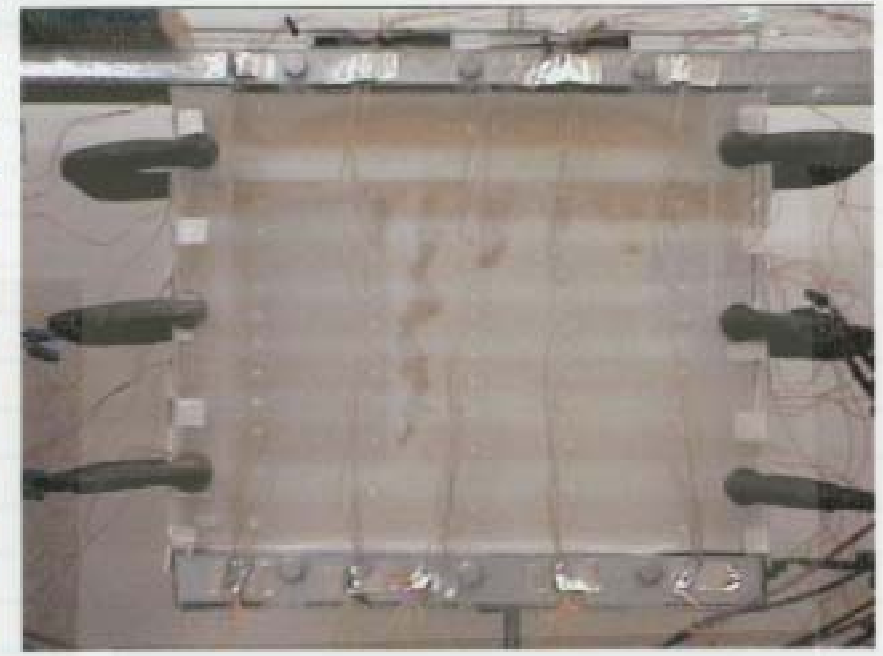
96



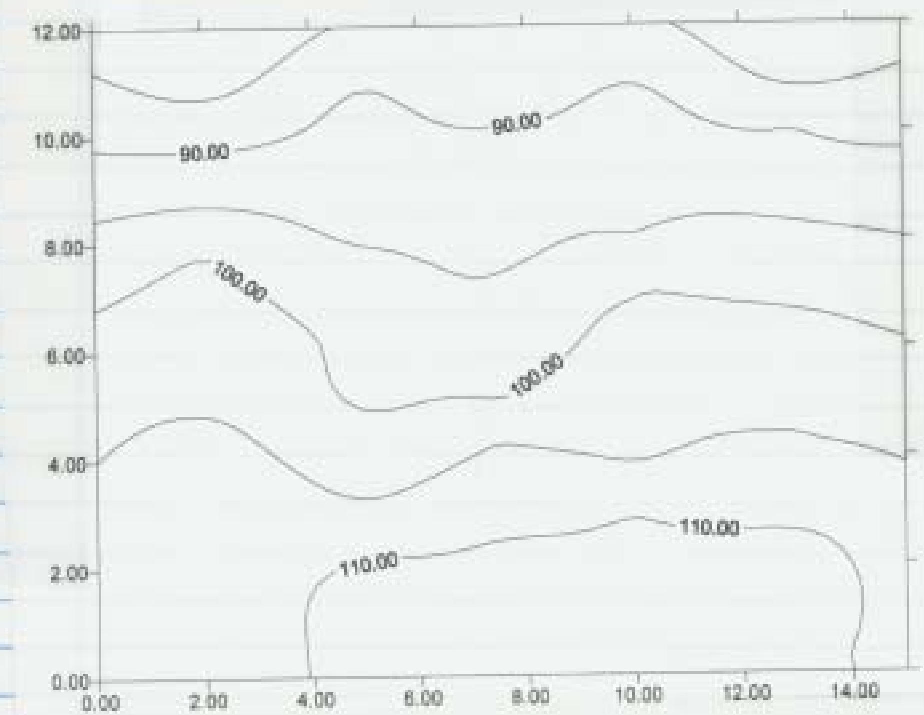
10 min into test



plot of temp field at 10 min



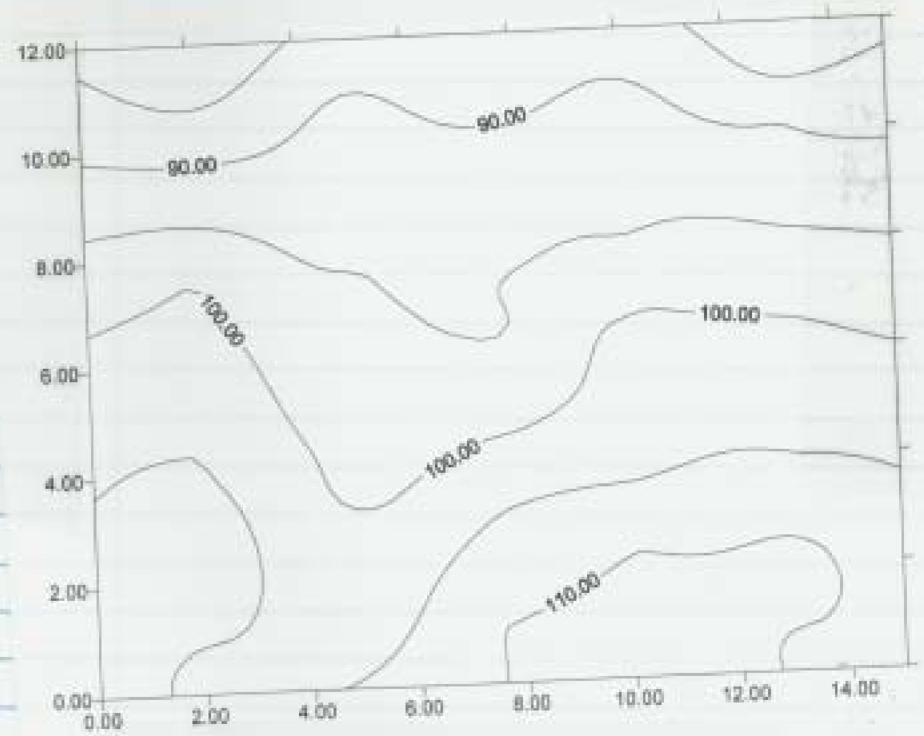
20 min into test



plot of temp field at 20 min

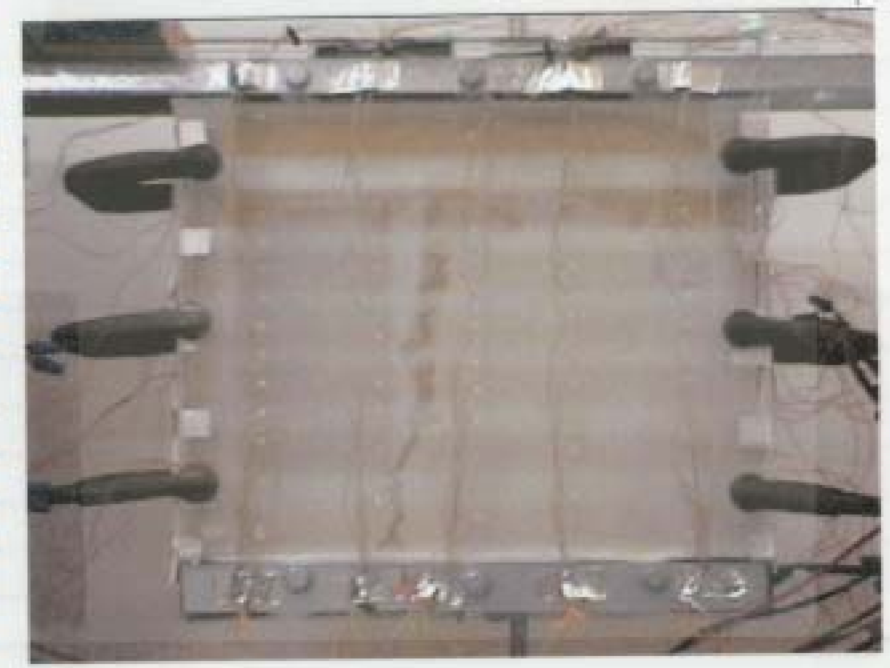
9d

40 min into test

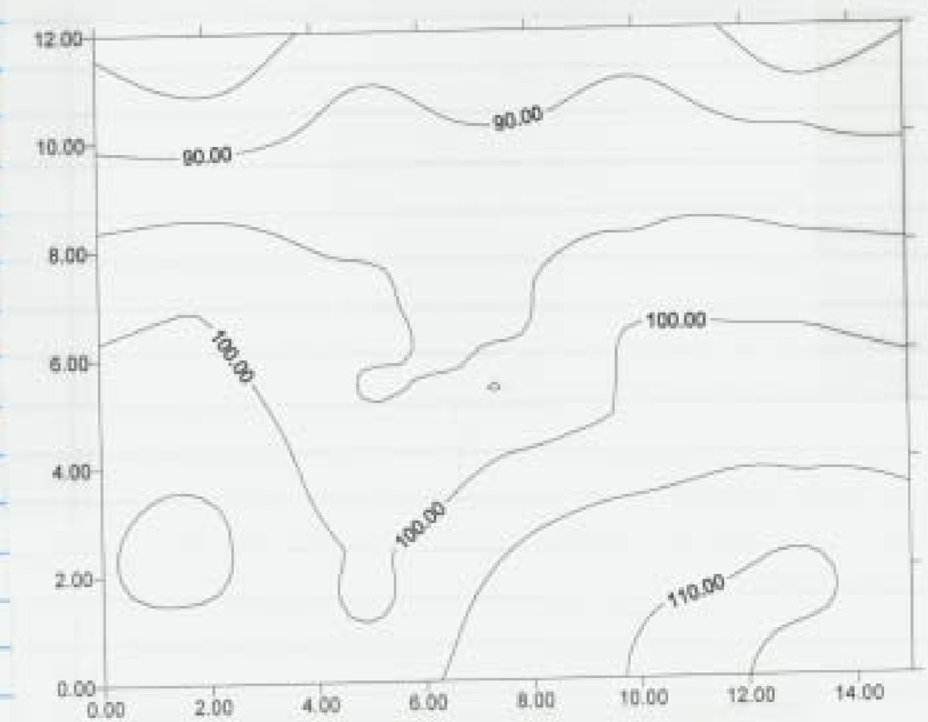


plot of Temp field at 40 min.

9e



60 min into test



plot of temp field at 60 min

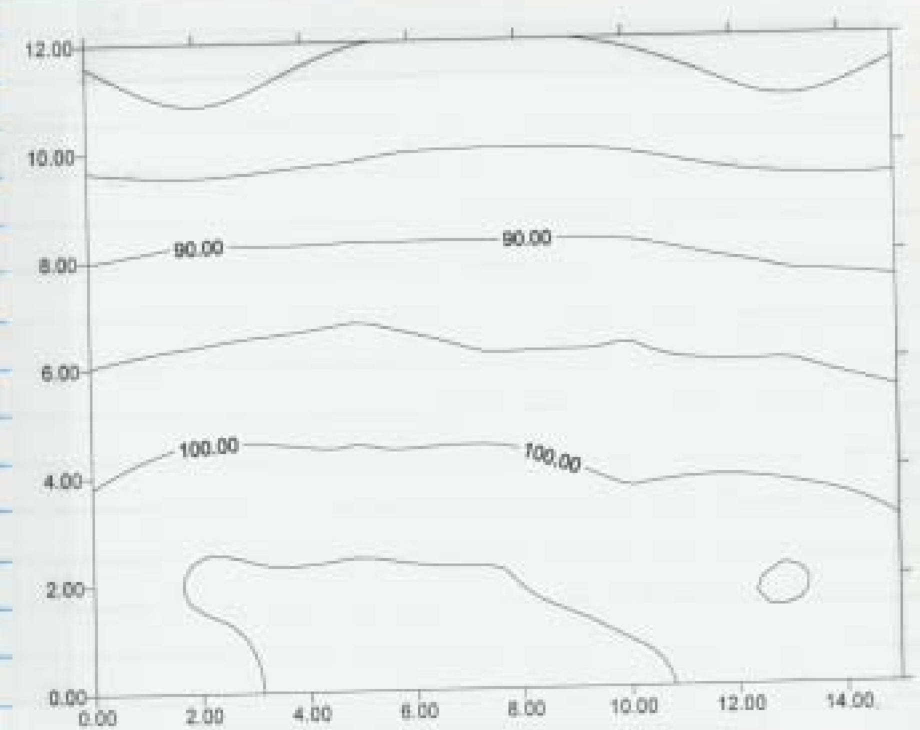
6/26/00 gp

Finger_run_10

Experiment run at flow rate of 0.1 ml/min

Temperature field established using settings on p 91.

Plot of initial temp field is shown below.

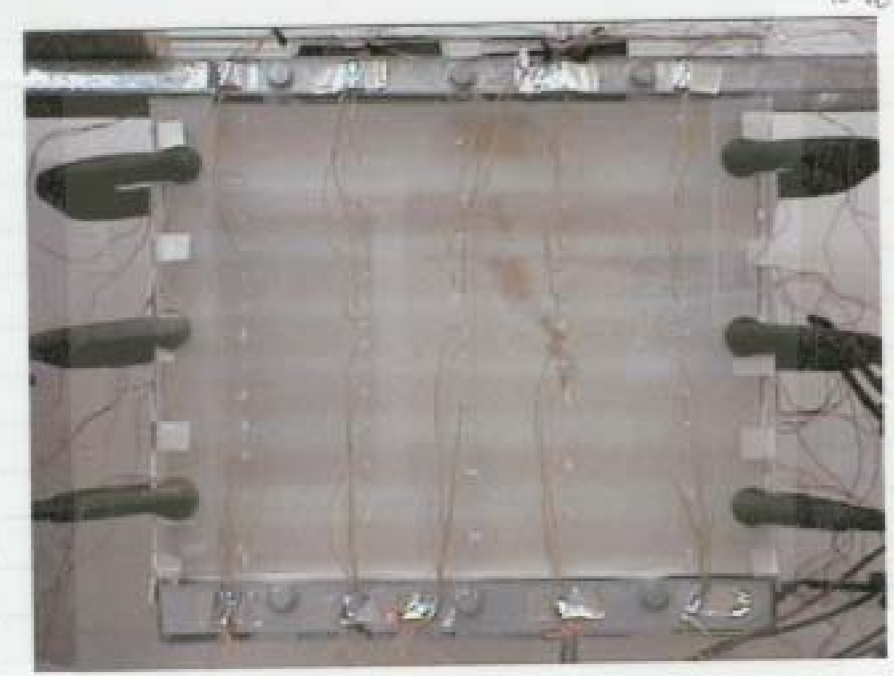


Temp data is stored in MS Excel file
Named Finger_run_10.xls
Digital videocassette of experiment is labeled
finger_run_10.video
Test run for ~ 60 min.

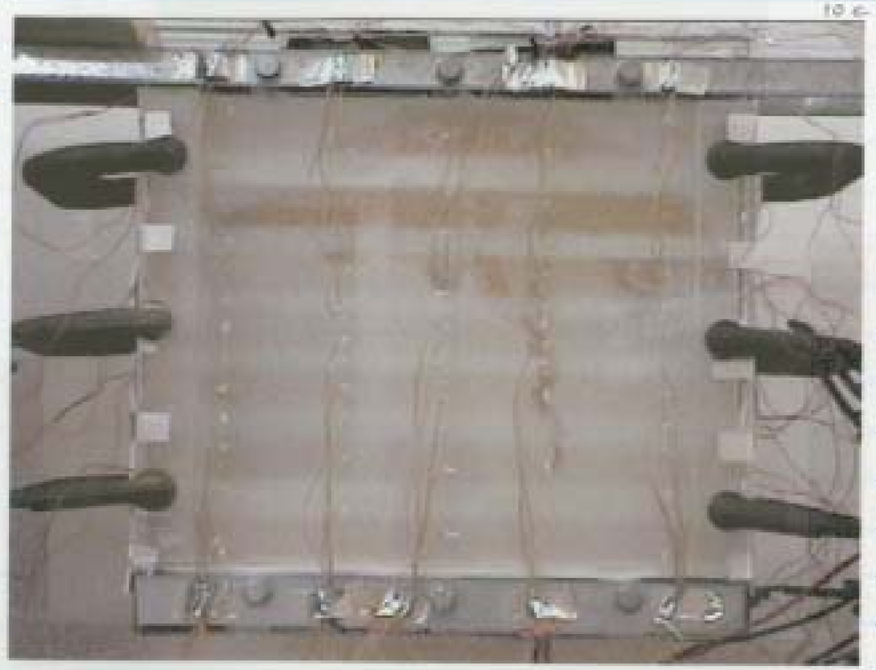
6/27/00 gp

Results & observations.

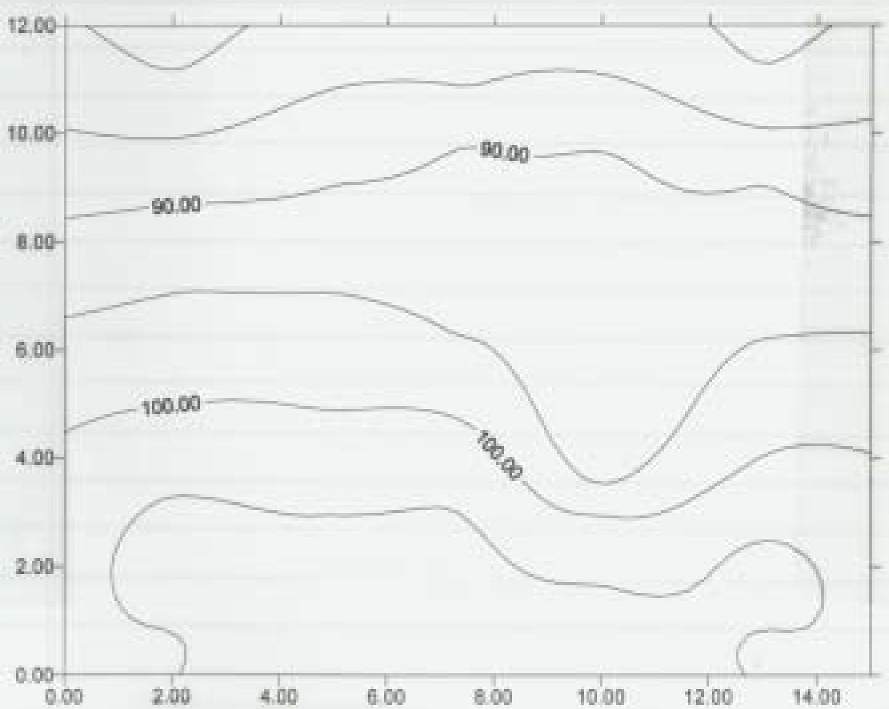
10 m



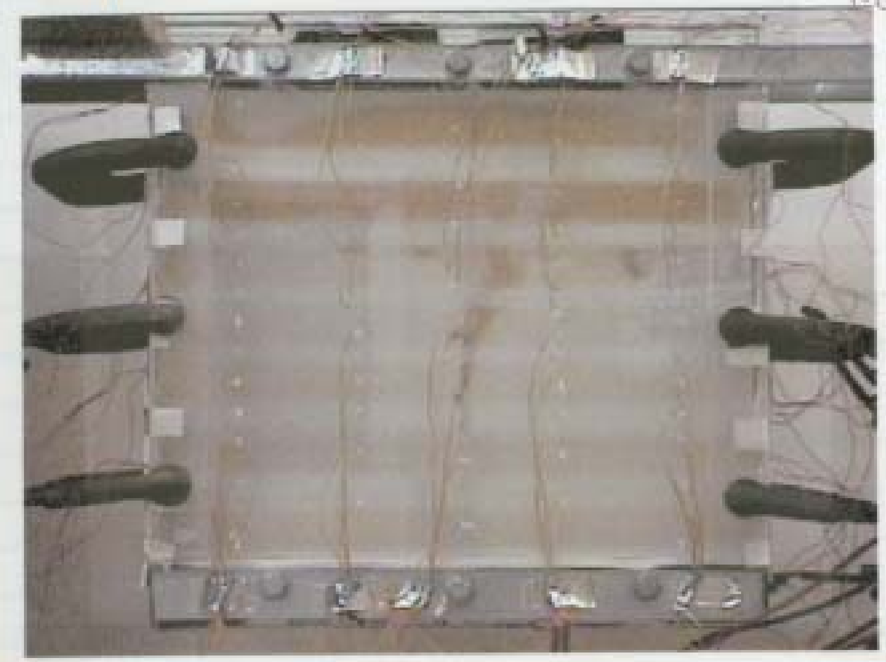
5 min into Test.



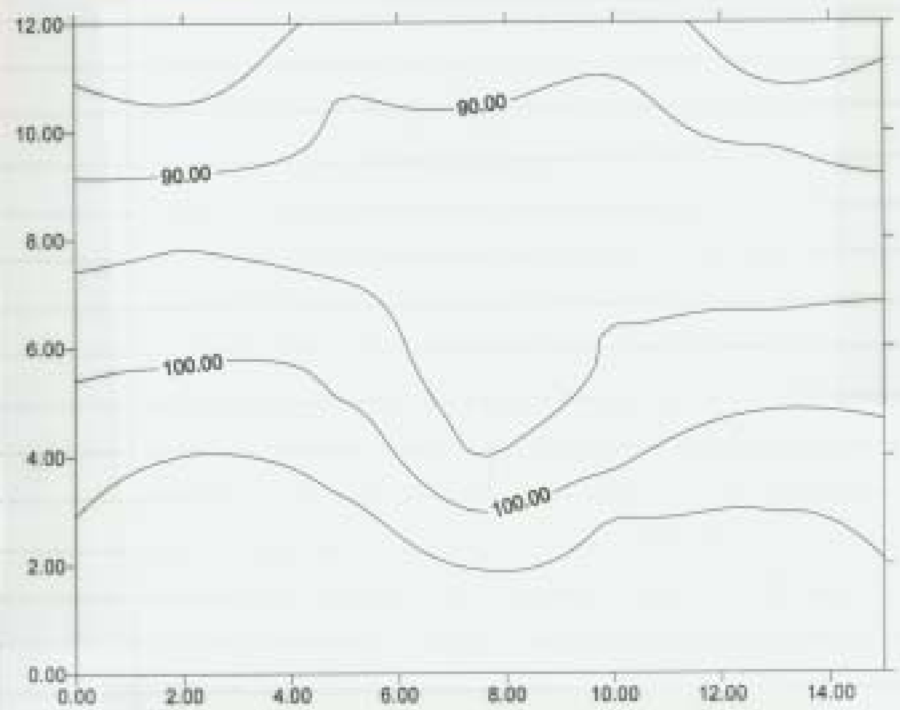
20 min into test



Plot of temp field at 20 min.



60 min into Test



Plot of temp field at 60 min

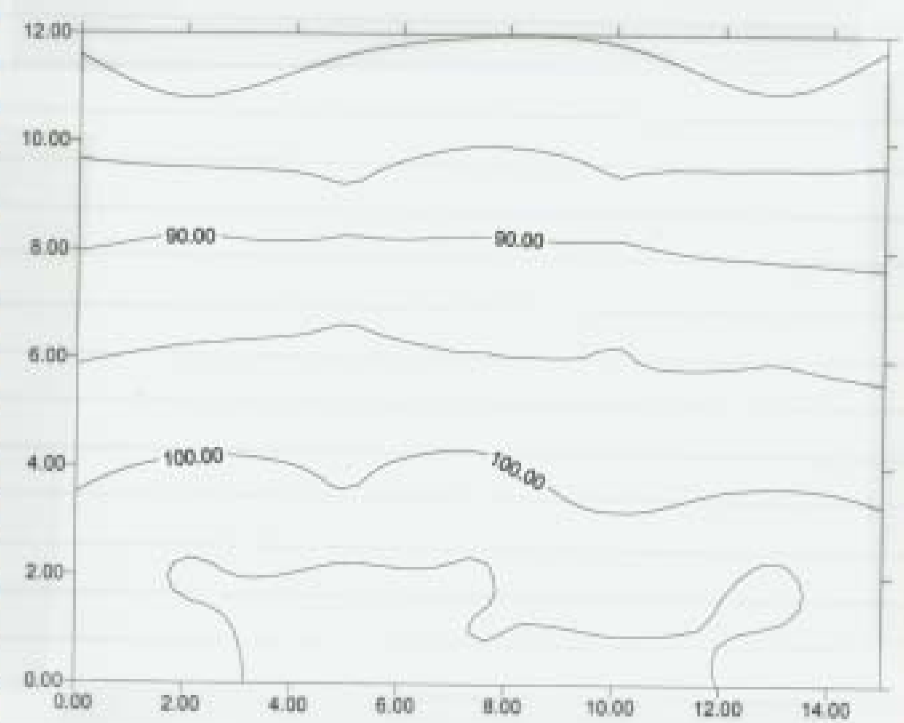
6/27/00 JP

Finger_run_11

Experiment run at 0.05 ml/min flow rate

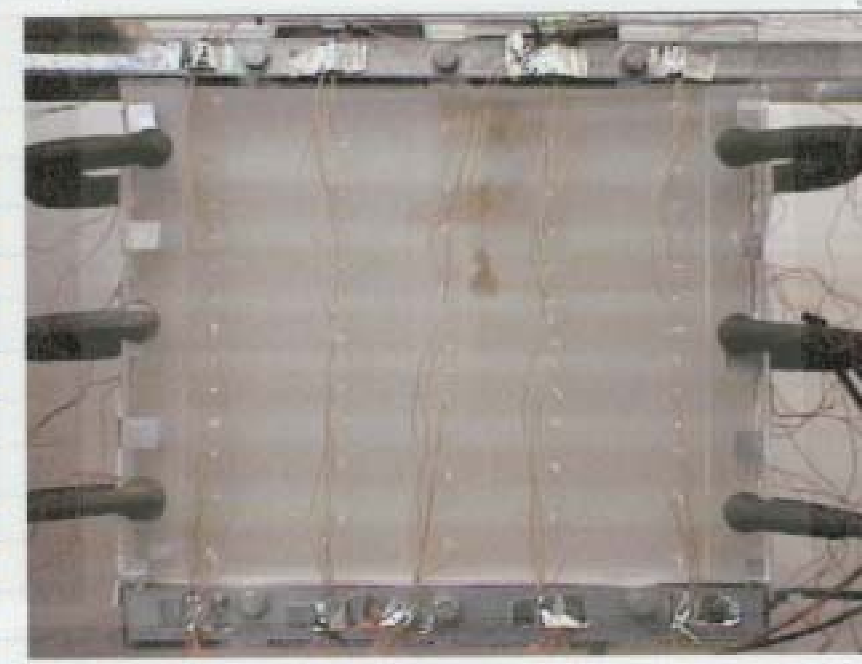
Temperature field established using settings on p 91.

Plot of initial temp field shown below



Temp data stored in MS Excel file named Finger_run_11.xls.
Digital videocassette of experiment is labeled Finger_run_11.video
Test run for ~60 min.

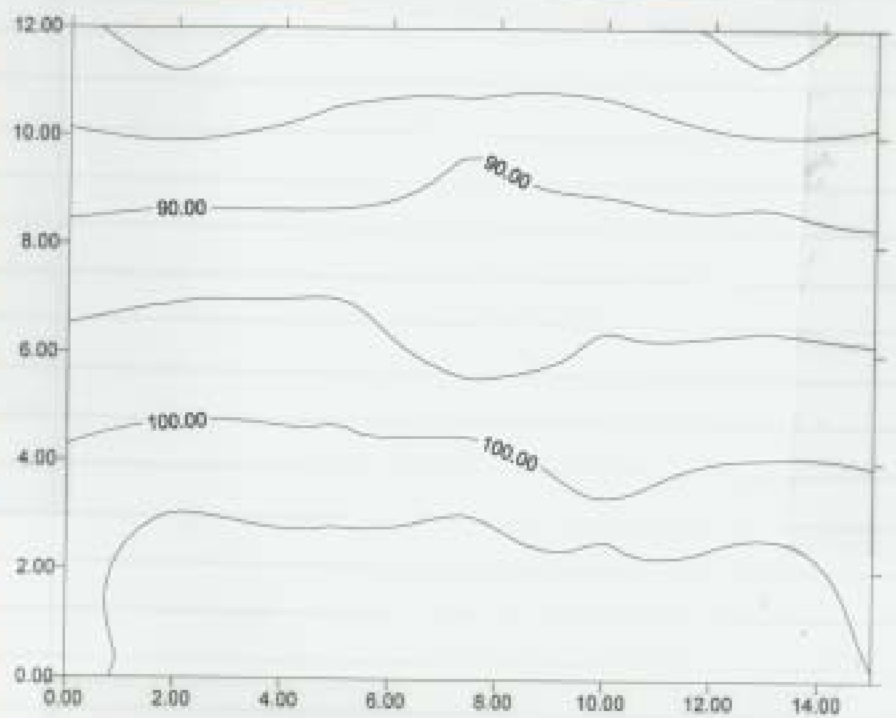
6/28/00 JP
Results and observations



5 min into Test.

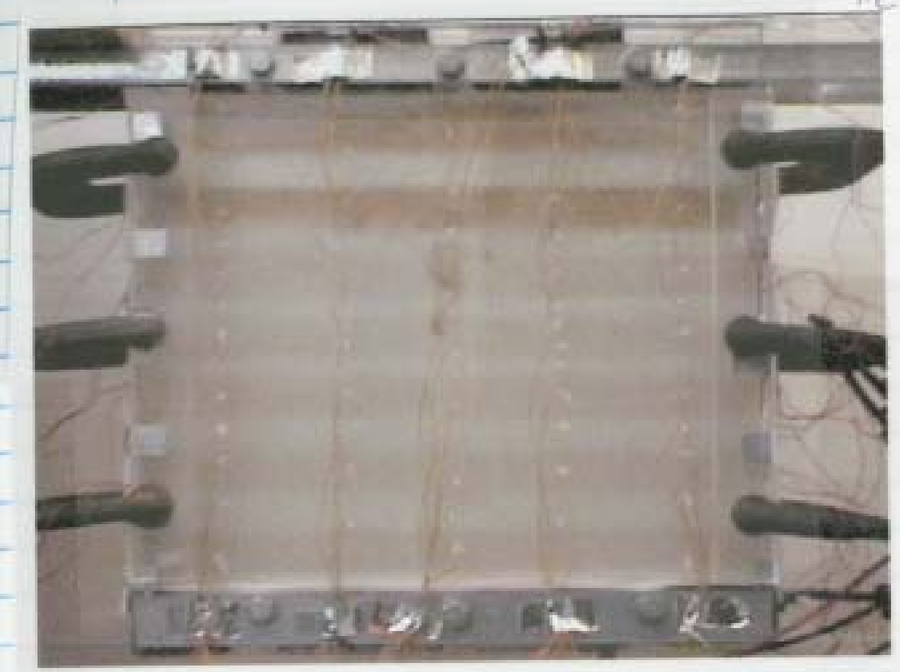
11c

20 min into test

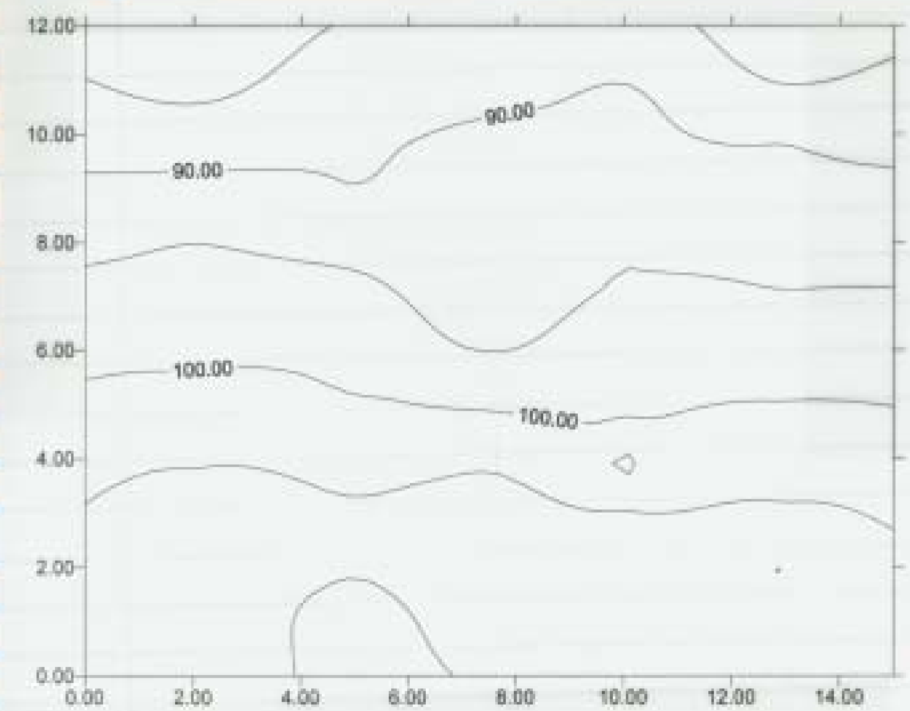


Plot of temp field at 20 min

11e



60 min into test



Plot of temp field at 60 min

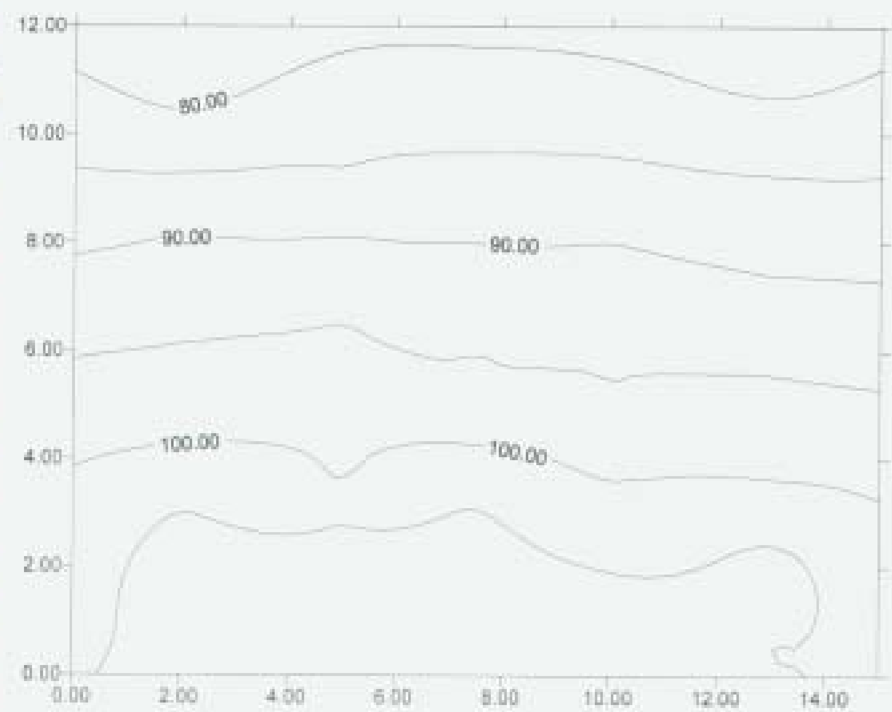
6/29/02 JP

Experiment run 12

Experiment run at 0.025 ml/min flow rate

Temperature field established using settings on p. 91

Plot of initial temp field is shown below



Temp data is stored in MS Excel file named experiment_run_12.xls

Digital videocassette of experiment is labeled experiment_run_12 video

Test was run for ~90 min.

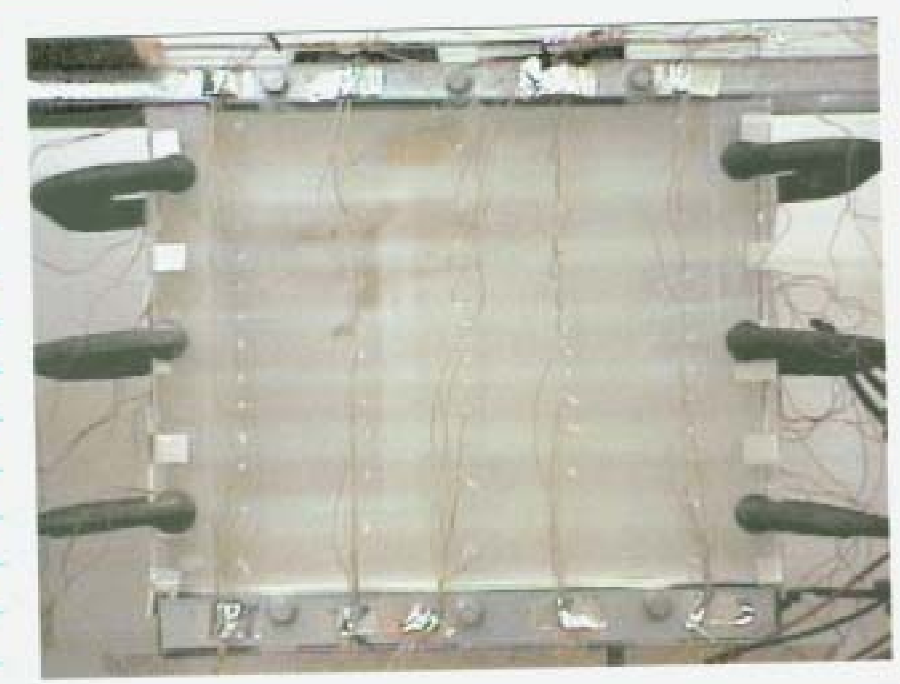
Times recorded on videocassette are as follows:

Min	Time recorded (min)
1-55	1-55
55-59	66-70
59-60	89-90

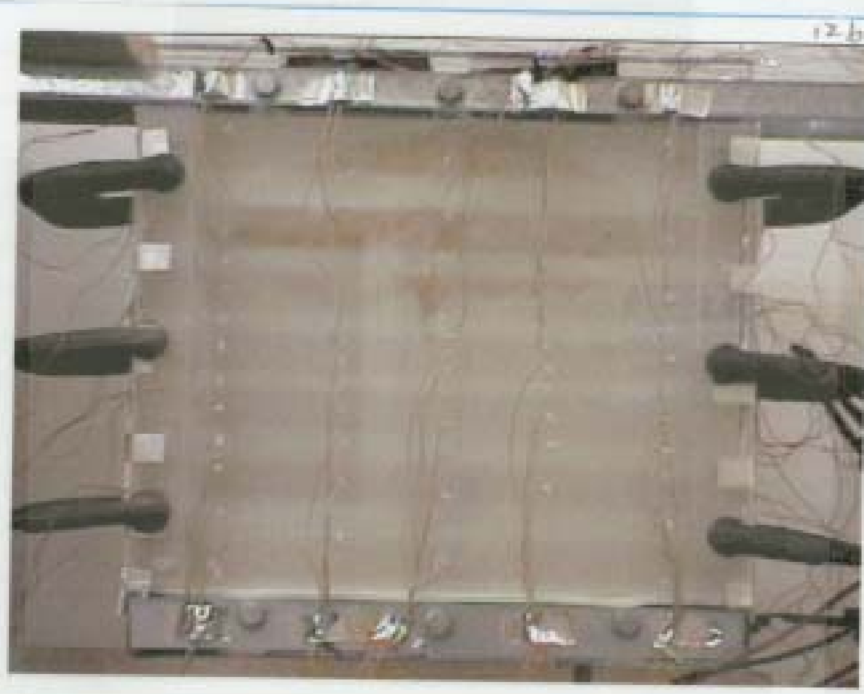
6/29/02 JP

Results + observations

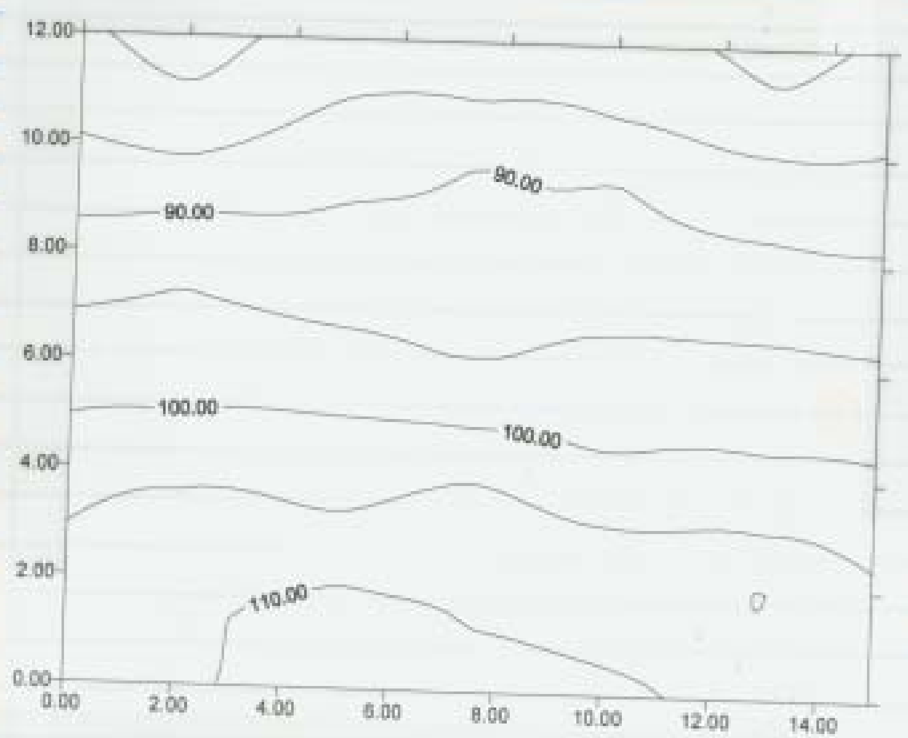
12a



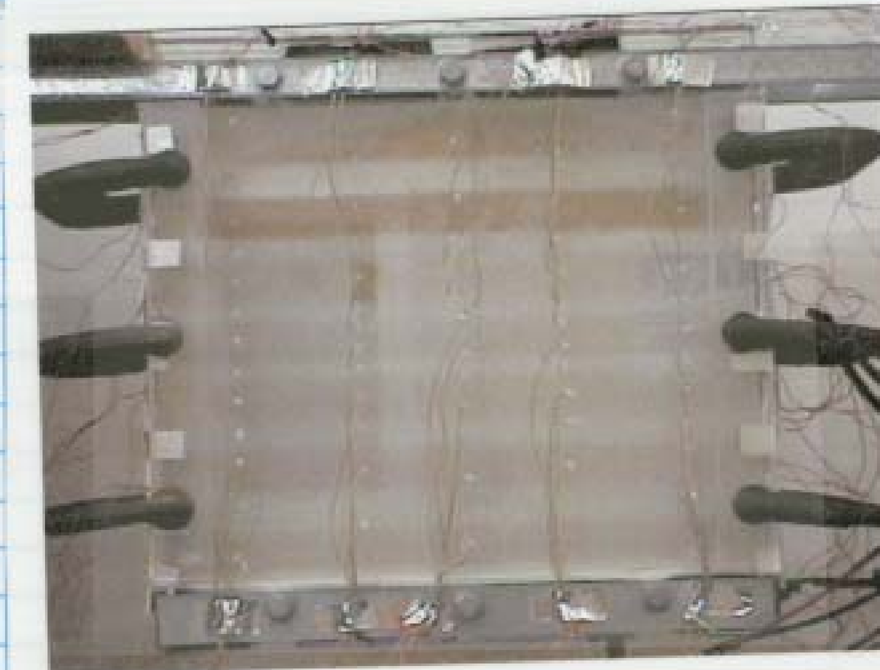
10 min into test



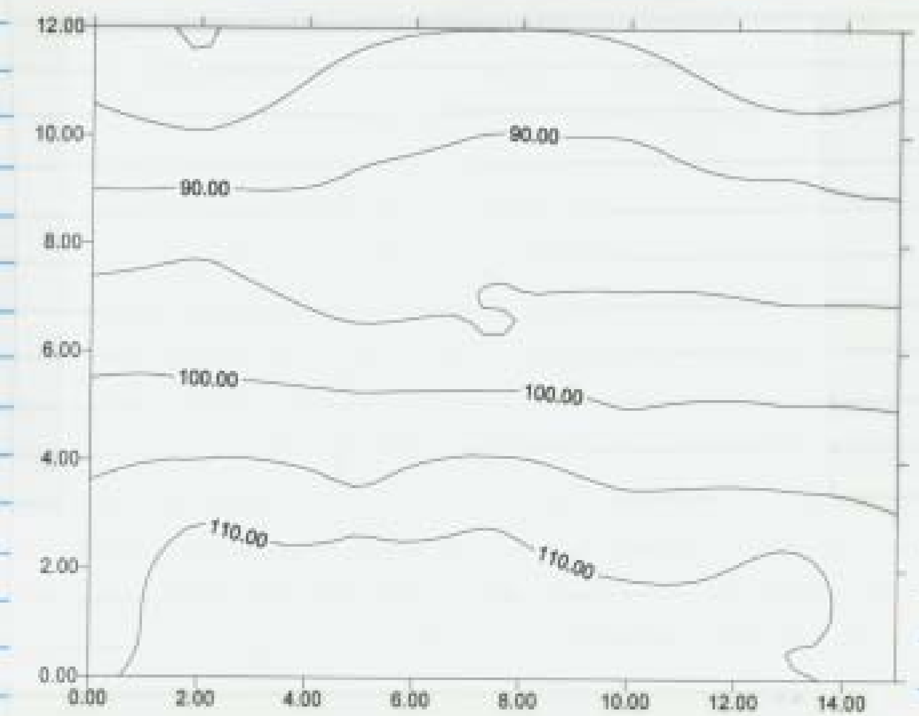
30 min
into test



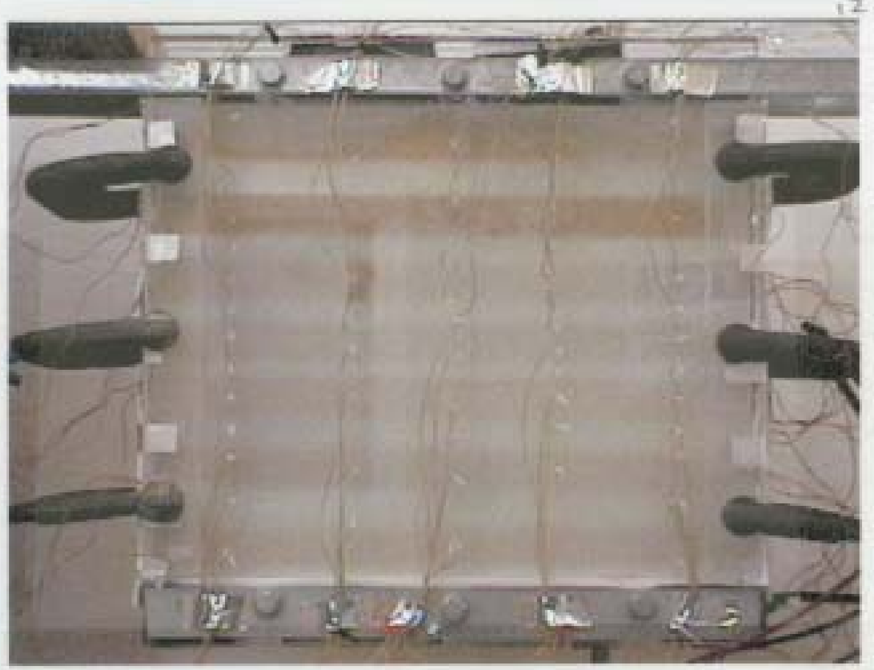
Plot of temp
field at
40 min



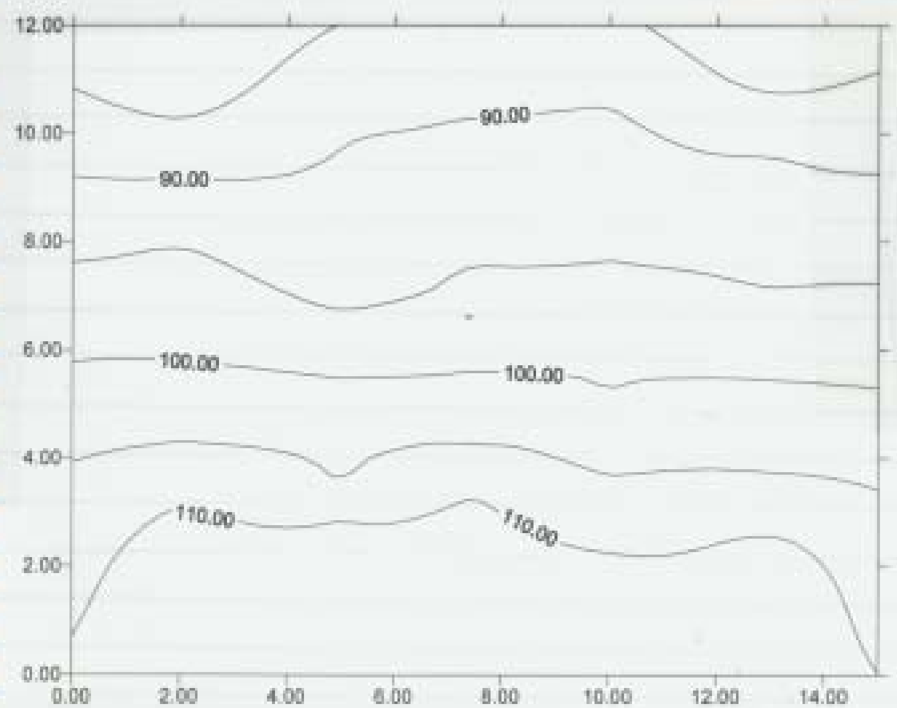
70 min into
Test



Plot of temp
field at
70 min



90 min into test



Plot of temp field at 90 min

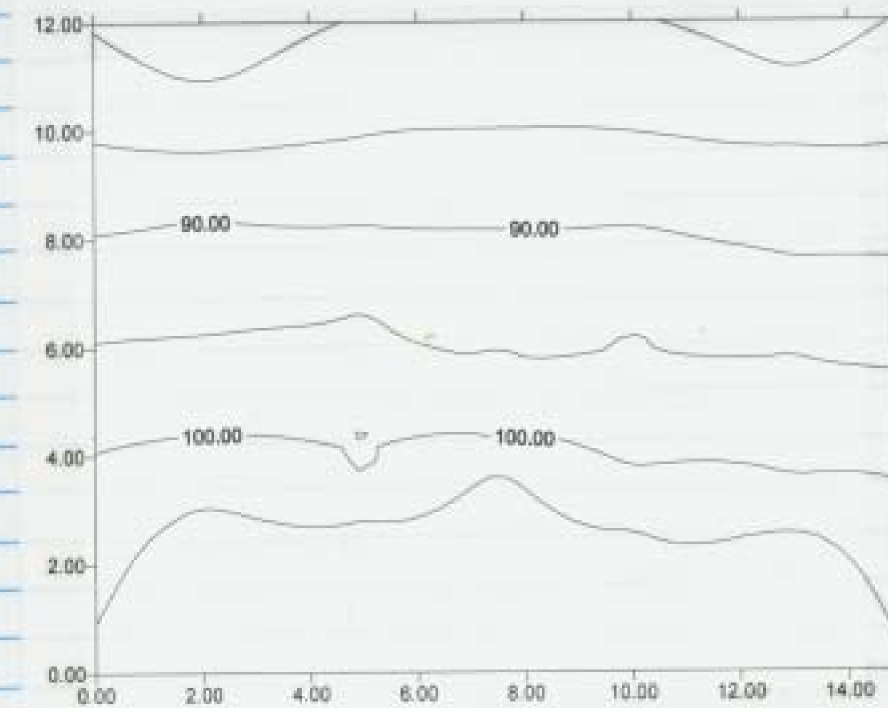
4/29/00 gp

Freeze run_13

Experiment run at 0.2 ml/min flow rate

Temperature field established using settings on p 91.

Plot of initial temp field is shown below.



Temperature data is stored in MS Excel
file named Sgpn_run_13.xls

Digital videocassette of experiment is labeled
Sgpn_run_13.video

Test run for about 74 min.
Times recorded on videocassette are as follows.

MIN	Time recorded (min)
1-58	1-58
58-60	72-74

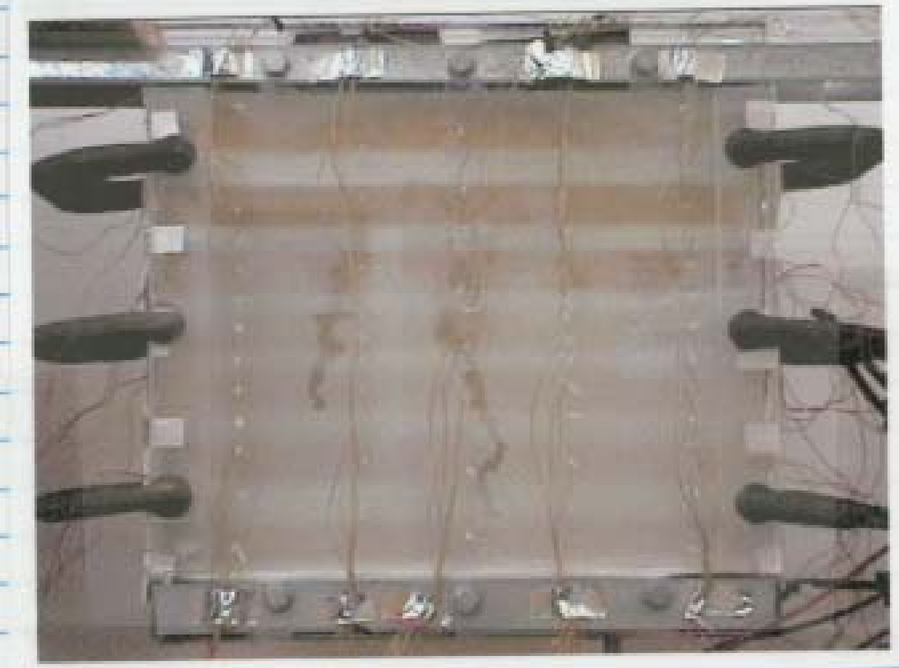
6/30/00 JP

Results + Observations

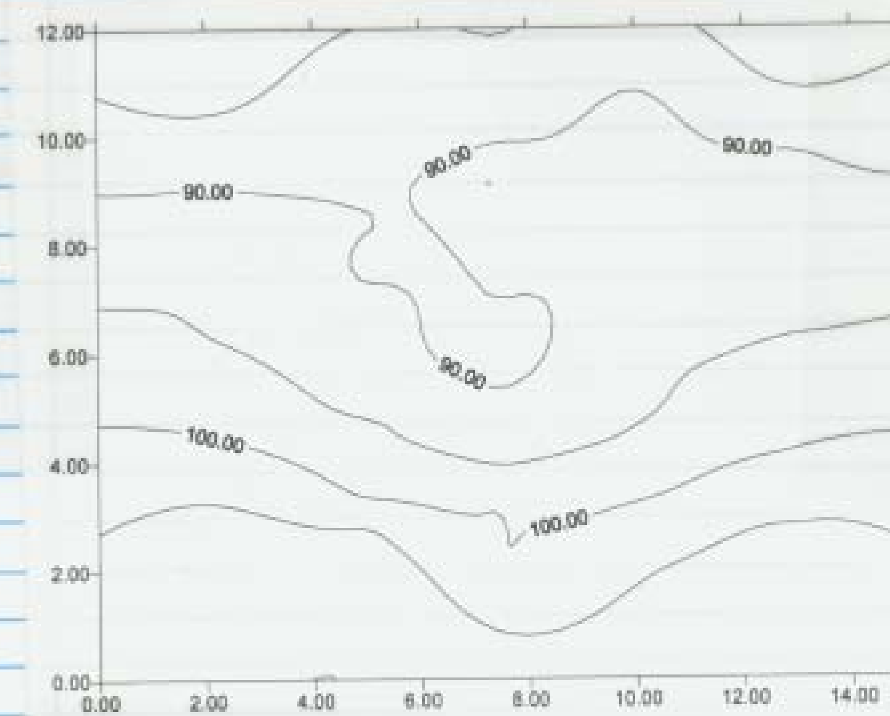
13a

5 min
into test

13c

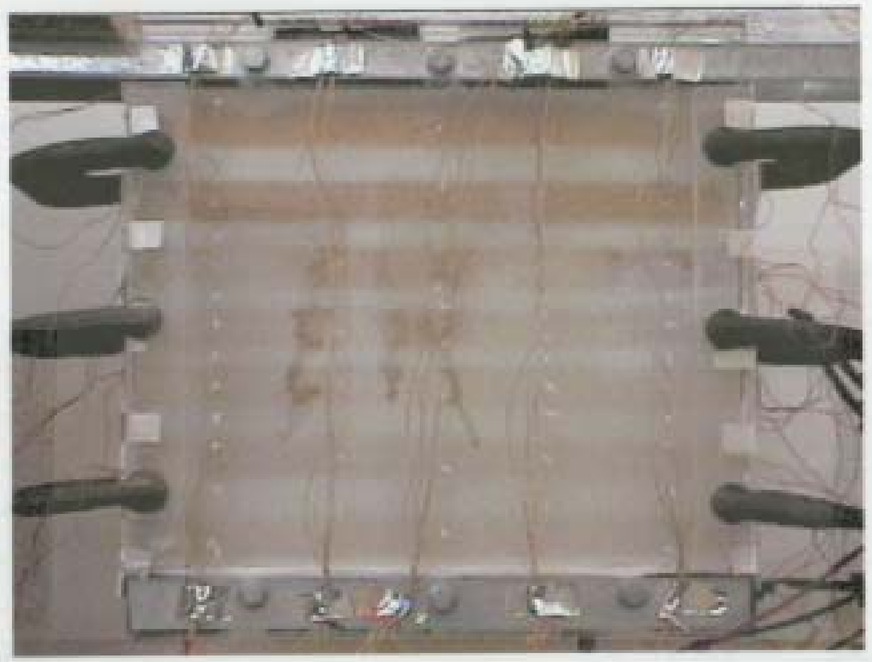


30 min into
test

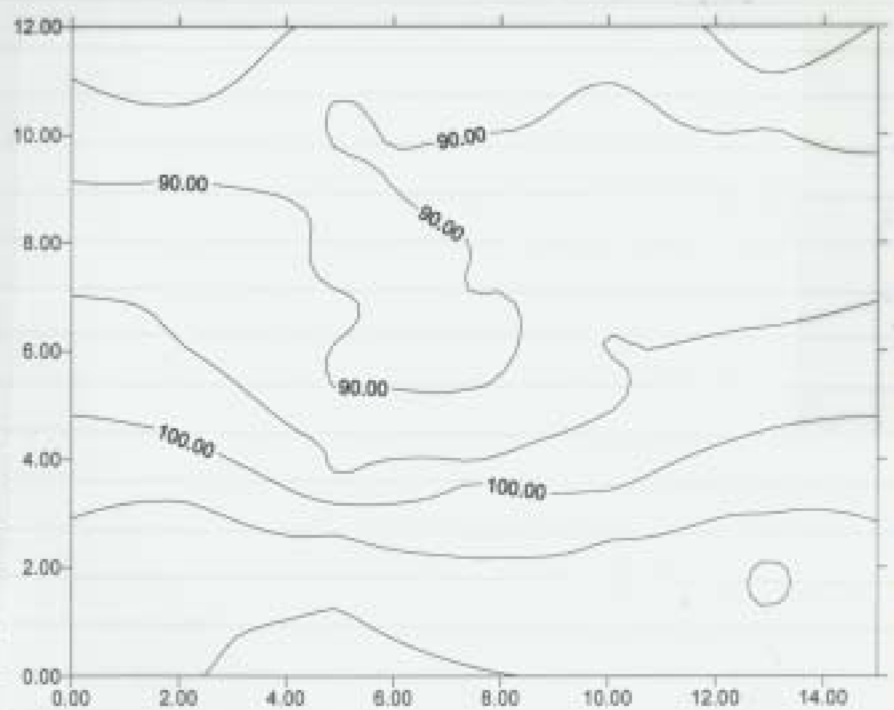


Plot of temp
field at
40 min

13 D

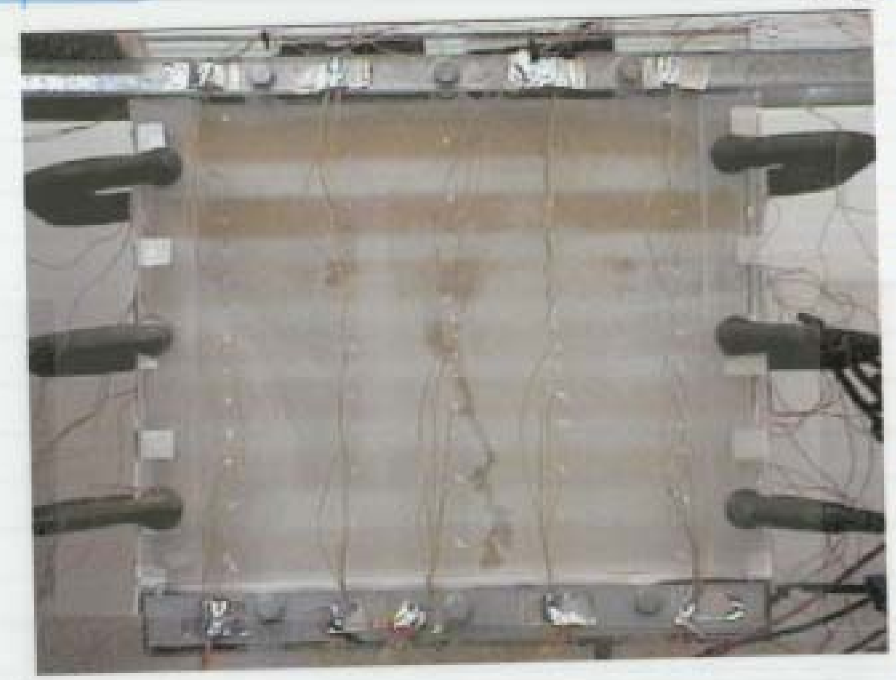


57 min into Test

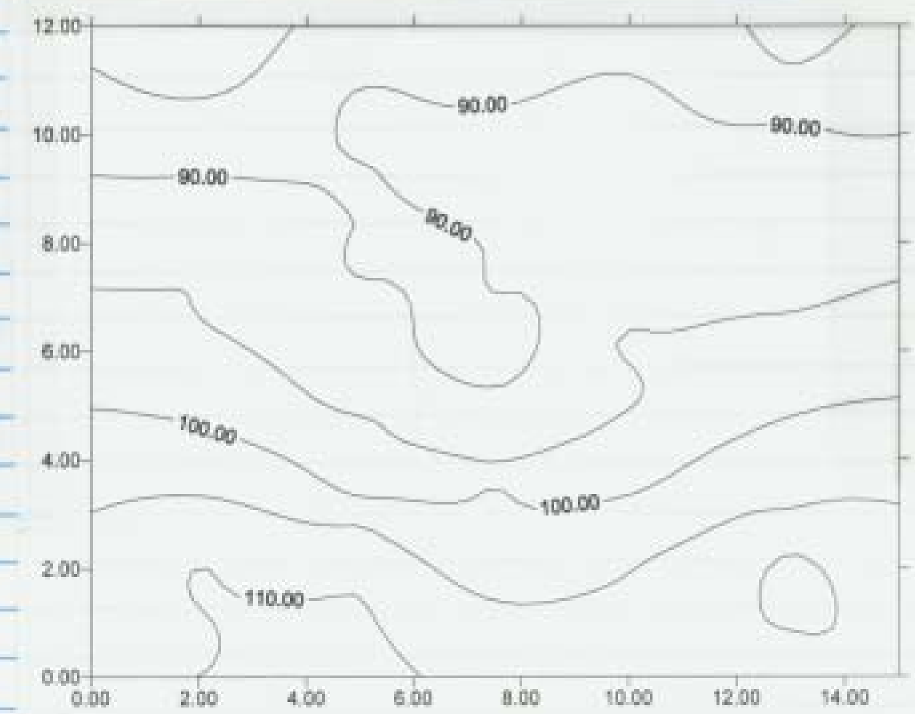


Plot of temp field at 60 min

13 c



74 min into test



Plot of temp field at 75 min

6/30/00 JP

Frozen_run_14

Experiment run at 0.01 ml/min flow rate

Temperature field established using setup on p91.

Temperature data is stored in MS Excel file named Frozen_run_14.xls

Digital videocassette of experiment is labeled Frozen_run_14.video

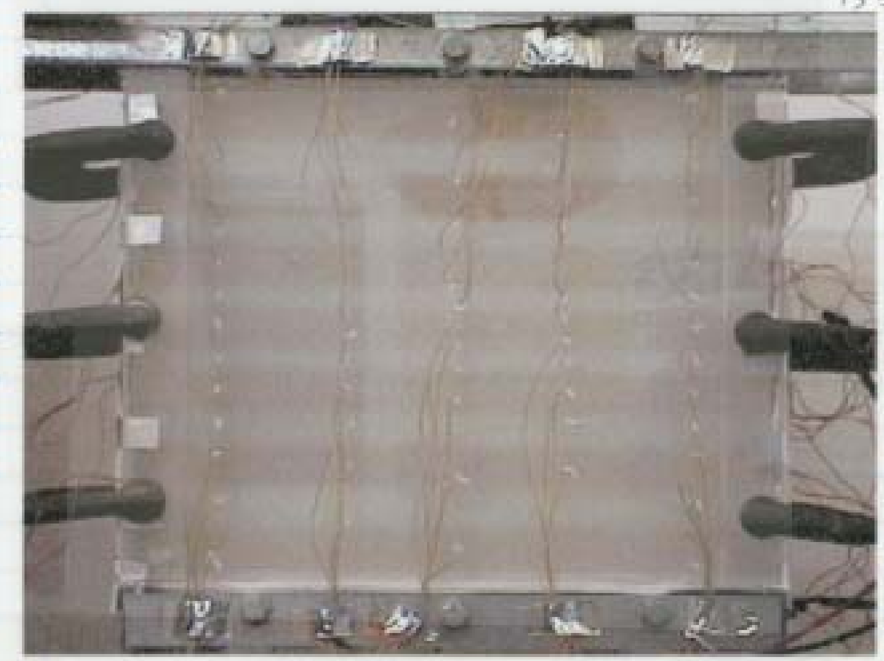
Test run for ~ 246 min
Times recorded on videocassette are as follows.

Min	Time recorded (min)
1-10	1-10
10-12	43-45
12-14	118-120
14-60	200-246

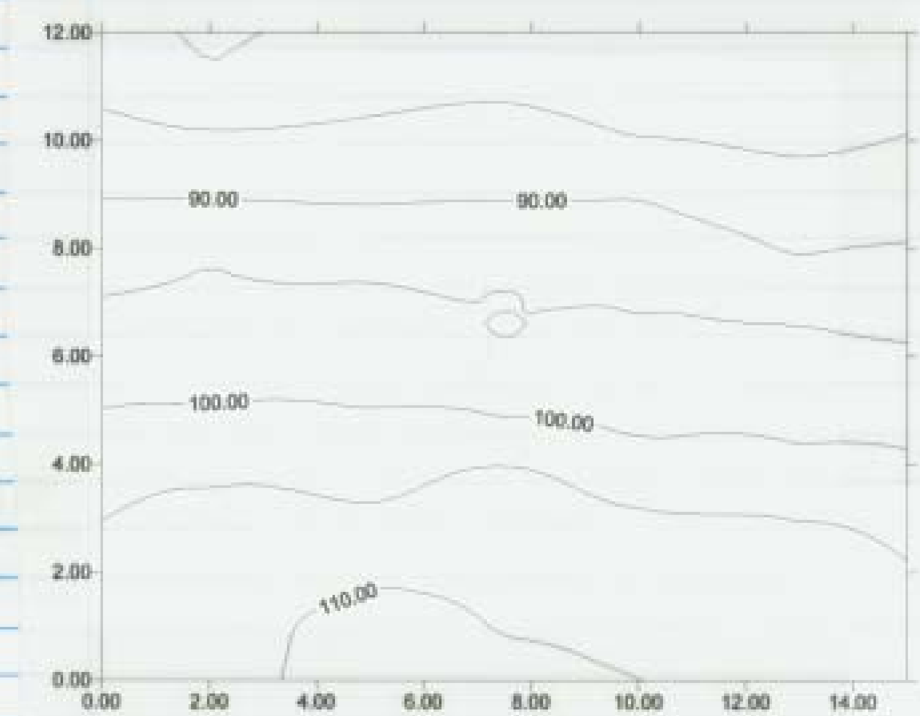
7/5/00 JP

Results + Observations

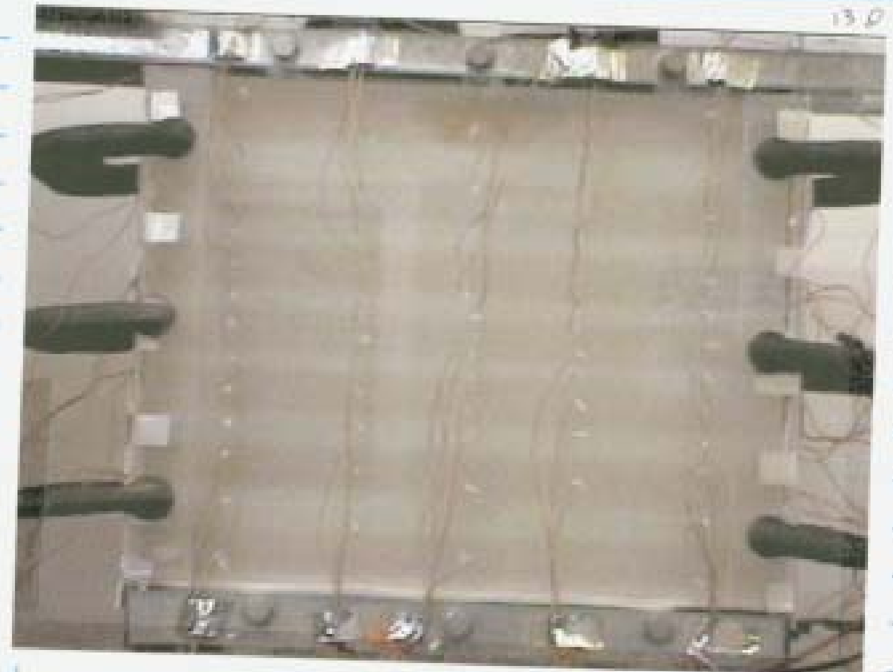
135



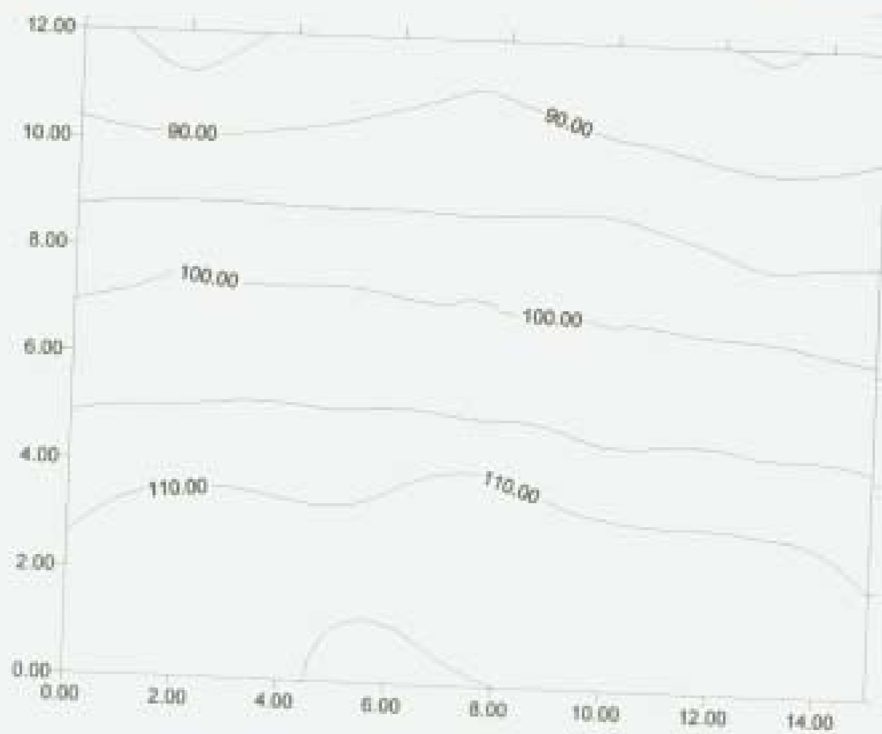
45 min into test



Plot of temp field at 30 min.



240 min
into test



Plot of
temp field
at 240 min

7/7/00 JP

Finger_run_15

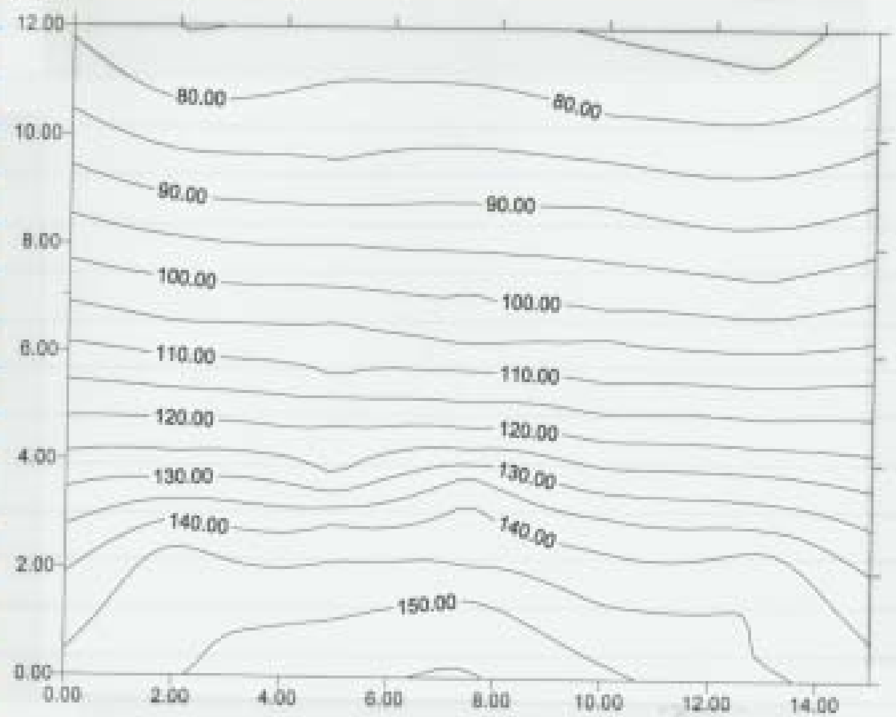
Data and video collected at flowrate of 0.2 ml/min

Settings below were used to establish a steady state temperature field across the glass plate assembly

Strip heater #	Transformer setting
7	0
6	0
5	0
4	20
3	38
2	55
1	71

Side heater #	Power supply setting
5	5
4	10
3	13
2	17
1	20

Plot of initial temperature field is shown below.



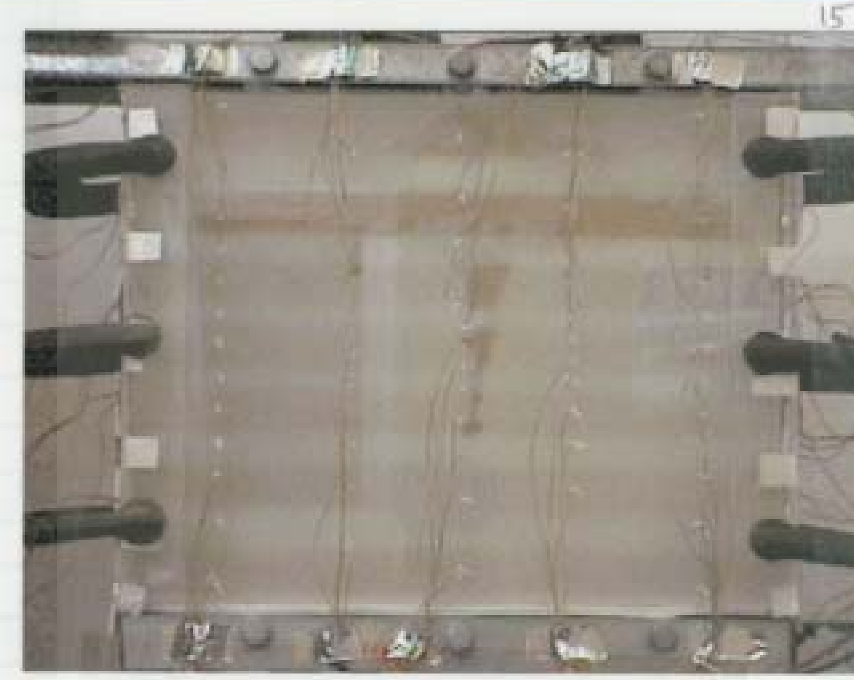
Temperature data is stored in an MS Excel file named Forge-run-15.xls

A digital video/movie of the experiment is labeled Forge-run-15.DV.mov
This test ran for ~60 min

7/10/00 JP

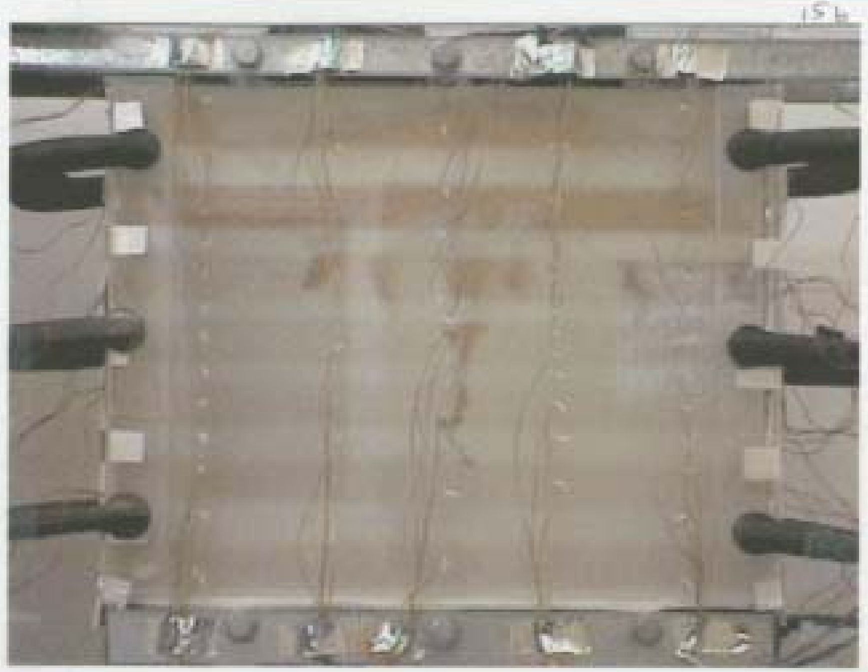
Results + observations.

15a

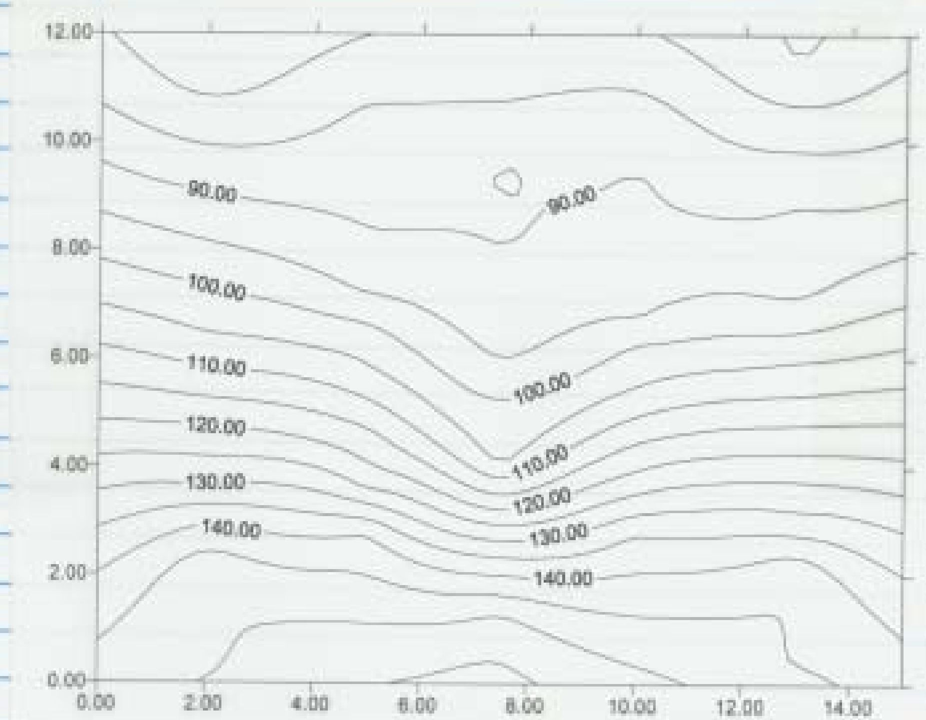


5 min into test

15b

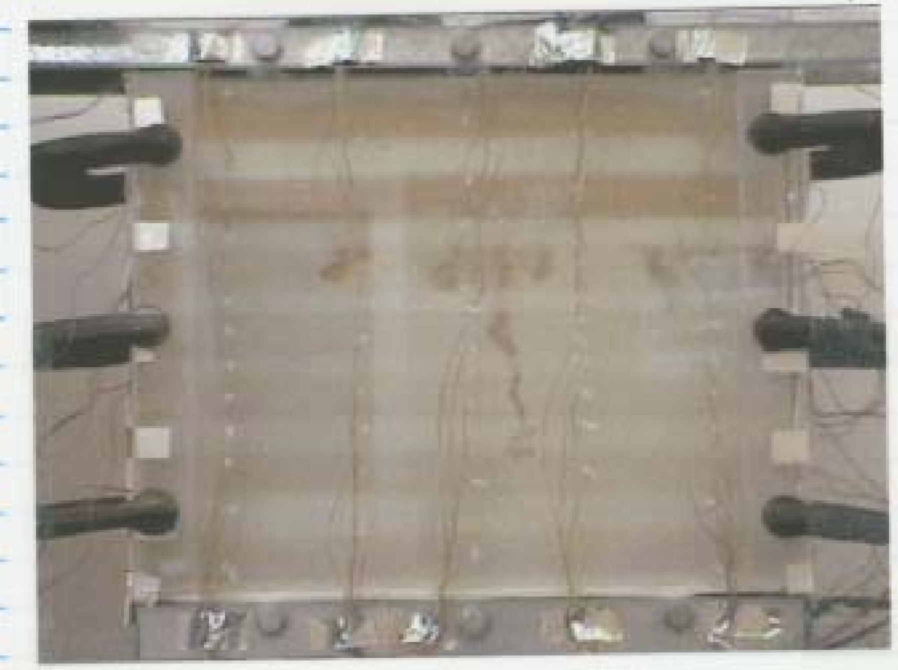


20 min into test

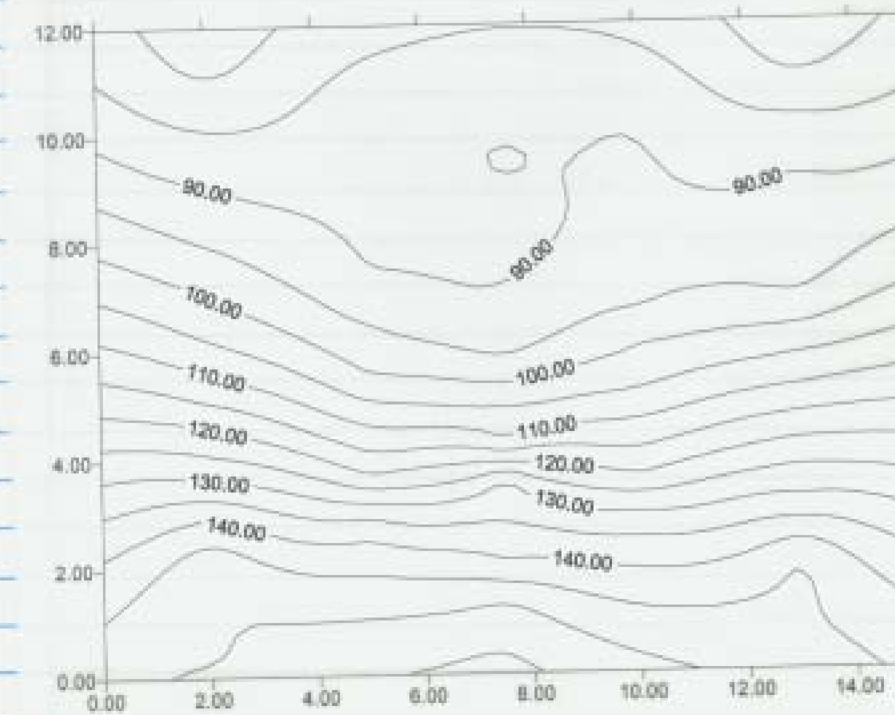


Plot of temp field at 20 min

15d



60 min into test



Plot of temp field at 60 min

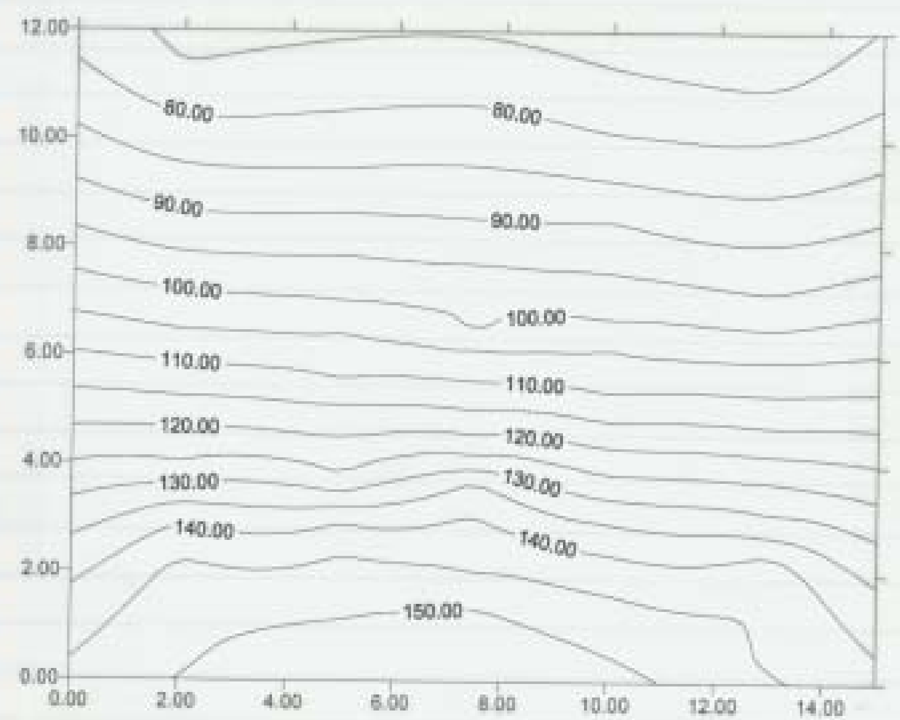
7/10/00 JP

Frozen run 16

Data and video collected at flow rate of 0.3 ml/min

A steady state temp field was established using settings on p 119

Plot of initial temp field is shown below.



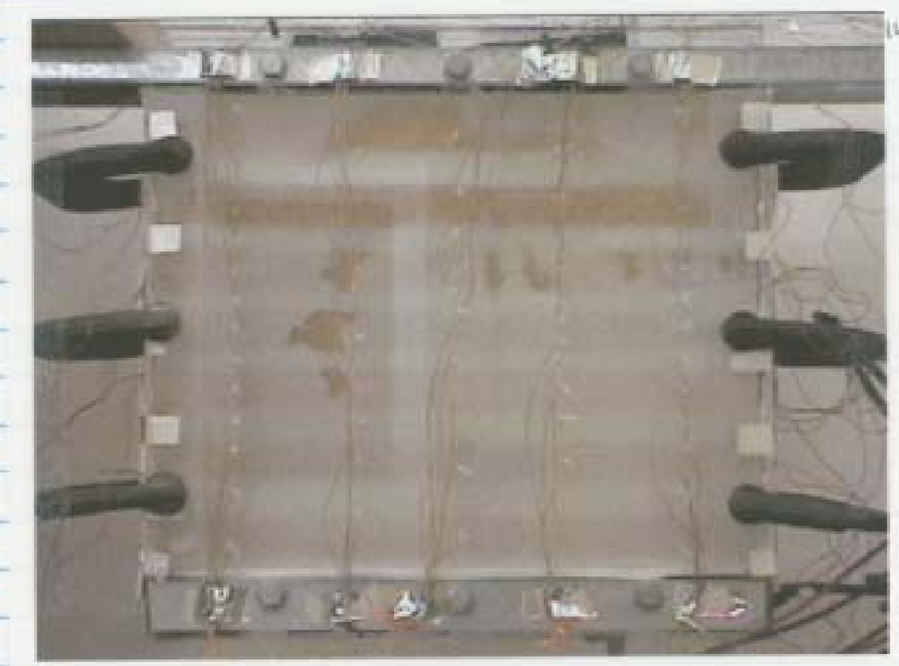
Temperature data is stored in an MS Excel file named Frozen_run_16.xls

Digital video cassette of experiment is labeled Frozen_run_16.video

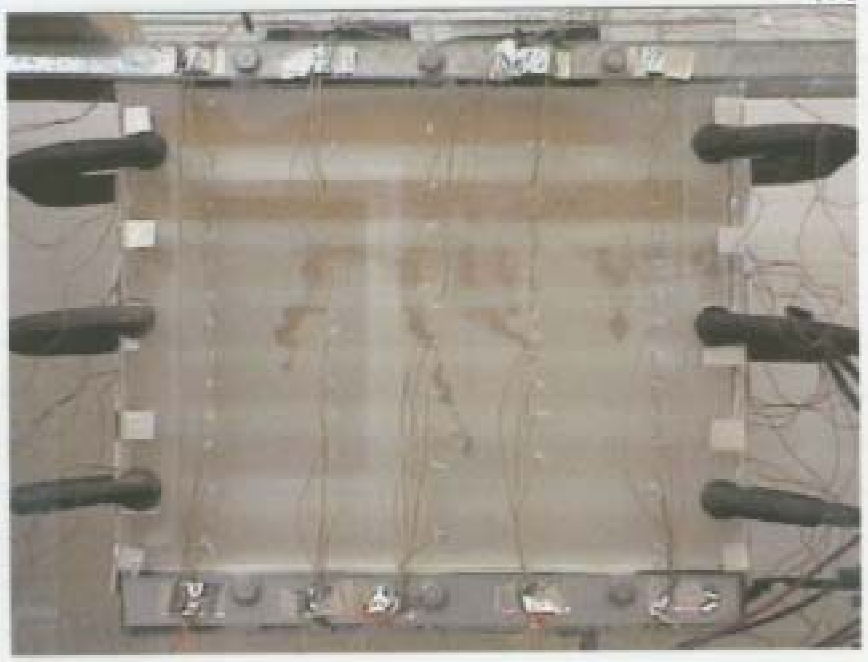
Test run for ~60 min

7/11/00 JP

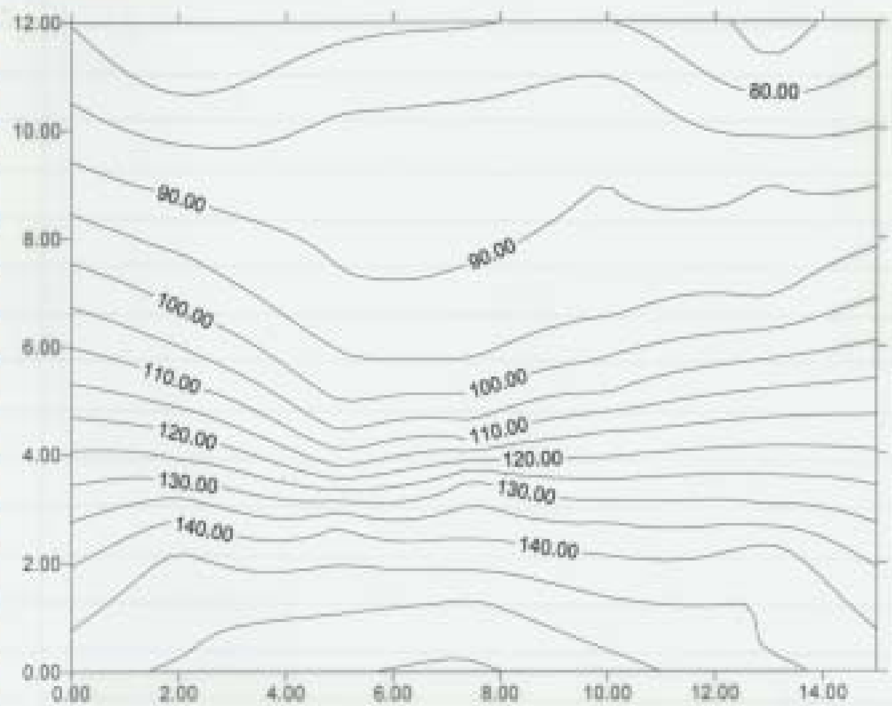
Results & observations



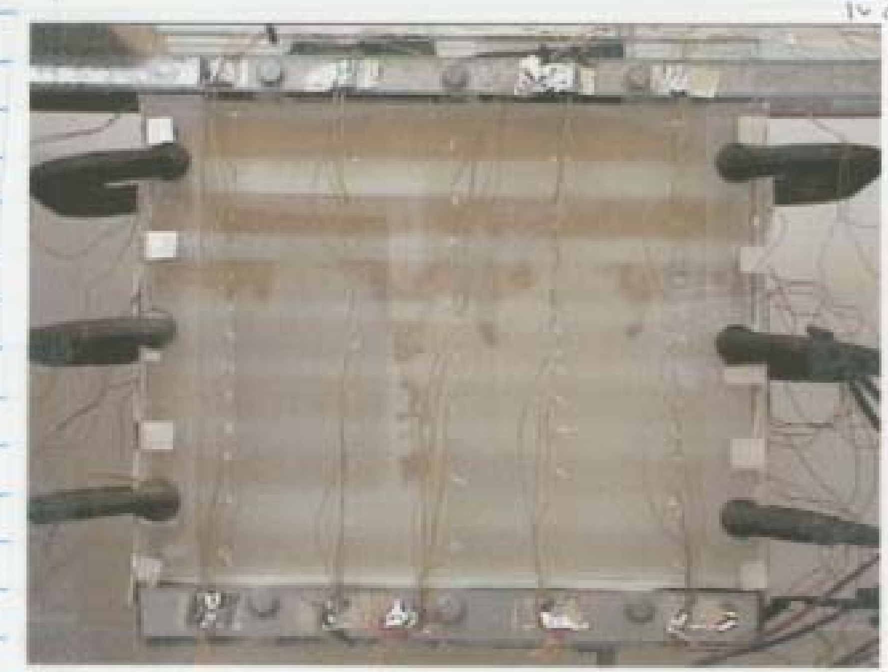
5 min into test



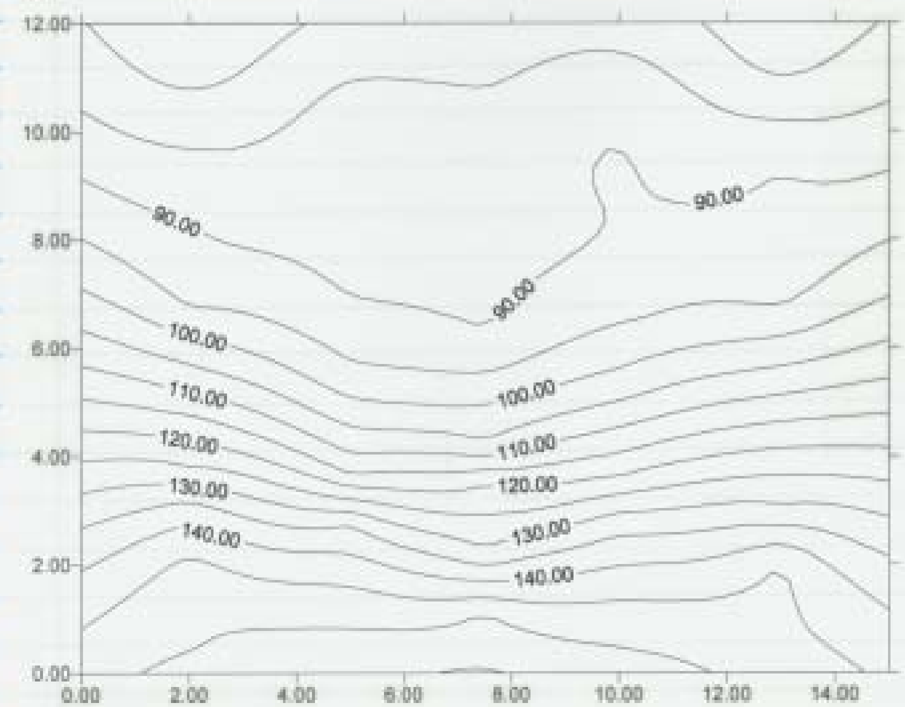
20 min
into test



Plot of
temp field
at 20 min



60 min
into test



Plot of temp
field at
60 min

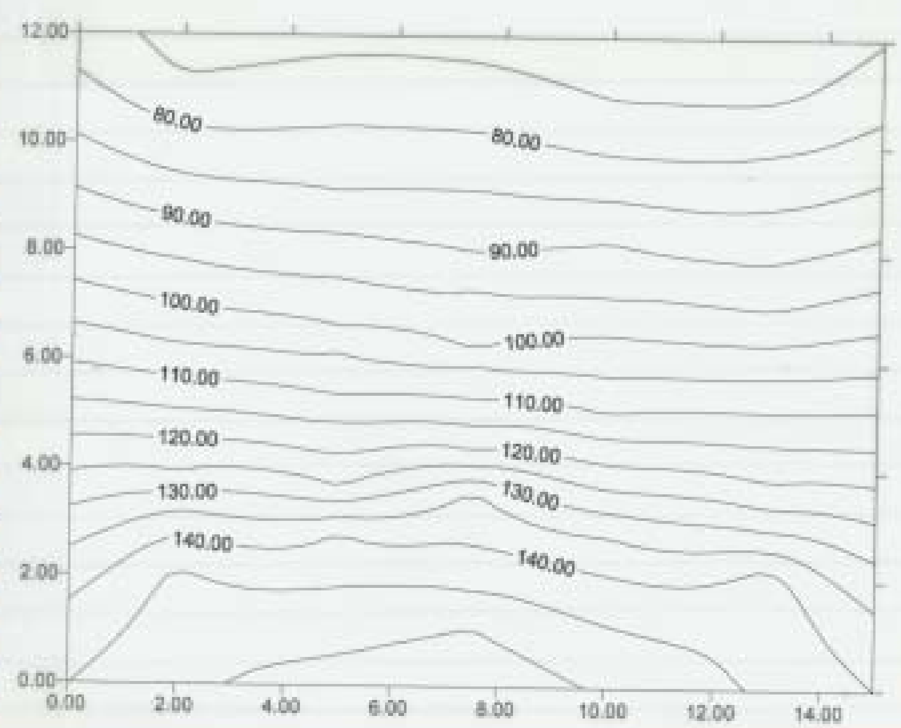
7/11/00 JP

Freeze run 17

Data & video collected at flow rate of 0.1 ml/min

A steady state temp field was established using setup on p 119.

Plot of initial temp field is shown below



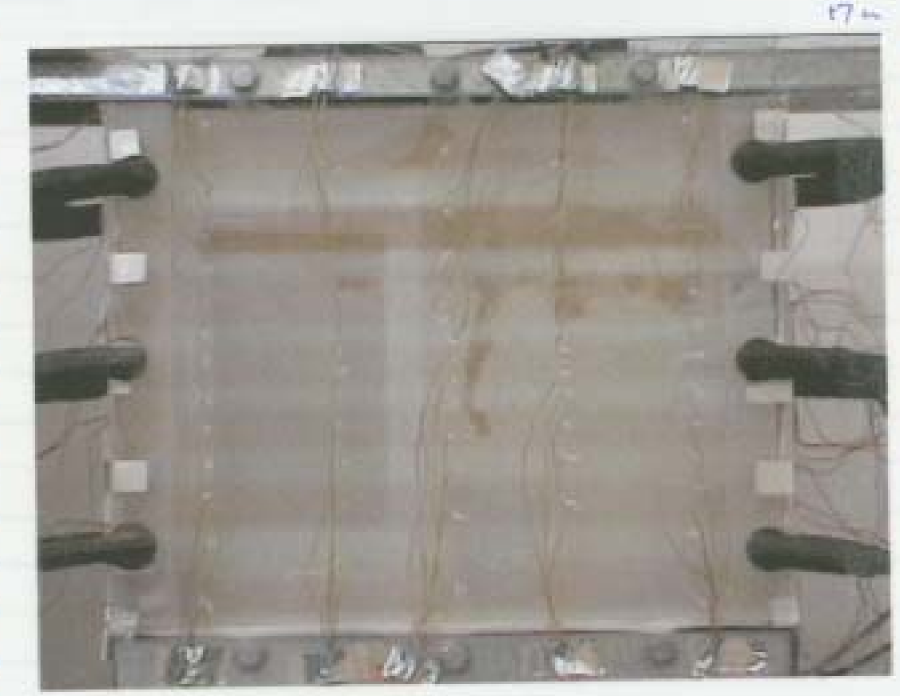
Temperature data is stored in file named Freezerun 17.xls

Digital video of experiment is labeled Freezerun 17 video.

Test run for ~60 min.

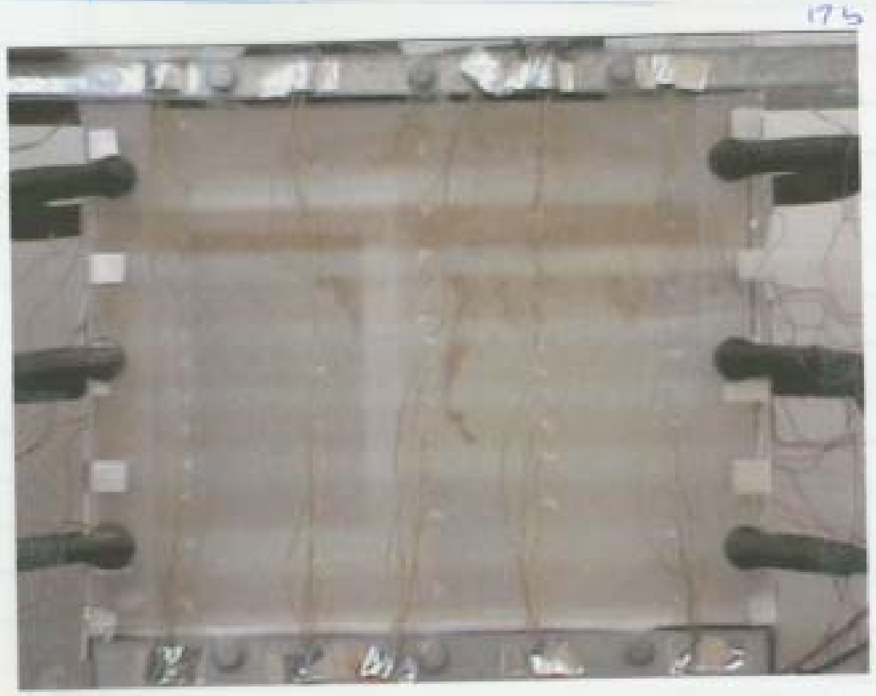
7/12/00 JP

Results & Observations.

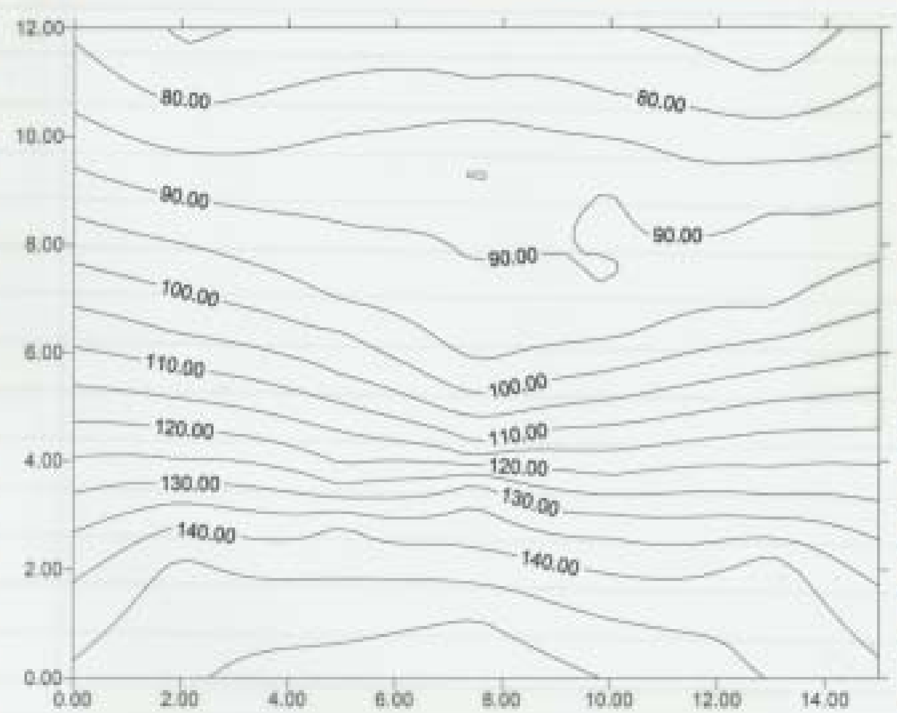


10 min into test

17b



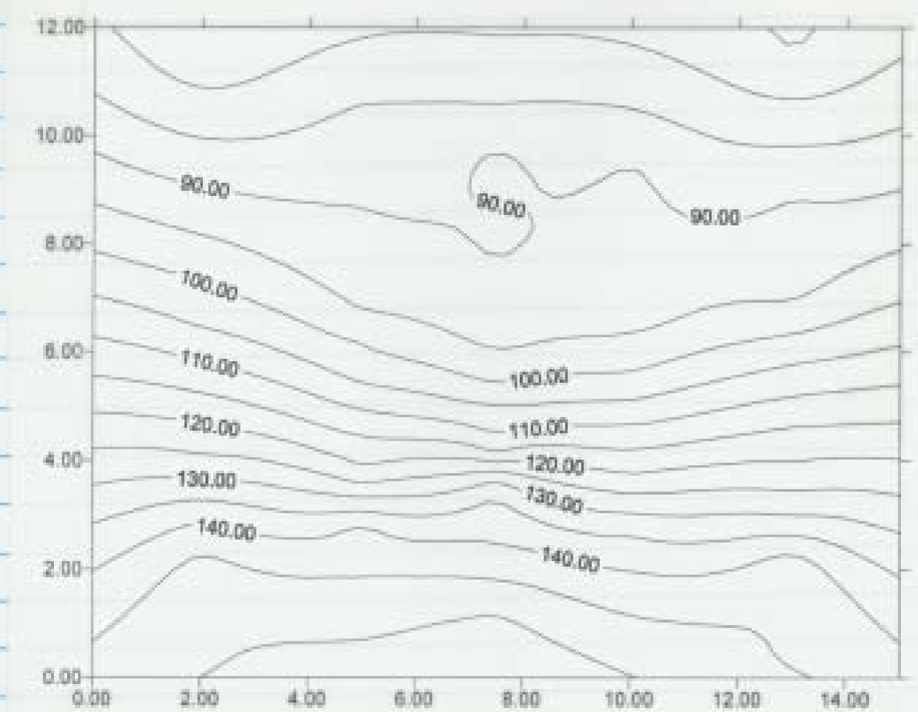
30 min
into test



Plot of temp
field at
30min

17c

60 min
into test



Plot of temp
field at
60 min

7/12/00 gp

Finger_run_18

Data + video collected at flow rate of 0.2 ml/min

Temperature data is stored in a MS Excel files named Finger_run_18a.xls and Finger_run_18b.xls. Finger_run_18a.xls contains temp data for first 45 min of test and was taken at 5 min and 30 sec intervals.
Finger_run_18b.xls contains temp data for last 60 min of test (45 min to 110 min) and was taken at 30 sec intervals.

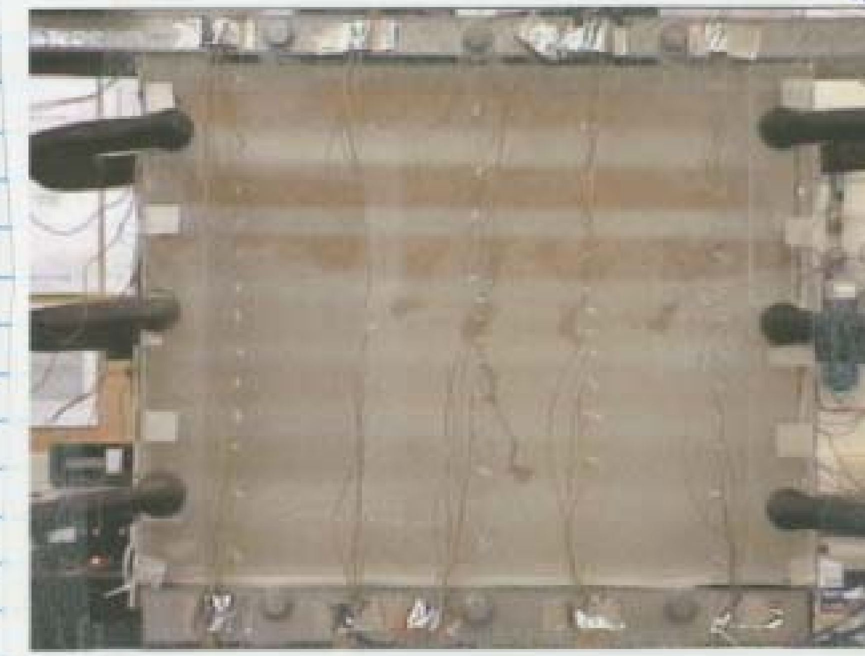
Digital videocassette of the experiment starting at 45 min into experiment is labeled finger_run_18b.video

Test run for ~110 min

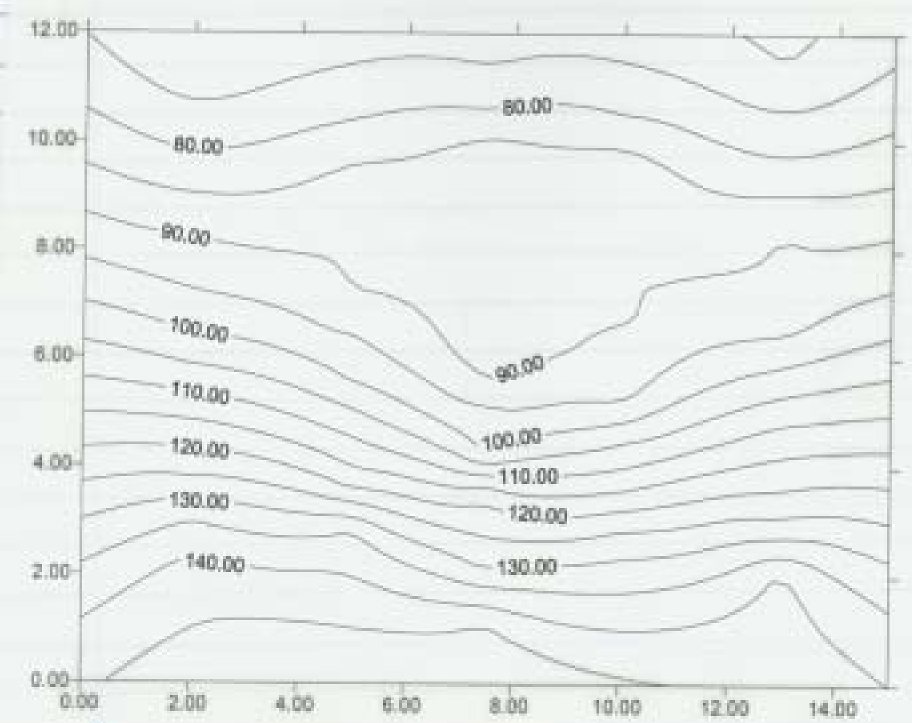
7/13/00

Results and observations.

18a

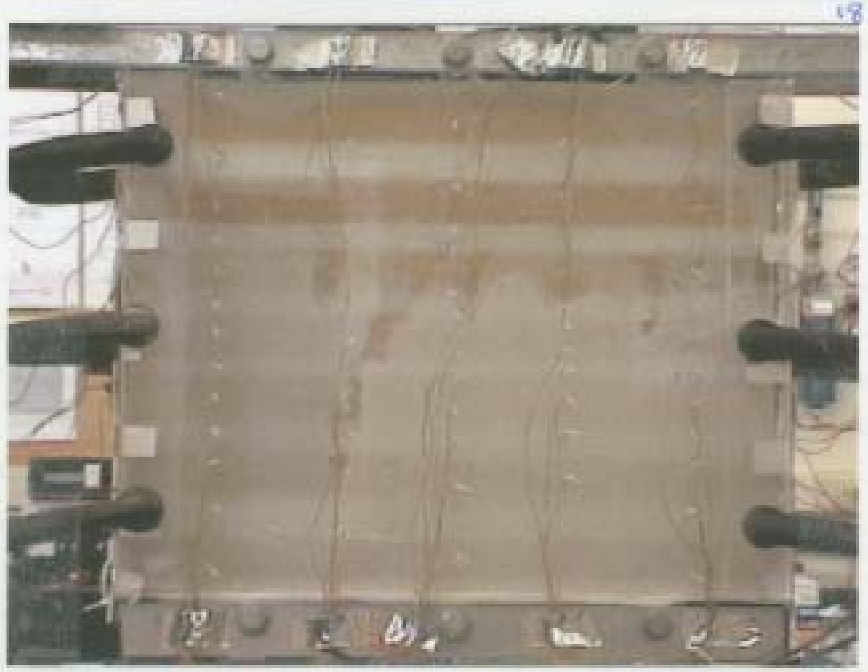


45 min into test

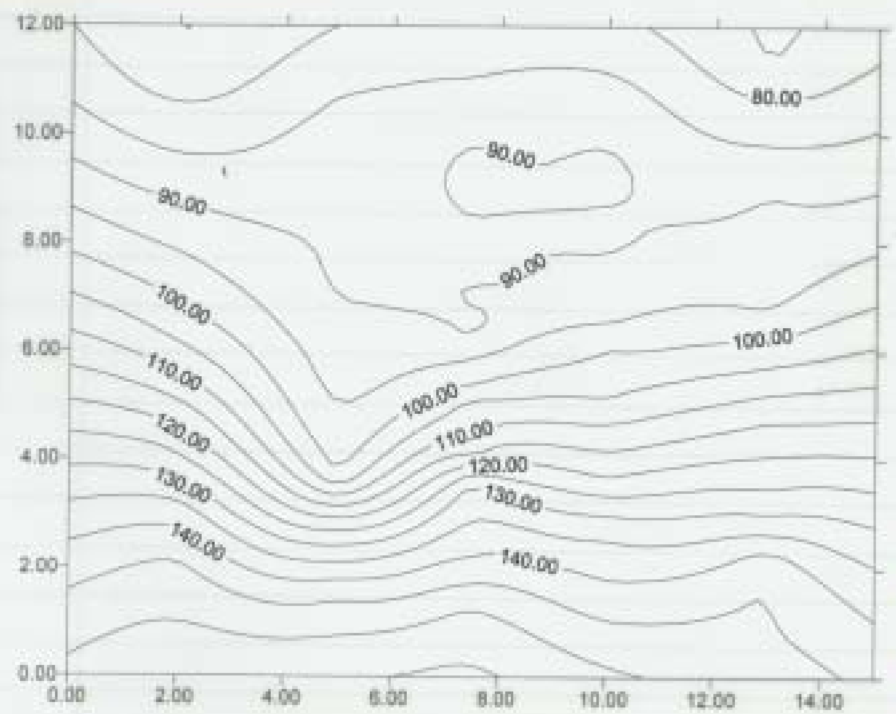


Temp field at 45 min.

186



110 min into test



Plot of temp field at 110 min

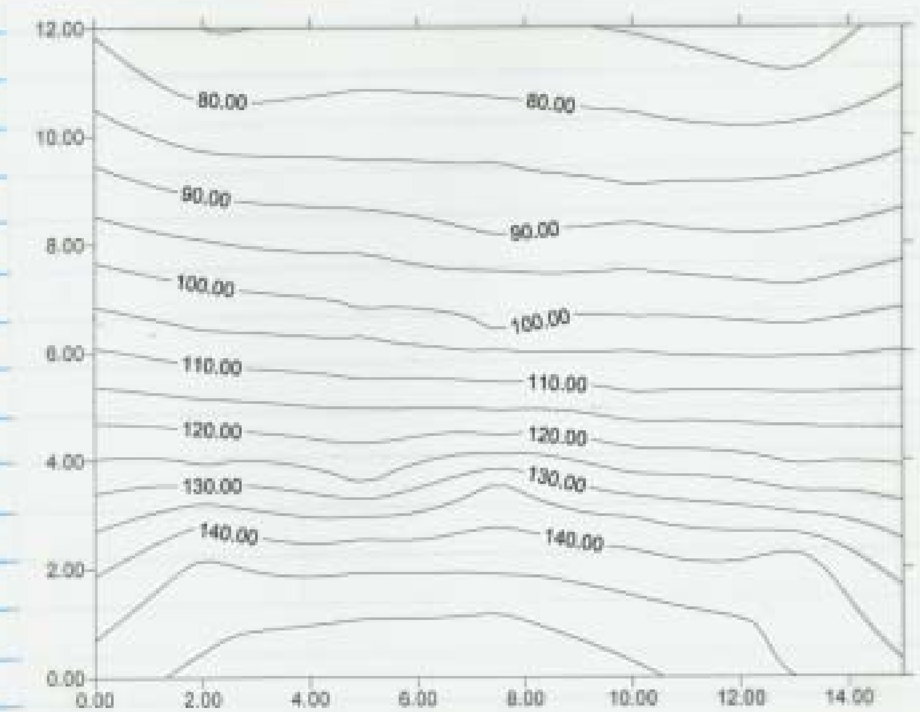
7/13/00 gf

Frozen run 19

Data + video collected at flow rate of 0.4 ml/min

Steady state temp field established using settings on p 119.

A plot of initial temp field is shown below.



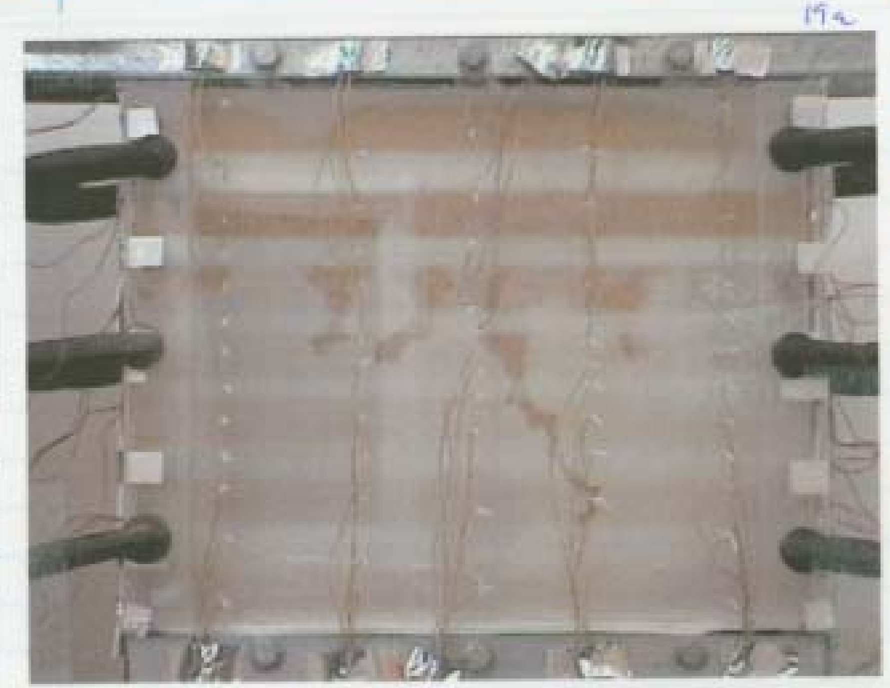
Temperature data is stored in file
named Fogar_run_19.txt

Digital video/movie of experiment is labelled
Fogar_rm_19.video

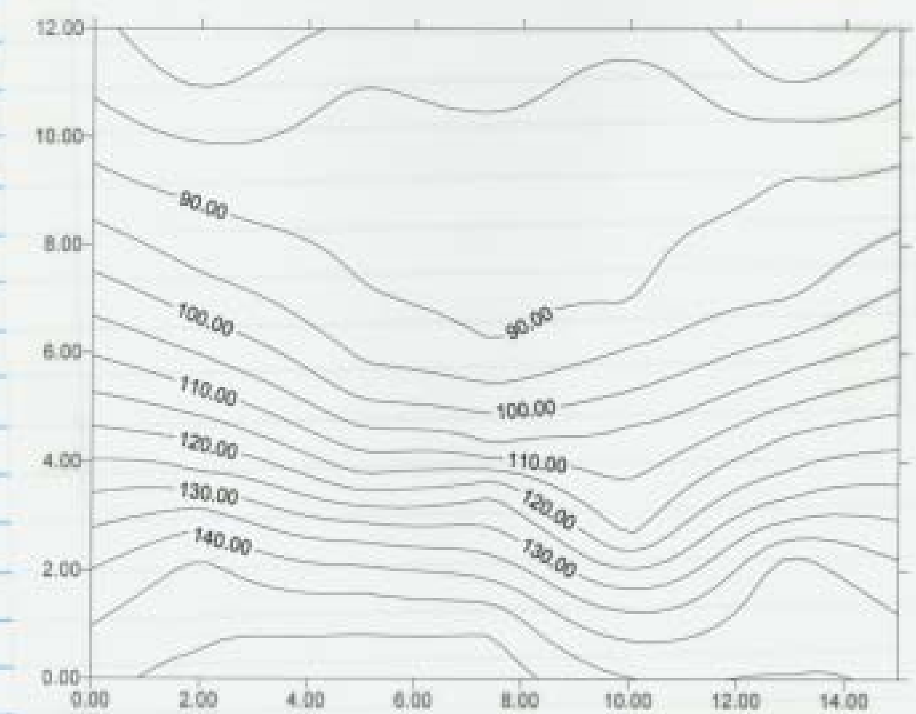
Test run for ~60 min.

7/13/00 [illegible]
Results + Observations

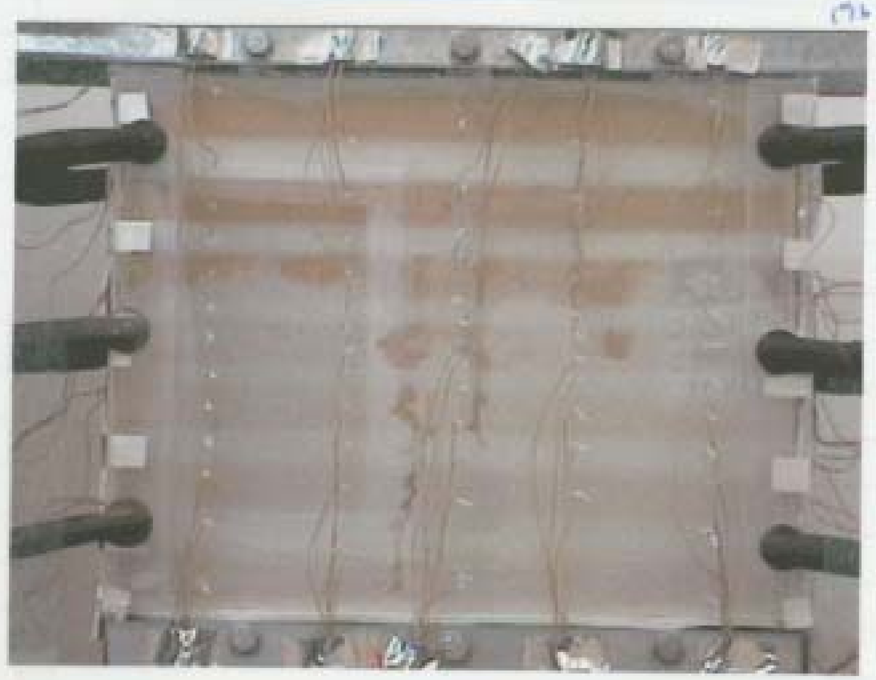
19a



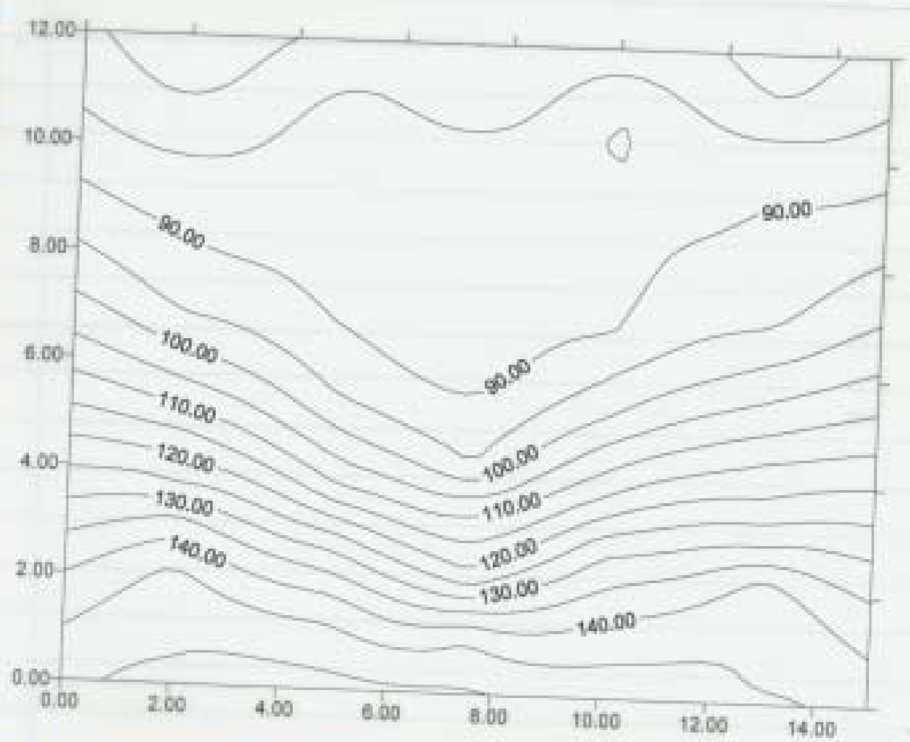
30 min into
test



Plot of temp
field at
30 min.



60 min into test.



Plot of temp field at 60 min.

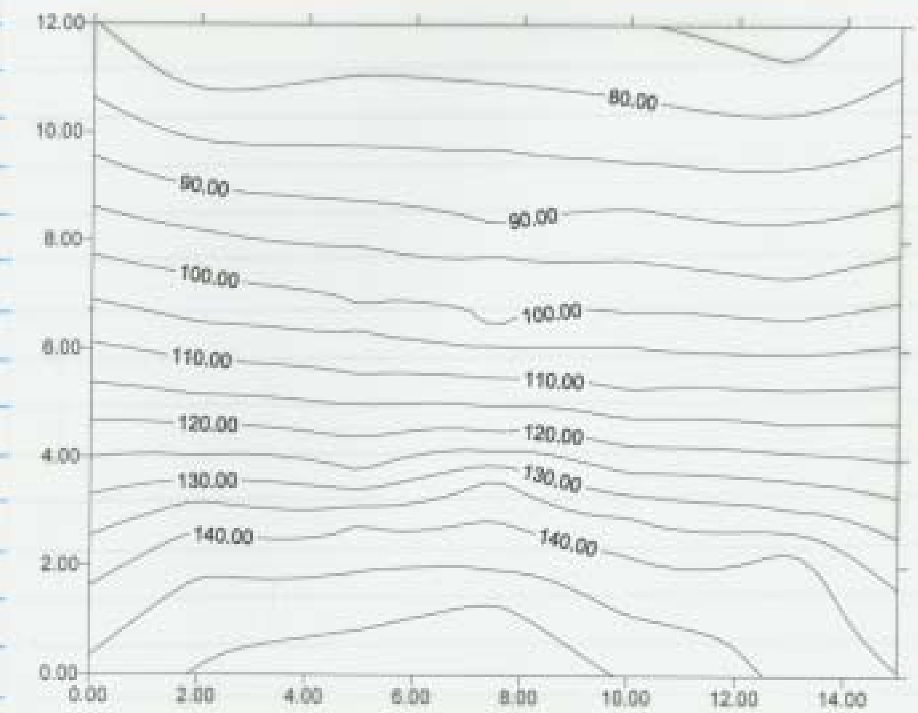
7/14/00 jf

Finger run 20

Data & video collected at flowrate of 0.05 ml/min

Steady state temp field established using settings on p 109

Plot of initial temp field is shown below.



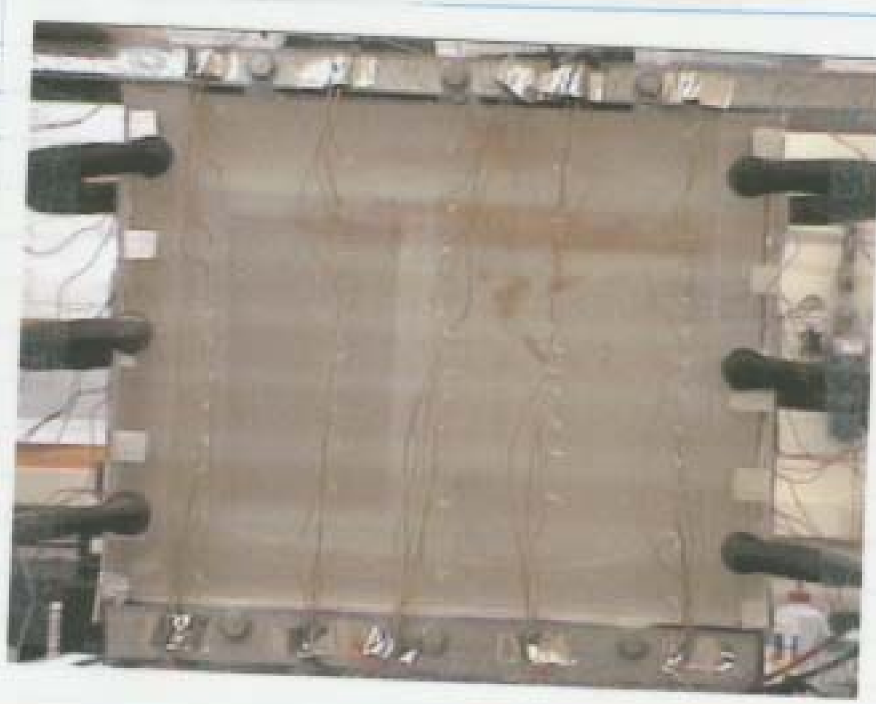
Temp data is stored in MS excel file named fryer-vm-20.xls

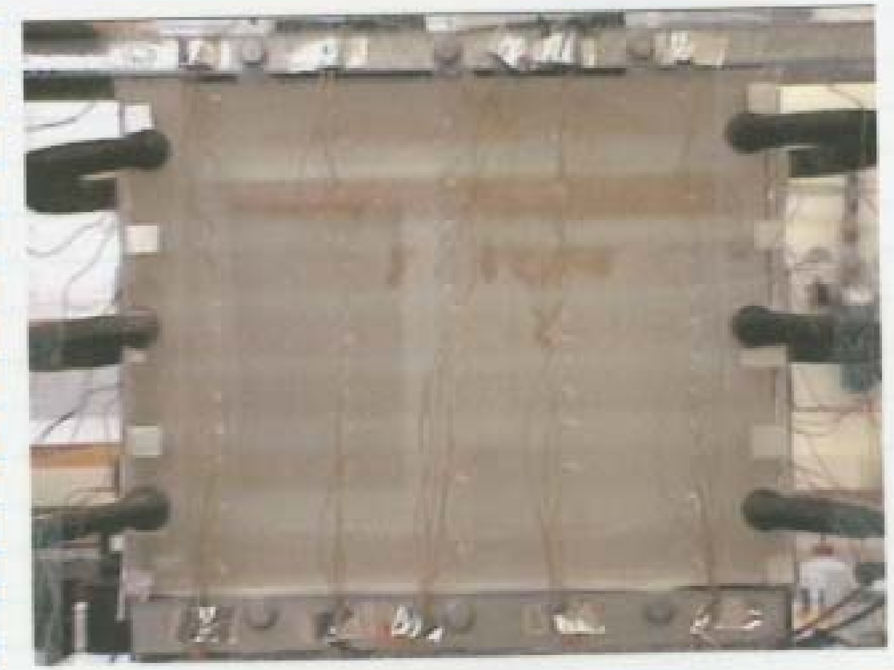
Digital videocassette of experiment is labelled fryer-vm-20.video

Test run for ~60 min

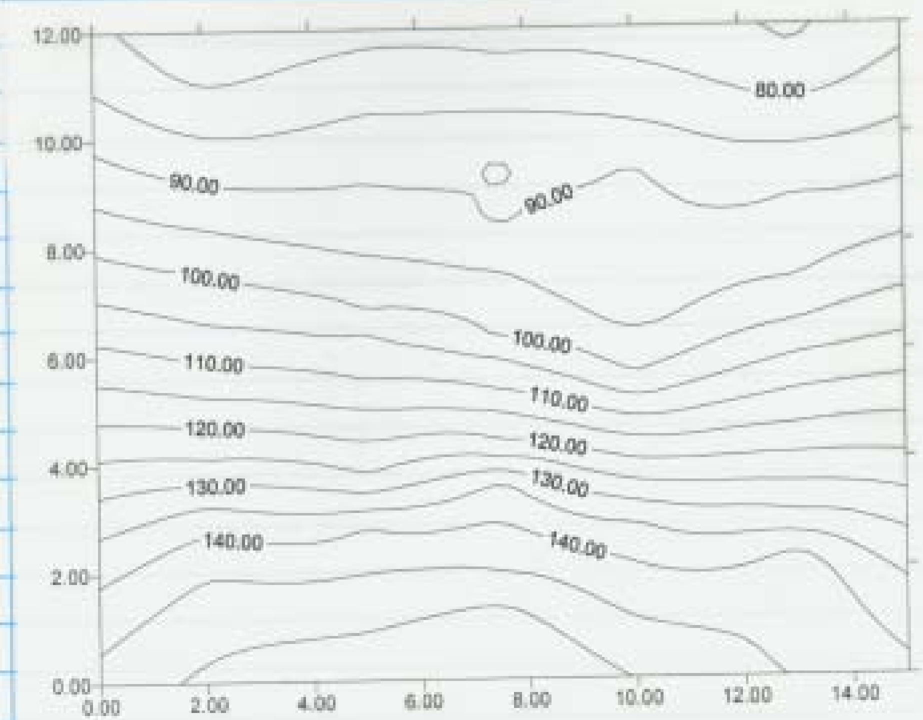
7/14/00 gp

Results & observations.

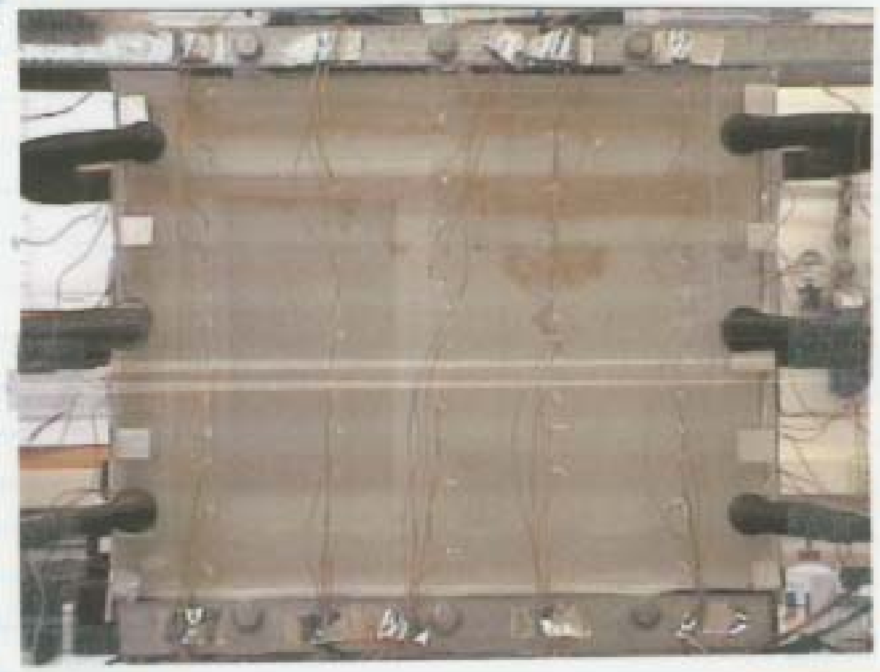




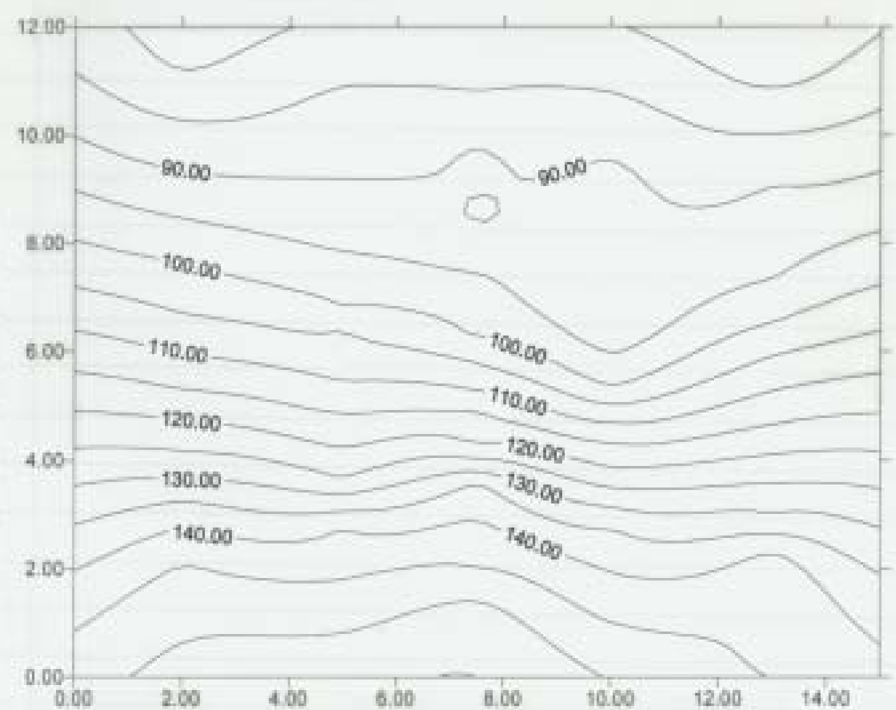
30 min into test



Temp field at 30 min



60 min
into test



Plot of temp
field at
60 min.

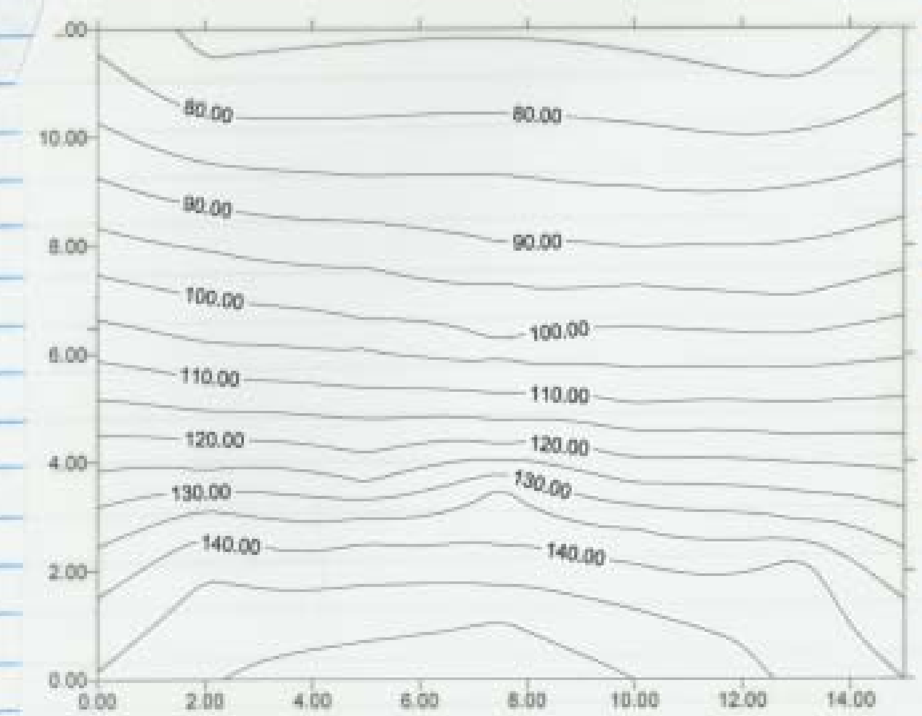
7/17/00 JB

Finger run 21

Data + video collected at flow rate of
0.025 ml/min

Steady state temperature field established
using settings on p 119.

Plot of initial temp field is shown
below



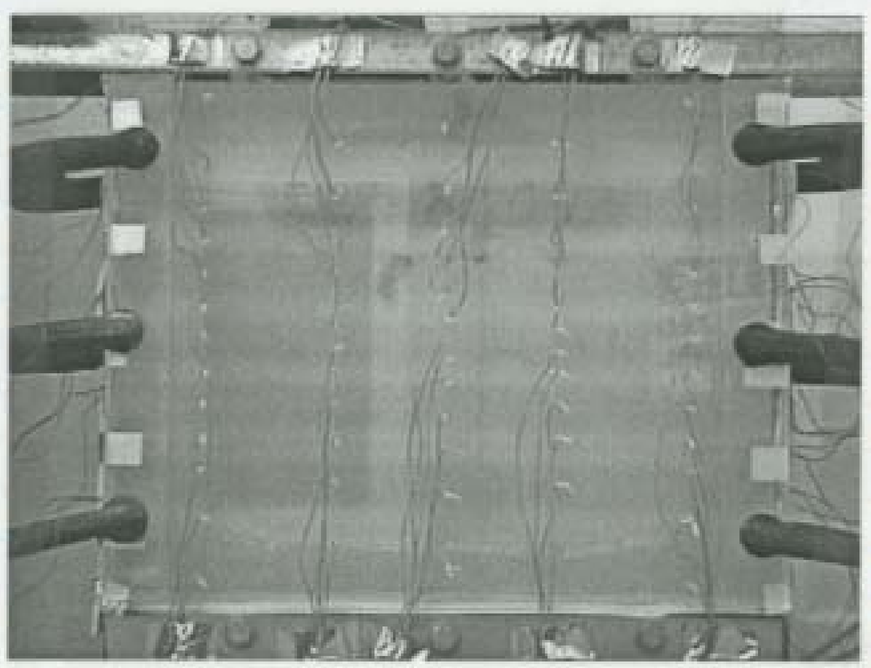
Temp data is stored in MS excel file named Figure_run_21.xls

Digital videocassette of experiment is labeled Figure_run_21 video

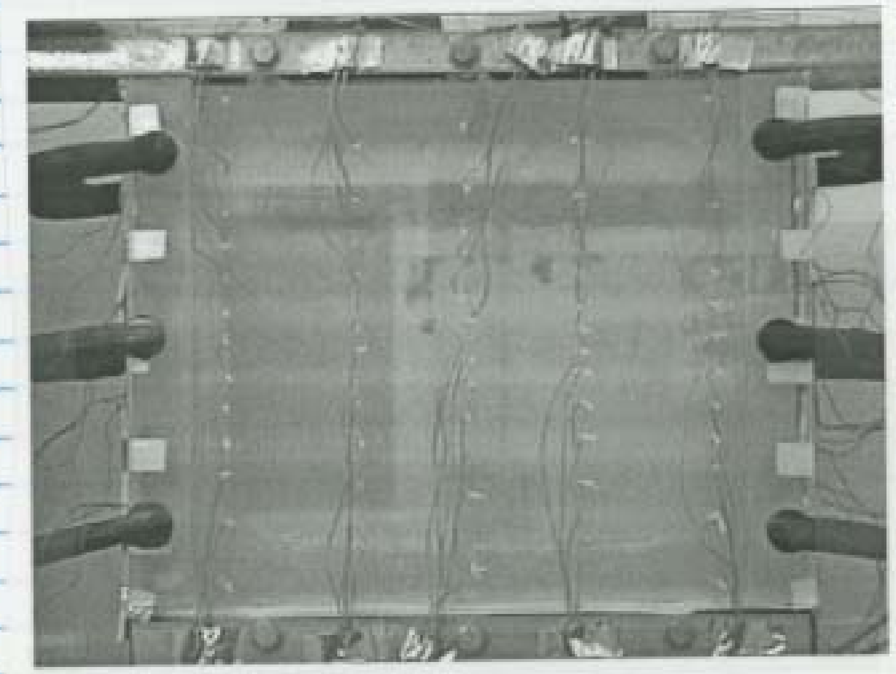
Test run for ~60 min.

7/17/00 JP

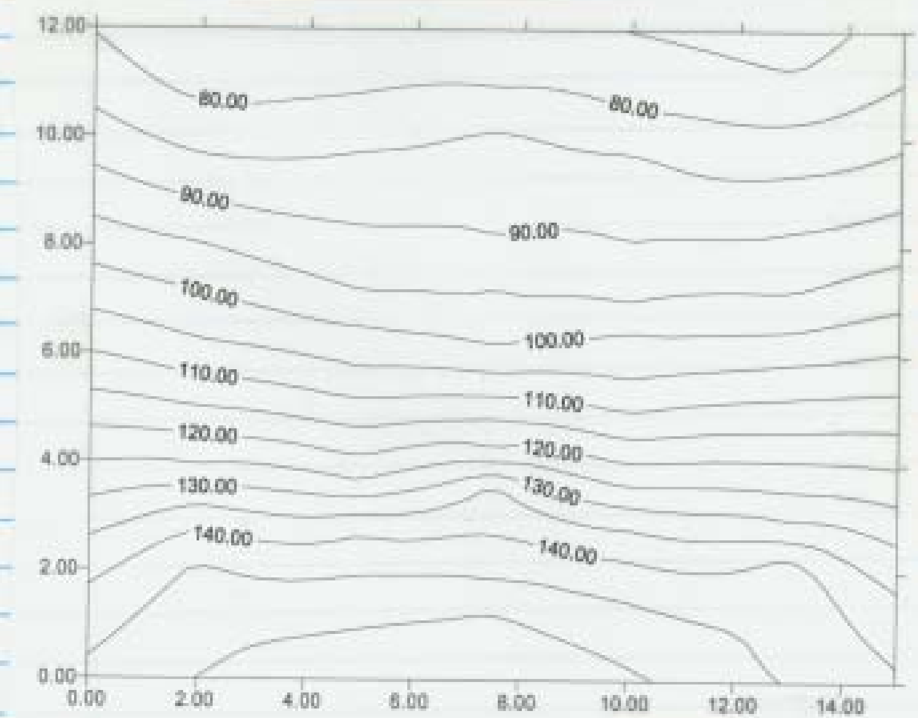
~~Results~~ Observation



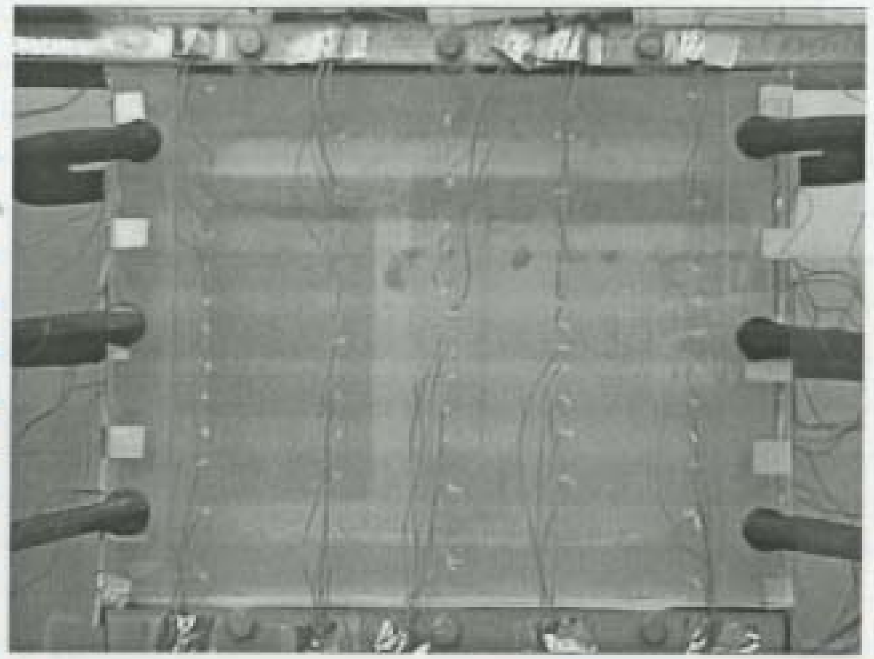
15 min into ~~test~~



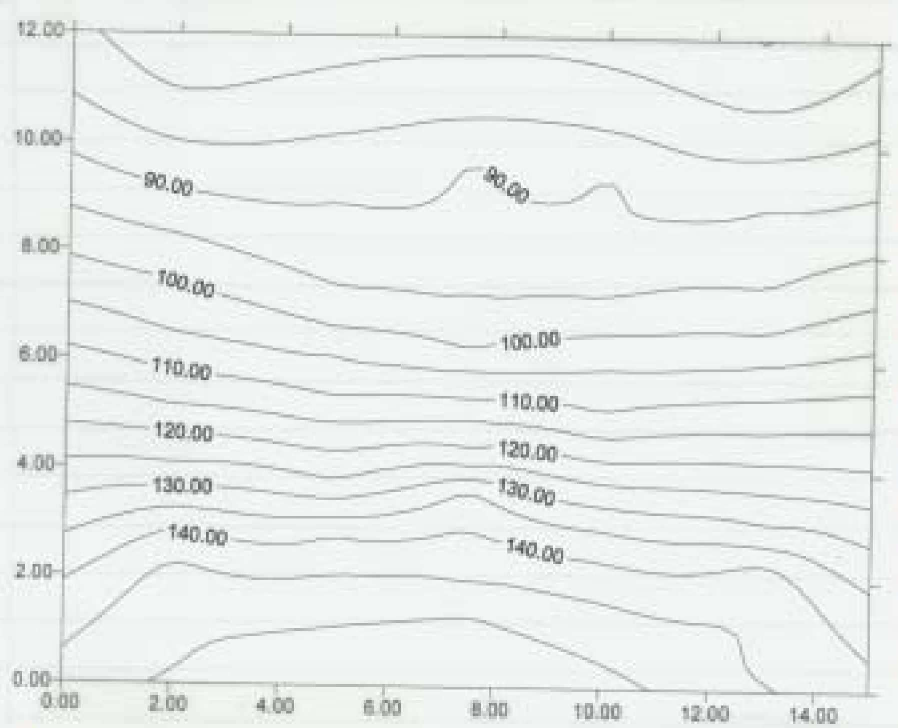
30 min into Test.



Plot of temp field at 30 min.



60 min into test.



Plot of temp field at 60 min.

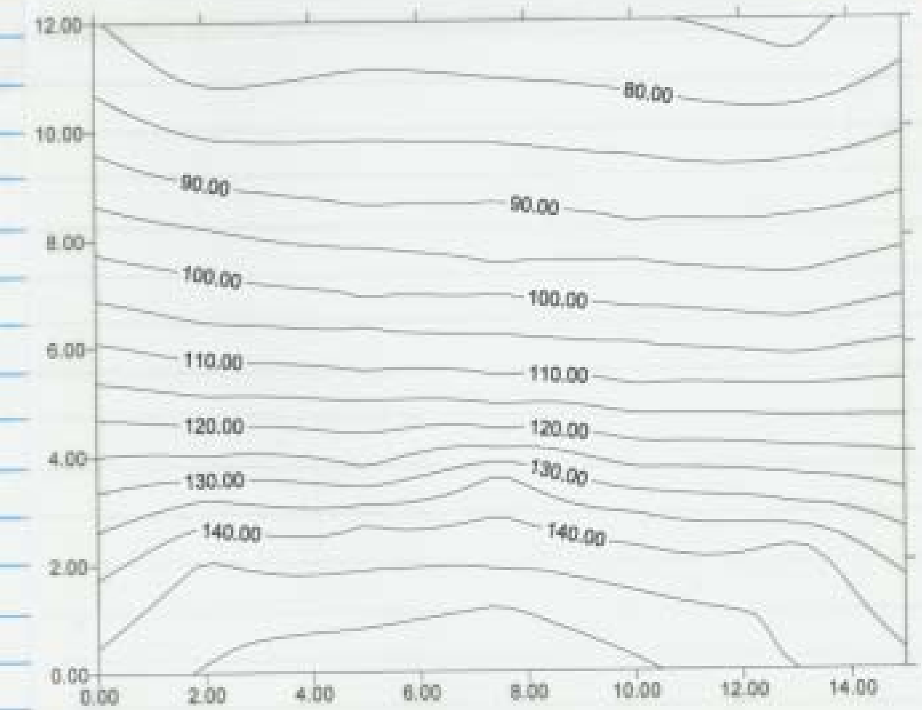
7/20/00 JP

Fingers run 22

Data + video collected at flow rate of 0.01 ml/min

Steady state temp field established using settings on p 119.

Plot of initial temp field is shown below.

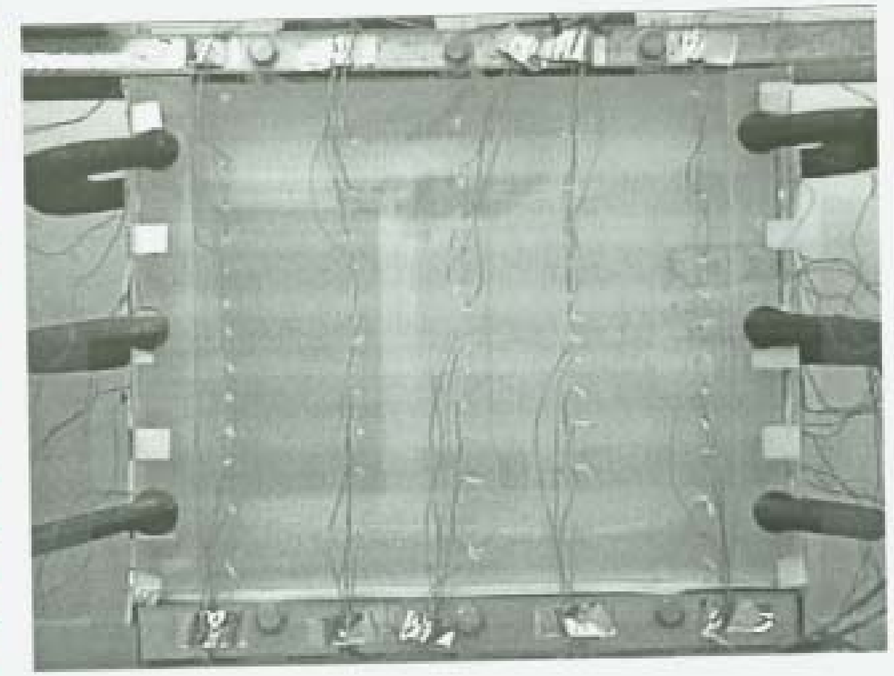


Temp data stored in MS excel file
named frozen_run_22.xls.

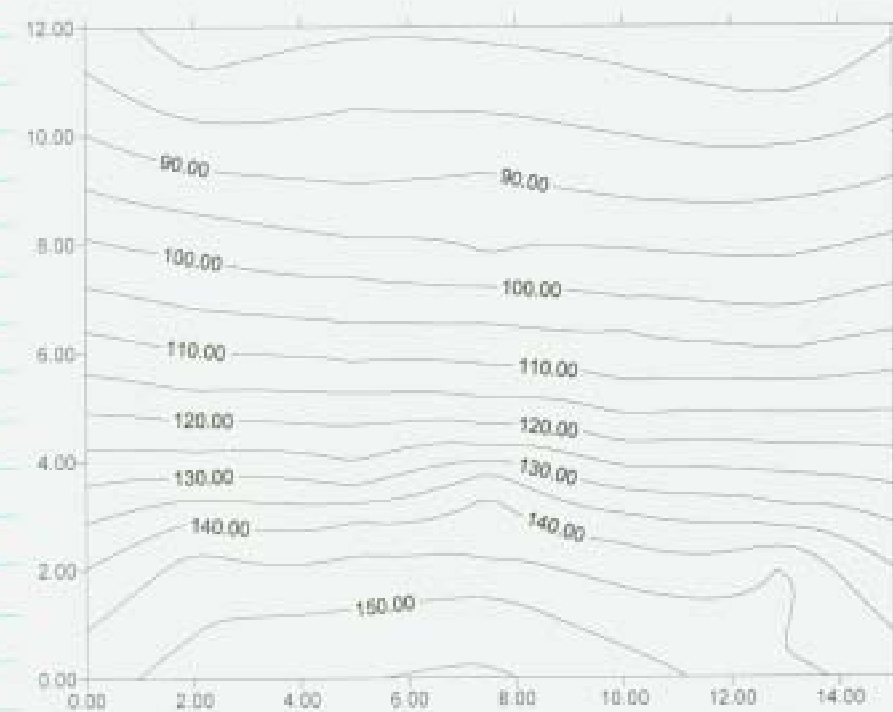
Digital videocassette of experiment
is labeled frozen-run-22-video.

Test run for ~60 min.

7/20/00 JJP
Results + observations

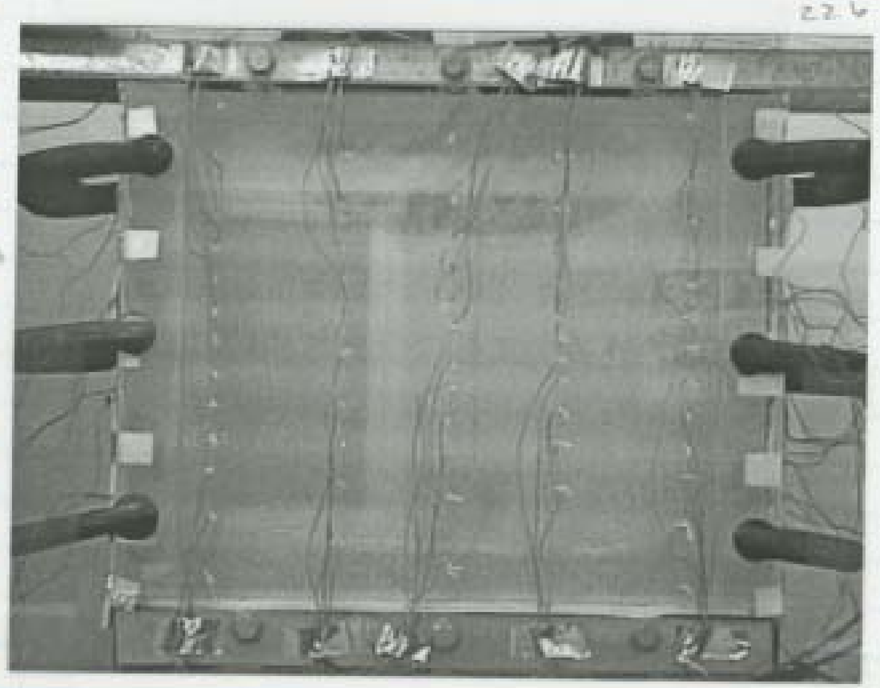


30 min into
test

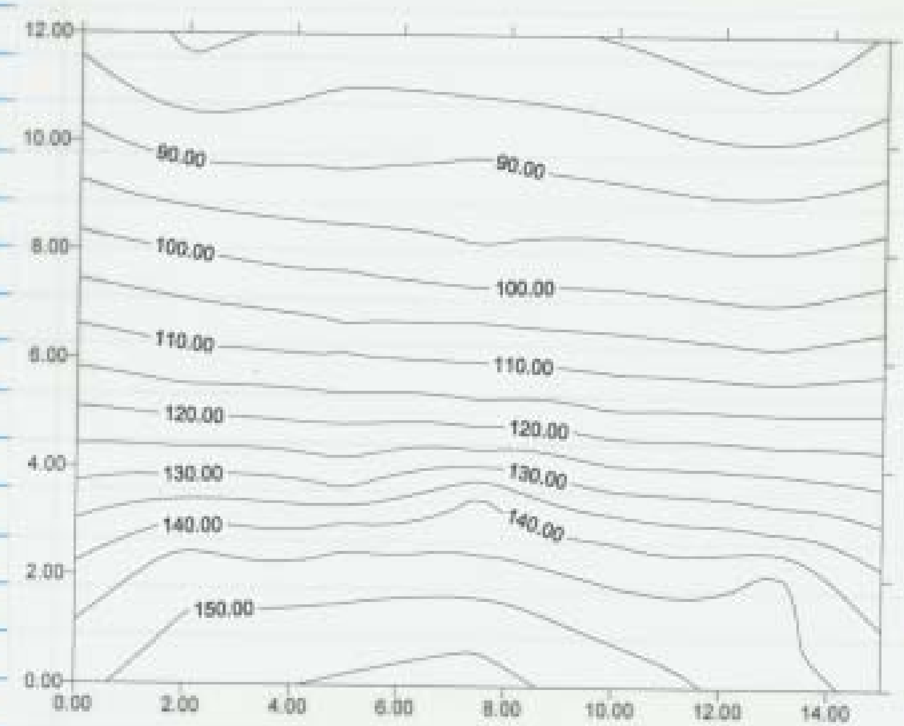


Temp field
at 30
min

226



60 min into test.



Plot of temp field at 60 min.

7/28/00 JP

Measurement of temperatures at face of glass plate/Lexan apparatus.

Obj - determine heat loss from front of glass plate apparatus for use in modeling calculations

Method - measure temperature at specific points on face of apparatus using a thin wire thermocouple.

Equipment and materials
- glass plate/lexan assembly as described on p 5-26 and p 40.
- Omega Precision fine wire thermocouple

Procedure
1. The transformer and power supply settings listed on pages 41, 91, and 119 were used to establish steady-state temperature fields across the glass/plate/lexan assembly.

(2) Once the steady-state temperature fields were established, a fine wire thermocouple was placed on the surface of the front lexan sheet adjacent to each hole that was drilled to accomodate thermocouples for measuring the temperature of the surface of the front glass plate (see p8 for these locations)

(3) The temperature measured by the fine wire thermocouple was recorded at each drill hole location on the lexan face.

(4) Temperature measurements for the 3 steady state temperature fields at each drill hole location are listed on the following page

Location	2.5C/inch	5C/inch	7C/inch
T1	48.1	51.9	56
T2	53.1	57.6	62.1
T3	52.9	57.5	61.1
T4	52.7	56.6	59.7
T5	51.5	55	57.3
T6	51.3	52.6	55.1
T7	50.3	51.7	53
T8	49.5	50.9	51.2
T9	48.9	49.5	50.1
T10	48.6	48.1	48.7
T11	48.3	46.7	47.2
T12	47.4	46	46
T13	45.4	42.8	43.7
T14	51.2	56.1	60.8
T15	50.5	54.9	59.8
T16	49.4	53.4	57.4
T17	49	52.1	56.1
T18	48.8	50.9	54.5
T19	48.4	49.9	52.5
T20	48	49.5	51.5
T21	47.9	48.9	50.8
T22	47.7	48.1	49.7
T23	47	47.2	48.8
T24	46.6	46.1	47.4
T25	46.4	45.1	46
T26	48.6	55.5	59.2
T27	49.3	55.6	59.3
T28	48.8	54.6	57.6
T29	48.1	52.7	54.8
T30	47.8	50.8	52.6
T31	47.6	49.3	51.4
T32	47.5	48.6	50.5
T33	47.3	47.5	49.6
T34	47.1	47.1	49.1
T35	47	46.7	48.5
T36	46.6	45.6	47.3
T37	46.2	44.9	46.9
T38	45.2	43.8	44.7
T39	49	54.8	57.9
T40	48.8	53.2	56.7
T41	48.7	51.9	55.1
T42	48.6	51.5	54.1
T43	48.3	50.1	52.2
T44	48	49.5	51.2
T45	47.4	48.5	50.1
T46	47	48	49.4
T47	46.6	46.7	48
T48	46	46.3	47.1
T49	45.4	44.9	46
T50	44.4	43.7	43.7
T51	46.1	50.6	54.1
T52	50.1	54	59.7
T53	49.5	52.7	56.9
T54	49.3	51.4	55.5
T55	48.7	50.8	54.2
T56	48.5	50.5	53.3
T57	48.3	49.9	52.2
T58	48.1	49	49.8
T59	47.8	48	48.6
T60	47.6	47.4	47.7
T61	47.4	46.8	46.7
T62	47.2	46.1	45.8
T63	45.5	43.5	43.4

Locations can be determined from figure on p8.

Temperatures are in degrees C

The 2.5C/inch column lists temperatures at face of glass/plate/lexan assembly for temperature field established using settings on p91.

The 5C/inch column lists temperatures at face established using settings on p41 and The 7C/inch column lists temperatures at face established using settings on p119.

8/11/00 JP

Measurement of heat flux at face of glass plate/lexan assembly

Obj - measure heat flux at face of assembly to help back calculate temperature at interface of glass plate.

Method - measure heat flux using heat flux sensor.

Equipment + materials
- glass plate/lexan assembly as described on p 5-26 + p 40
- HP 3458A multimeter
- RdF microfoil heat flux sensor (S/N 00067902).

Procedure
① The transformer + power supply settings listed on pages 41, 91, and 119 were used to establish temperature fields across the glass plate/lexan assembly

② Once the steady state temperature fields were established, a heat flux sensor was placed on the surface of the front lexan sheet adjacent to the middle row of thermocouples (see p. 8 for locations) (Channels 126-138). Measurements were taken on both the left + right adjacent sides of the thermocouples

③ The heat flow measured by the sensor in µV was recorded at each measurement location. The ~~temperature~~ measured by the thermocouple (i.e. at the glass plate - lexan interface) was also recorded as the heat flux measurements were taken

④ Heat flux measurements for the 3 temperature gradients are listed on ~~the~~ ~~following~~ pages 158-159. JP 9/20/00

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8/11/00 JB

Heat flux measurements

Heat flow was measured at the face of the front lexan sheet using an RdF microfoil heat flux sensor. Measurements were taken on both sides (left and right) of the middle row of thermocouples at each temperature gradient. Temperatures measured on the face of the front glass plate and the temperature of the room were also taken.

Heat flow measurements

Location	x	y	Channel
T38	7.5	11	138
T37	7.5	9.5	137
T36	7.5	8.5	136
T35	7.5	7.75	135
T34	7.5	7	134
T33	7.5	6.5	133
T32	7.5	6	132
T31	7.5	5.5	131
T30	7.5	5	130
T29	7.5	4.25	129
T28	7.5	3.5	128
T27	7.5	2.25	127
T26	7.5	1	126

	2.5C/inch gradient	
Heat Flow left microvolts	Temperature degrees C	Heat Flow right microvolts
166	82.9	161
180	86.4	178
189	88.3	191
214	91.5	215
225	93.7	222
236	93.1	238
243	94.7	241
247	95.8	245
250	96.5	252
270	99.1	265
295	101.3	295
316	104.8	315
288	106.9	290

Room temperature = 22.4C

Heat Flux calculation

Calibration constant = 3.7 microvolt/Btu/Ft2-Hr
Conversion factor 1Btu/Hr = 0.293 W

Location	x	y	Channel
T38	7.5	11	138
T37	7.5	9.5	137
T36	7.5	8.5	136
T35	7.5	7.75	135
T34	7.5	7	134
T33	7.5	6.5	133
T32	7.5	6	132
T31	7.5	5.5	131
T30	7.5	5	130
T29	7.5	4.25	129
T28	7.5	3.5	128
T27	7.5	2.25	127
T26	7.5	1	126

	2.5C/inch gradient	
Heat Flux left W/m2	Temperature degrees C	Heat Flux right W/m2
141.50	82.9	137.24
153.43	86.4	151.73
161.11	88.3	162.81
182.42	91.5	183.27
191.79	93.7	189.24
201.17	93.1	202.87
207.14	94.7	205.43
210.55	95.8	208.84
213.10	96.5	214.81
230.15	99.1	225.89
251.46	101.3	251.46
269.36	104.8	268.51
245.50	106.9	247.20

	5C/inch gradient	
Heat Flow left microvolts	Temperature degrees C	Heat Flow right microvolts
147	78.2	155
184	84.1	185
202	88.5	198
213	92.5	210
221	96.8	223
256	99.1	236
268	102.5	250
275	104.6	275
290	108.5	282
320	113.9	323
330	125.1	326
370	126.7	343
383	132.5	367

Room temperature = 22.3C

	7C/inch gradient	
Heat Flow left microvolts	Temperature degrees C	Heat Flow right microvolts
170	79.4	164
184	85.9	188
209	90.6	205
235	95	231
256	100.1	257
281	102.2	280
287	106.4	291
301	109.3	308
338	115	325
390	122.7	394
444	131	452
519	142.2	517
585	154	580

Room temperature = 22.5C

	5C/inch gradient	
Heat Flux left W/m2	Temperature degrees C	Heat Flux right W/m2
125.30	78.2	132.12
156.84	84.1	157.70
172.19	88.5	168.78
181.56	92.5	179.01
188.38	96.8	190.09
218.22	99.1	201.17
228.45	102.5	213.10
234.41	104.6	234.41
247.20	108.5	240.38
272.77	113.9	275.33
281.30	125.1	277.89
315.39	126.7	292.38
326.47	132.5	312.84

	7C/inch gradient	
Heat Flux left W/m2	Temperature degrees C	Heat Flux right W/m2
144.91	79.4	139.80
156.84	85.9	160.25
178.15	90.6	174.74
200.32	95	196.91
218.22	100.1	219.07
239.53	102.2	238.68
244.64	106.4	248.05
256.58	109.3	262.54
288.12	115	277.03
332.44	122.7	335.85
378.47	131	385.29
442.40	142.2	440.70
498.66	154	494.40

Final Entry:

I have reviewed this scientific notebook and find it in agreement with QAP-001. There is sufficient information regarding methods used for conducting tests, acquiring and analyzing data so that another qualified individual could repeat the activity.

E. C. Pearcy
9/26/2001