LABORATORY NOTEBOOK

CNWRA/SwRI

NOTEBOOK NO. ____________

ISSUED TO Debra Hughson

ON Oct 5 **19**98

DEPARTMENT ____________

RETURNED ____________ **19**____

CNWRA
CONTROLLED
COPY 292

PO # 03116

—SCIENTIFIC NOTEBOOK CO.—
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616-429-8285

INSTRUCTIONS

1. **The primary purpose of this notebook is to protect your and the Company's Patent-Rights by keeping records of all original work in a form acceptable as evidence if any legal conflict arises.**

2. • When starting a page, enter the title, project number, and book number.
   • Use ink for permanence -- avoid pencil.
   • Record your work as you progress, including any spur-of-the-moment ideas which may be developed later.
   • Avoid making notes on loose paper to be recopied.
   • Record your work in such a manner that a co-worker can continue from where you stop. You might be ill and to protect your priority it could be urgent that the work continue while you are absent.

3. • Give a complete account of your experiments and the results, both positive and negative, including your observations.
   • Record all diagrams, layouts, plans, procedures, new ideas, or anything pertinent to your work including the details of any discussions with suppliers, or other people outside the Company.
   • Do not try to erase any incorrect entries; draw lines deleting them, note the corrections, sign and date the changes. This extra care is worthwhile because of the necessity of original data to prove priority of new discoveries.

4. • After entering your data, sign and date the entries.
   • Explain your work to at least two witnesses who are not co-inventors, and have them sign and date the pages in the place provided.
   • Record the names of operators and witnesses present during any demonstration and have at least two witnesses sign the page. If no witnesses are present during an experiment of importance, repeat it in the presence of two witnesses.

5. Since computer programs can be patented these instructions apply to the development of computer software. In this case a description of the structure and operation of the program should be recorded in the notebook, together with a basic flow diagram which illustrates the essential features of the program. In the course of developing the code, the number of lines of code written each day should be recorded in the notebook, together with a statement of the portion of the flow diagram to which the section of code is directed.

6. This notebook and its contents are the exclusive property of the Company. It is confidential and the contents are not to be disclosed to anyone unless authorized by the Company. You must return it when completed, upon request, or upon termination of employment. It should be kept in a protected place.
   If loss occurs, notify your supervisor immediately, and make a written report describing the circumstances of the loss.

TITLE TEF thermal effects on flow — Project No. 20-1402-661 — Book No. 292

From Page No.

this notebook is for recording the results of modeling the Drift Scale Heater Test, referred to as DST.

A previous notebook regarding drift-scale thermohydrology & some carbonate equilibria chemistry is # 284, also for TEF 20-1402-661

This work is done in association with, and under the direction of, Ron Green, P.I. on the TEF KTI

Simulations done using the fortran 77 code Multiflo 1.2β by Peter Lichtner and Mohan Seth. Previous ECM simulations of drift scale test done by Amit Armstrong.

Oct 6, 1998

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Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by DH	10/6/98

From Page No.

This first model is primarily exploratory to see how large the leaked zone becomes in 4 years, so that the dimensions of the model can be appropriately scaled to reduce boundary effects.

Domain takes advantage of symmetry through centerline of leaked drift. Contacts of tsw34 with tsw33 and tsw35 are approximate.

Properties for these units are the same as used in Book 284 pages 6 and 7 Tables 3-10 and 3-11

Infiltration rate is 3.6 mm/year from top boundary (metra type 5). Left & right boundaries are no-flow and bottom boundary is prescribed.

Model is DCM dual continuum. ~~Ste~~ DH 10/6/98

Starting by getting initial equilibrium conditions for steady state with excavated but unleaked drift

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		Recorded by DH	10/6/98

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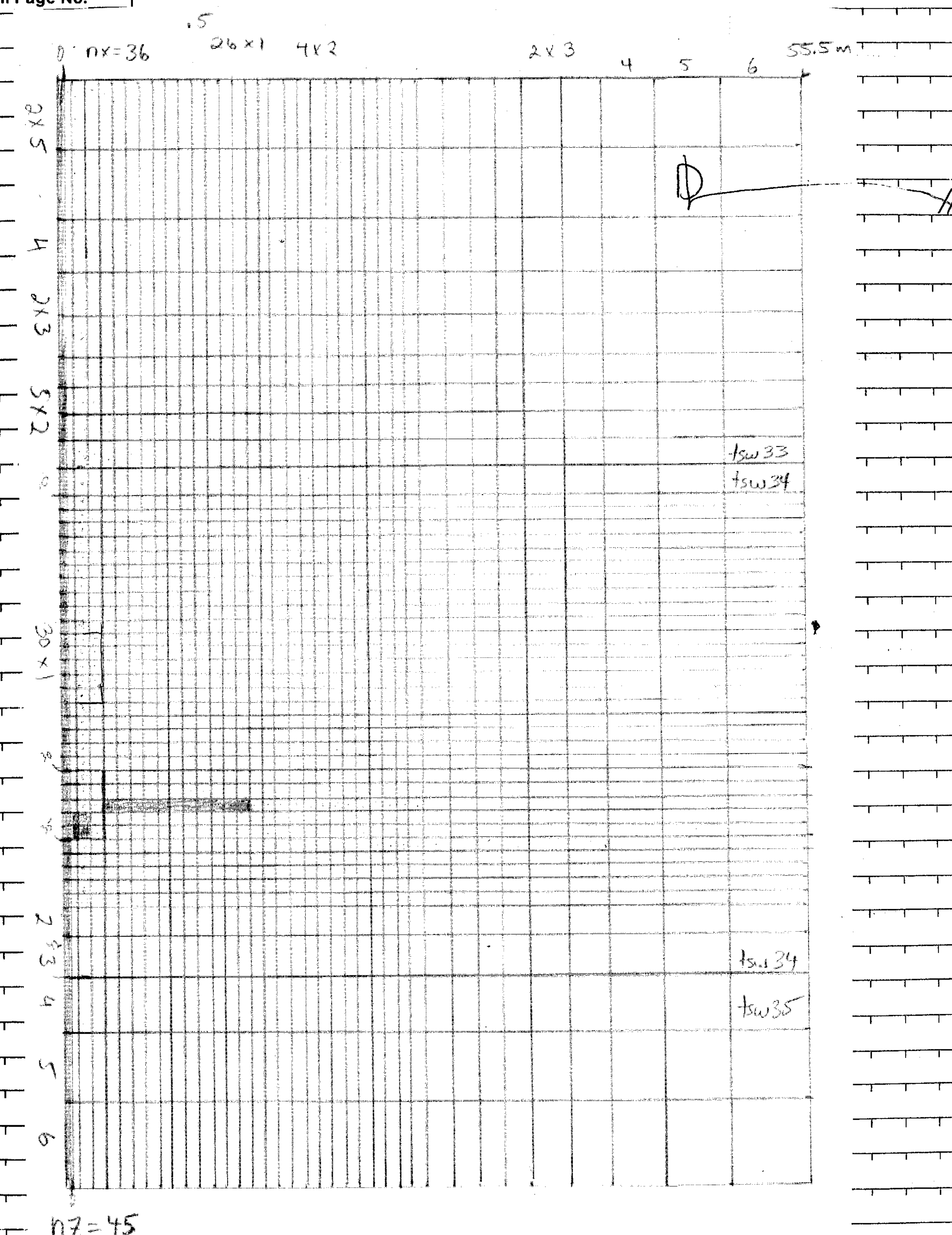

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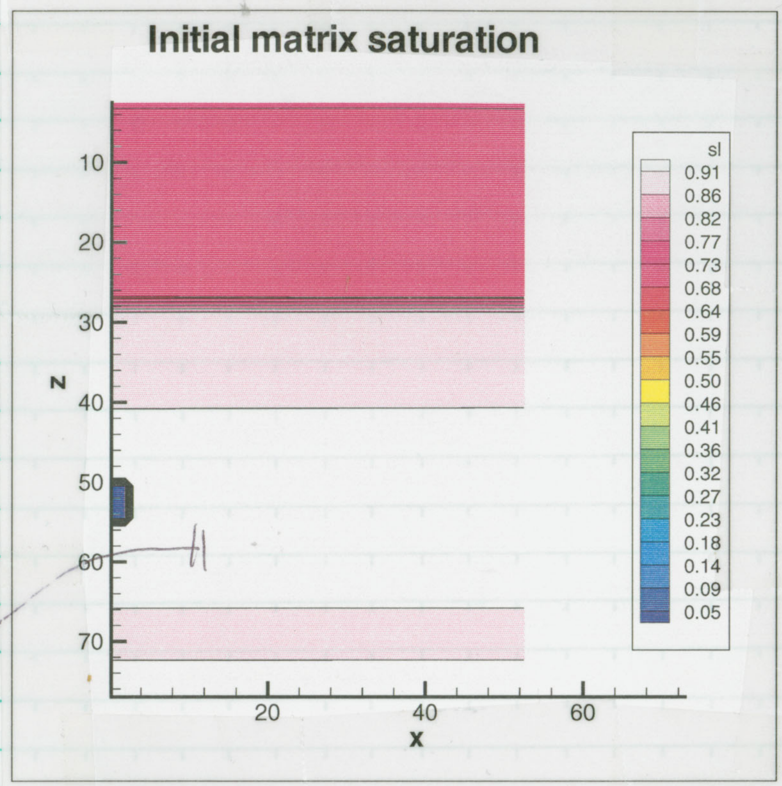
		Recorded by DH	10/6/98

Project No. 20-1402-661
Book No. 292 TITLE TEF

From Page No. ___ Oct 7, 1998

Initial condition in equilibrium with 3.6 mm/yr infiltration. Liquid saturation in the matrix



unit tsw 33
approx .9 to .91

Liquid sat in fractures is ~ zero

Add in heat source for 1 wing heater and a fraction of one floor cannister heater

Reference:

Overview of In Situ Thermal Testing at Yucca Mtn for the Expert Elicitation Workshop on Near-Field Coupled Effects by Ralph Wagner

Nov 5-7, 1997

To Page No. ___

Witnessed & Understood by me, | Date | Invented by | Recorded by [signature] | Date 10/7/98

From Page No. ___

Heater Power 212 kW designed use

Wing (50) 144 KW length = 11.5 m
Floor (9) 68 KW length = 4.6 m
@ 80% = 54 kW dia = 1.7 m
DH 10/19/98

Drift length = 47.5 m

Area heated by wing heaters
1092.5 m^2

Area heated by
floor cannisters
237.5 m^2

DH 10/19/98
~~load = 131.8 w/m^2~~
load = 130.9 w/m^2
distr. over 11 blocks $1m^3$
11.9 W per block

load = 227.4 W/m^2
distr over 2 $1m^3$ blocks
& 2 $0.5m^3$ blocks
75.8 W ea $1m^3$ blck
37.9 W ea $0.5m^3$ blck

Oct 19, 1998

this job has been running since Oct 8 and has reached a simulation time of 1.134 years. Maximum temperature inside heat drift is 76.26 C at 1 year.

Option 31 = rate for each grid block (W)

Nominal wing heater length = 10m

model symmetric halfspace

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		Recorded by DH	10/19/98

From Page No.

Wing heaters

Area of outer $(5m)(38m) = 190\ m^2$

Total $= (25)(1.719\ kW) = 43\ kW = 226\ W/m^2$

Area of inner $(5m)(38m) = 190\ m^2$

Total $= (25)(1.145\ kW) = 28.6\ kW = 151\ W/m^2$

Total area of floor $(47.0m)(5m) = 235\ m^2$

Total 54 kW = 230 W/m² (DH 11/12/98)

area of all blocks is $1\ m^2$ except for 1st column which is $0.5\ m^2$

~~Ste~~ Set (DH 11/12/98) DPMXE = 9e+2
DPMX = 27e+2

start Oct 19, 1998 9 am

~~reset 1m gap between wing heater & drift wall & no gap between inner & outer wing~~

start Oct 19, 1998 10:30am

Killed Nov 12, 1998 2:PM because I needed metra recompiled for 3D seepage study. this simulation had reached 1,375 years

To Page No.

Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by DH	Nov 12 1998

From Page No. Oct 26, 1998

Attempt to compile METRA on Cray J90 sp.networkcs.com

Problem: inconsistent use of real*8 real*4

fix 1, change source using dble() or change function to double as necessary. Changes all documented.

fix 2 use -dp compiler option to force everything to single precision

Result of fix 1 and fix 2 the same

WATSOLU: no diag in L/U

Same thing happens on t3d sr.networkss.com

Dec 14, 1998

Changes to DST multi.dat file to attempt to speed up run time

Stalled at 1,331 years

From the thermal Workshop CD

Cannisters ~52 kW } → Individual ~ 5.6-5.9 kW
Wing ~137 kW } → 130 to 132 at 180 days

Individual Inner 1.15 kW

Individual Outer 1.55 kW

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From Page No.___ Dec 23, 1998

Reduce outer Wing heaters to 200 W/m²
Reduce floor heaters to 220 W/m²

leave inner Wing heaters at 151 W/m²

Run stopped - time step cuts exceeded max
time step 3287 time 1.382 years

Change porm to 1.0 to attempt to
reduce gas pressure buildup around
Wing heaters.

Successful run ~ 2 day run time

Temp °C in fracture continuum on pg 9

Temps in matrix continuum very similar

Sat of water in fractures pg 10
Sat of water in matrix pg 11

Archive as

~dhughson/multiflo/inputbak/multi.28

Output & plots residing for the time at

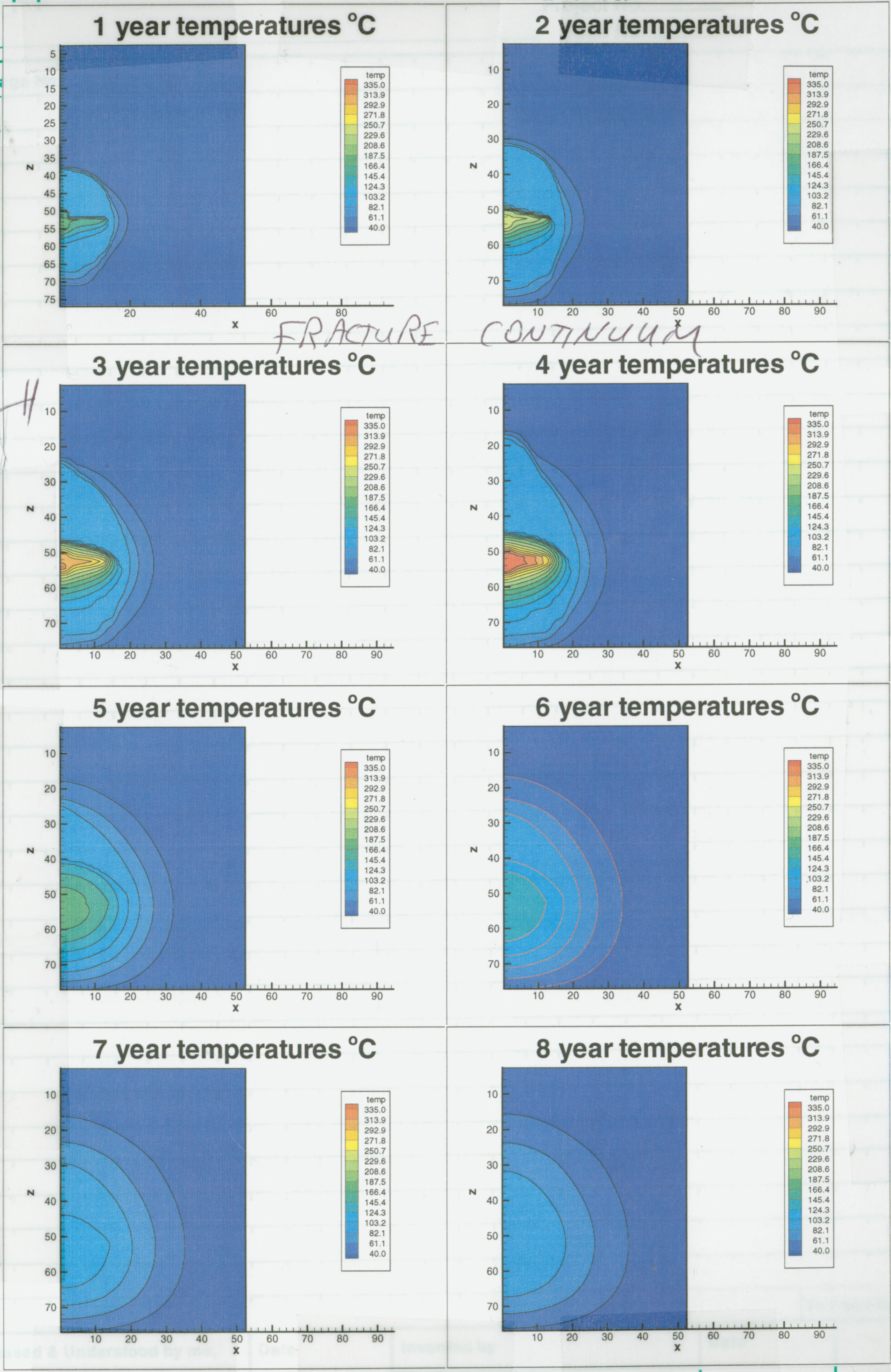
~dhughson/multiflo/dst/8yrun/*

To Page No.______

Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by DH	Jan 4 1999

TITLE

From Page No.



D-H

Witnessed & Understood by me, Date

Invented by

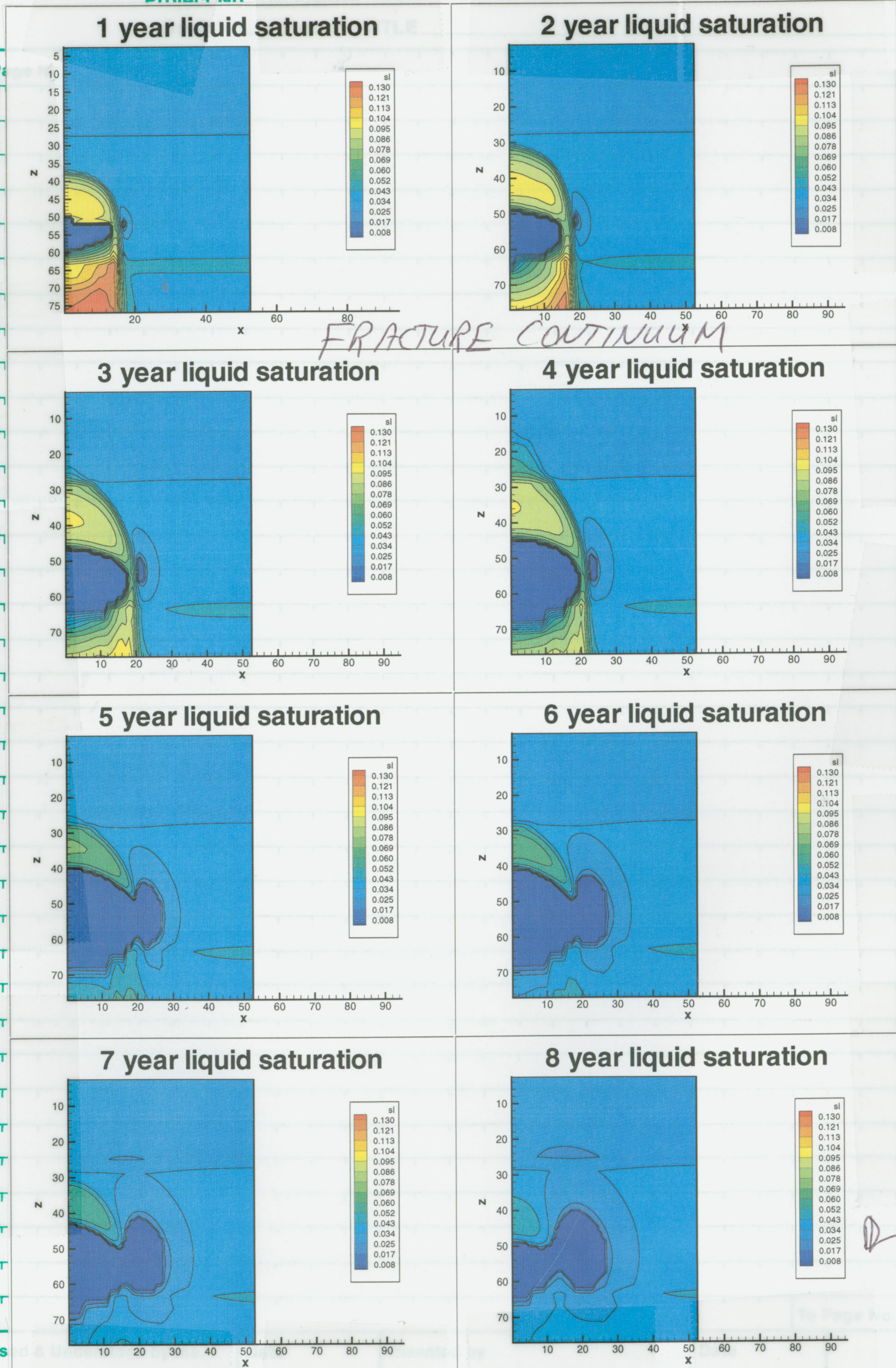
Recorded by

DH
Jan 4
1999

20-1402-601 TEF 292

Project No

From Page



FRACTURE CONTINUUM

Jan 4 1999

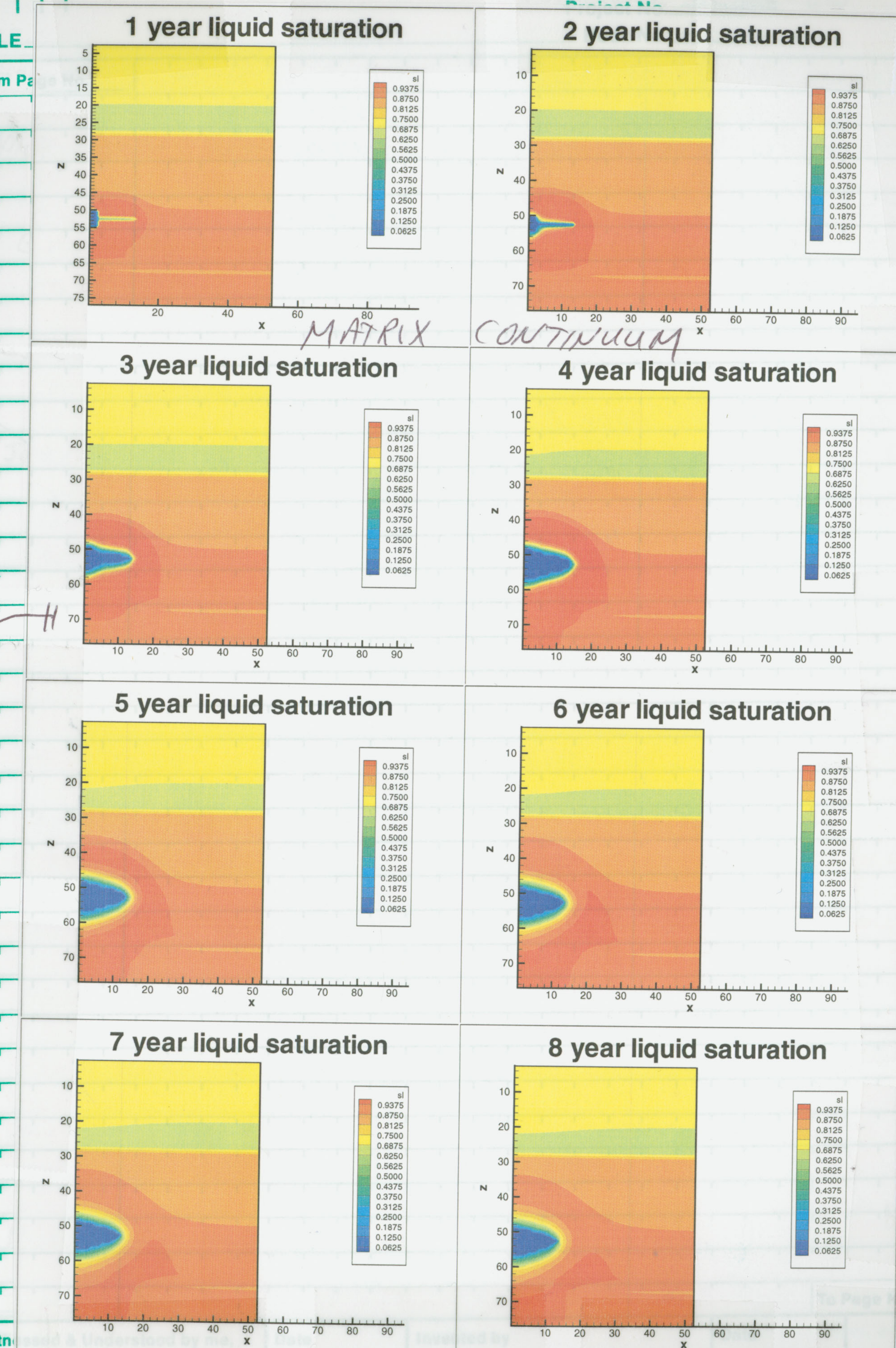
Witness

Recorded by

20-1402-601 TEF 292

TITLE

From Page



MATRIX CONTINUUM

To Page No.

Witness

Recorded by

DLH Jan 4 1999

From Page No.

Jan 7, 1999

Meeting with Bret Leslie regarding VA review

Scott ~~P.~~ DH 1/25/99 by KESA by second week of Feb

Following template in white paper

Quantity & Quality of water contacting waste packages

Feb 1 telecon Appx 7

To Page No.

Witnessed & Understood by me,	Date	Invented by / Recorded by	Date
			DH 1/25/99

From Page No.

Grid refinement From page 3 (on page 16)

Move drift up 10m so top ~~of~~ drift is 40 m from top boundary

Grid refined in vicinity of drift as show on following ~~page.~~ DH 1/25/99 page 16

thickness – dz = 1m, average slice through midsection ~ y = 23m

Jan 21 – First run on refined grid – very fast run until its untimely death around 2.3 years. Temperatures are too high ~ 230C at 2years over top of wing heaters

Jan 22, 1999

Calibrate by adjusting temp multiplyer factor

to match approx temp data at 271 days

from the ~~TMD~~ DH 1/25/99 Thermal-Mechanical Data from the Drift Scale Test 6/1/1998 – 8/31/1998

Inner Wing heater set to 151 W/m² for blocks 9-13

Outer Wing heater set to 200 W/m² for blocks 15-19

Floor heater set to 230 W/m² for blocks 1-3

these heat load approximated by averaging power out put over drift test area.

Adjustment factor = 0.85

15% due to ventilation loss from bulk head ?

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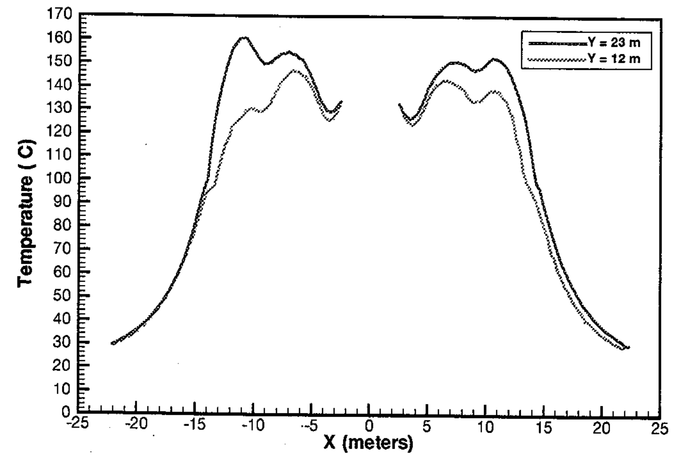
Witnessed & Understood by me,	Date	Invented by / Recorded by	Date
		Recorded by DH	Jan 25 1999

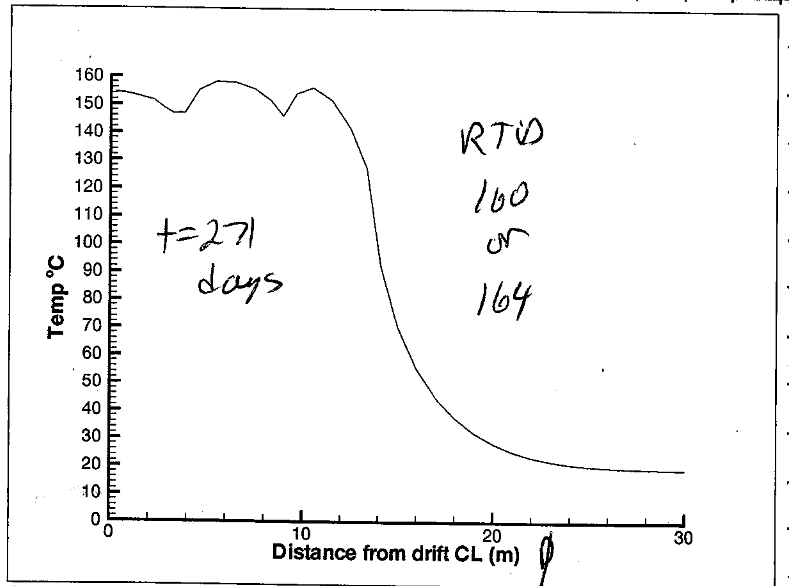
From Page No.

Temperatures Measured in Horizontal RTD Holes After 271 Days of Heating



DH

From Thermal-Mechanical Data from the Drift Scale Test 6/1/1998–8/31/1998 CD



DH

Results of DCM Multiflo model at 271 days

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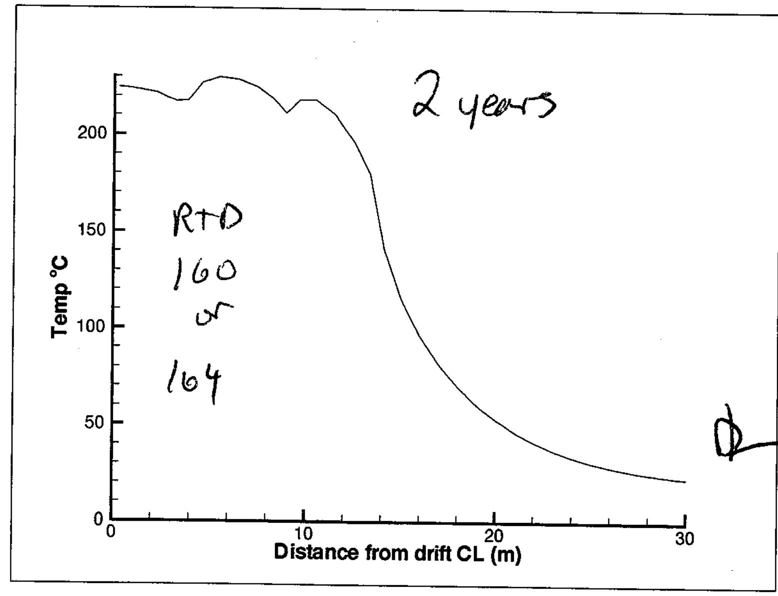
Witnessed & Understood by me, | Date | Invented by | Recorded by DH | Date Jan 25 1999

From Page No. Jan 25, 1999

Simulation calibrated to RTD data at 271 days tried at 2.2 years.

Temp profile at 2.0 years shown



DH

Changing thermal conductivity in the drift from 20 W/mK to 10 W/mK makes at most 1°C difference in temp. Essentially negligible.

Problem: If I set the heater output to match the measured temp profile in RTD 160 and 164 (y=23m) at 271 days then temps inside the drift and wing heater bore holes exceed maximum allowed temp of 200 C before 2 years of heating.

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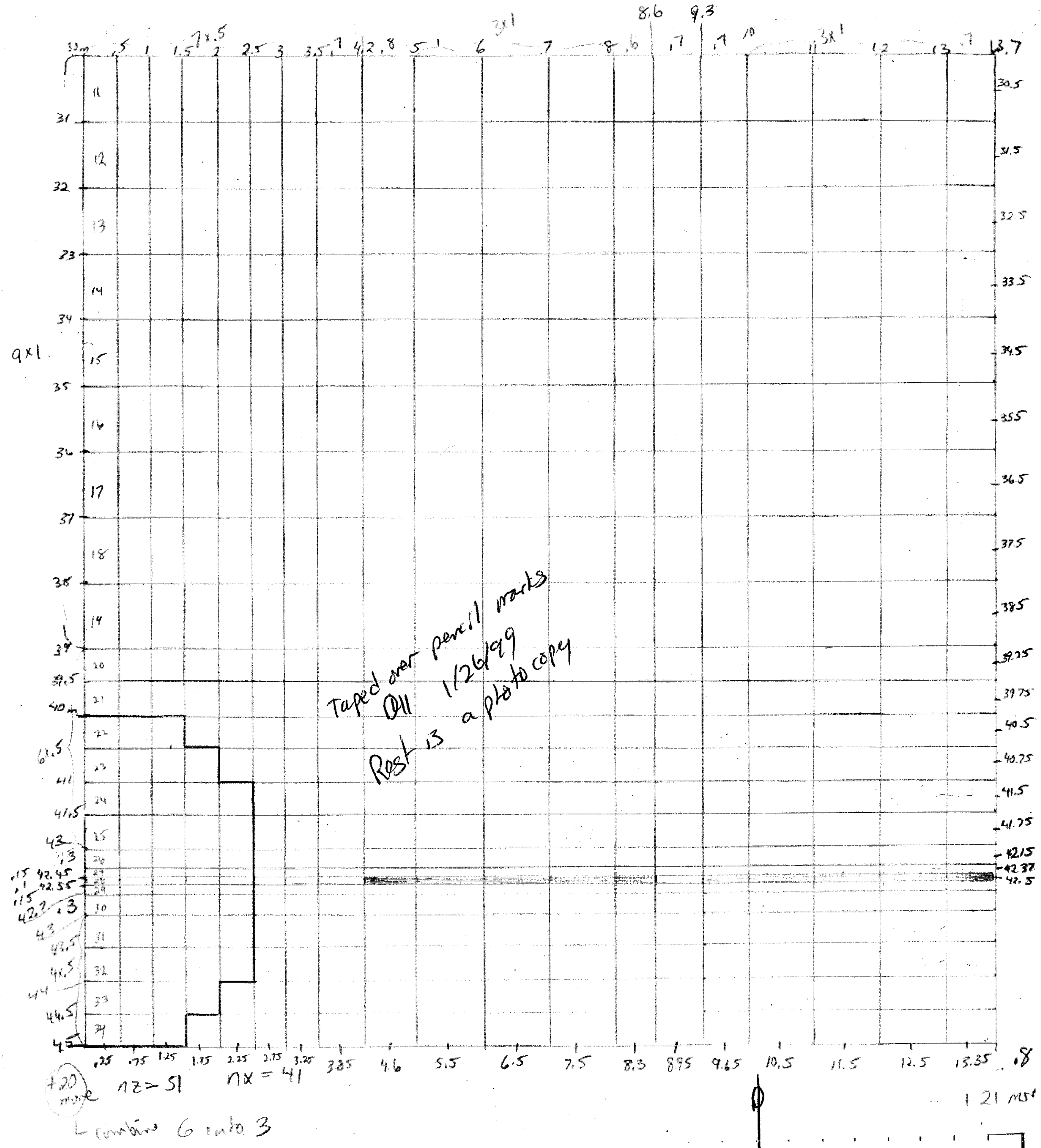

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Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by DH	Jan 26 1999

From Page No. Jan 26, 1999

From the Thermal-Mechanical Data from the Drift Scale Test CD
6/1/1998 – 8/31/1998

Reading off a powerpoint graph:

Total Power = ~ ~~205 KW~~ 185 KW (DH 1/27/99)
Wing Heaters = ~135 KW → 133 KW → 135 KW
Cannisters = ~50 KW → 52 KW

Outer Wing Heaters = ~1.5 – 1.6 KW each (1.55)

Inner Wing Heaters = ~1.1 – 1.2 KW each (1.15)

Note: Wing heater temps ~~can~~ exceed 300 C (DH 1/27/99)
in thermocouples TC-1 & TC-4

Use 50 m Heated drift length
5 m Heated drift width

Area of cannister heat = 250 m^2 Load = 208 W/m^2

Area of Outer wing heaters = 450 m^2 use 1.52 KW each

Outer Wing heater Load = 168.9 ≅ 169 W/m^2

Area of Inner wing heaters = 450 m^2 use 1.14 KW each

Inner wing heater load = 126.7 W/m^2

Start at 9:45 AM

Died PM ~~at~~ 2.85 yr (DH 1/27/99) temp in drift wall
= 209 – 217 C P = 7–8 bar

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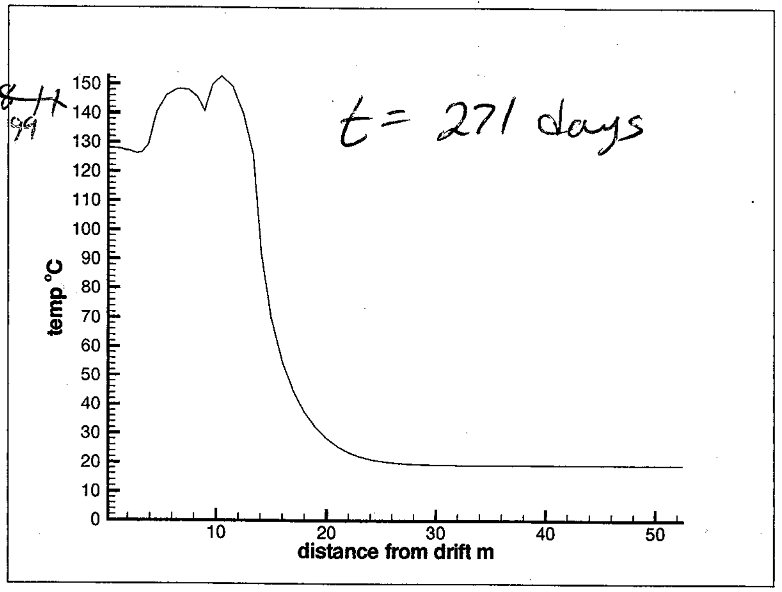
From Page No.

2-D slice of DST near y=23m

Smeared heat source
inner wing heaters 126.7 W/m^2
outer wing heaters 169 W/m^2
floor heater 208 W/m^2

DH 8 Feb 99



Simulation results at t = 0.7425 years

Compare with measurements shown on page 14

Peak temps about 10°C too low for y=23

Peak temp closer to y = 12 m

Maximum Drift wall temp at t=271 days ~ 130 C

At t = 2 years maximum drift wall temp ≈ 195 C

which looks pretty good except for anomalously high gas pressures in the matrix continuum representation of the drift

max(P(t=271)) = 237460 Pa

max(P(t=2years)) = 757700 Pa

This is with areamodf = 1 in the drift space

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Witnessed & Understood by me, | Date | Invented by | Recorded by DH | Date Feb 8 1999

From Page No.

~~I Killed this~~ DH 2/11/99 In the drift area, increase FMX from 1 to 10 and decrease length btwn fractures from 1 to 0.1 in an attempt to reduce matrix gas press.

In the drift

max[P(t=271 days)] = 94223 at x = 2.25 y = 43.75

max[P(t=2 years)] = 98717 at x = 2.25 y = 43.75

max[P(t=3 years)] = 99387 at x = 1.25 y = 40.25

I killed this run by accident just before 4 years simulation time.

Attempt rerun – no modifications

Feb 11, 1999 – Run died at simulation time 4.358 years

In the drift MAX(T(t=4years)) = 244.9 C (2.25, 43.75)

MAX(P(t=4years)) = 98762 Pa (1.25, 40.25)

In the wing heater area

MAX(P(t=4years)) = 902060 Pa (14.1, 42.5)

Pressures reach 1.9e6 Pa ≈ 19 bar above & below wing heaters in matrix

Change swext for TSw34 matrix from -1e8 to 0
Change dtfac from 0.334 to 0.5

Restart ~~8:30~~ 8:33 AM DH 2/11/99 AM Feb 11, 1999 Died at 4.370 years

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Witnessed & Understood by me, | Date | Invented by | Recorded by DH | Date Feb 11 1999

From Page No. ___ Feb 12, 1999

Simulation died at 4,370 years

MAX (T(t=4 yrs)) = 244.8 C @ (2.25, 43.75) In drift

MAX (P(t=4 yrs)) = 98153 Pa @ (1.25, 40.25) In drift

At 4,370 years cooled down to 182.3C

Change Isolve from 4 to 3
Change Areanodf in drift from 10 back to 1
Change xlm ylm zlm in drift from 0.1 to 0.01

Restart 8:40 AM Feb 12, 1999

Unable to get simulation past 4+ something years

Return to original grid page 3

Witnessed & Understood by me, | Date | Invented by / Recorded by DH | Date Mar 3 1999

From Page No. ___ Mar 3, 1999

Results from simulation reported on the following page. Files used are in

~dhughson/multiflo/dst/4yrun

Estimate of Q from Phillips (1996) length scale

$$l_3 = \left[\frac{\rho Q h}{k \beta}\right]^{1/2}$$

$\rho = 1000\ kg/m^3$

$h = 2.4 \times 10^6\ J/kg$

$k = 1\ W/(mK)$

Boiling isotherm ≈ 95C

$t = 271$ days $\quad z_1 = 38.4\ m \quad t_1 = 91.86\ C$
$\quad z_2 = 39.15\ m \quad t_2 = 107.4\ C$

DH 3/3/99 ~~$\frac{y-y_1^*}{x-x_1^*}$~~

$$\boxed{\frac{y-y_1^*}{x-x_1^*} = \frac{y_2^*-y_1^*}{x_2^*-x_1^*}}$$

$$\beta = \left(\frac{z_2 - z_1}{t_2 - t_1}\right)^{-1}$$

~~$Q = \ldots$~~ DH 3/3/99

$$y = \left(\frac{y_2^*-y_1^*}{x_2^*-x_1^*}\right)(x - x_1^*) + y_1^*$$

$$z_b = \left(\frac{39.15-38.4}{107.4-91.86}\right)(95 - 91.86) + 38.4 = 38.55$$

$$\beta = \frac{39.15 - 38.4}{107.4 - 91.86} = 4.8 \times 10^{-2}\ m/K = 20.72\ K/m$$

$$Q = \frac{l^2 k \beta}{\rho h} = \frac{(1.45\ m)^2 \left((J/s)/(mK)\right) 20.72\ K/m}{(1000\ kg/m^3)(2.4 \times 10^6\ J/kg)} = 1.815 \times 10^{-8}\ \frac{m^3}{s}$$

$1.09 \times 10^{-3}\ \frac{l}{m} = 6.5 \times 10^{-2}\ \frac{l}{hr}$

Witnessed & Understood by me, | Date | Invented by / Recorded by DH | Date Mar 3 1999

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$y = \left(\frac{y_2-y_1}{x_2-x_1}\right)(x-x_1) + y_1$ $\beta = \frac{t_2-t_1}{z_2-z_1}$ $Q = \frac{l^2 K \beta}{\rho h}$

t = 1 year $z_1 = 37.5$ m $t_1 = 93.78$C
$z_2 = 38.4$ m $t_2 = 110.8$C

DH 3/3/99
$z_b = 37.56$ m $\beta = 18.91$ $Q = 4.69 \times 10^{-8}\ m^3/s$
2.8×10^{-3} L/min $= 1.7 \times 10^{-1}$ L/hr

t = 1.5 years $z_1 = 31.5$ $t_1 = 62.93$
$z_2 = 32.5$ $t_2 = 96.79$

$z_b = 32.45$ $\beta = 33.86$ $Q = 8.04 \times 10^{-7}\ m^3/s$
4.8×10^{-2} L/min $= 2.9$ L/hr

t = 2 years $z_1 = 27.95$ $t_1 = 57.5$
$z_2 = 29.35$ $t_2 = 96.72$

$z_b = 29.29$ $\beta = 28$ $Q = 1.34 \times 10^{-6}\ m^3/s$
8.0×10^{-2} L/min $= 4.8$ L/hr

t = 3 years $z_1 = 19.5$ $t_1 = 74.49$
$z_2 = 22.25$ $t_2 = 96.89$

$z_b = 22.02$ $\beta = 8.15$ $Q = 1.10 \times 10^{-6}\ m^3/s$
6.6×10^{-2} L/min $= 3.96$ L/hr

t = 4 years $z_1 = 12$ $t_1 = 52.3$
$z_2 = 16$ $t_2 = 96.48$

$z_b = 15.87$ $\beta = 11.05$ $Q = 2.68 \times 10^{-6}\ m^3/s$
1.6×10^{-1} L/min $= 9.6$ L/hr

$Q \left(\frac{m^3}{s}\right)\left(\frac{1000\ L}{m^3}\right)\frac{60 s}{min}$

$\left(\frac{1\ ml}{cm^3}\right)\left(\frac{L}{1000\ ml}\right)\left(\frac{100\ cm}{m}\right)^3 = \frac{1000 L}{m^3}$

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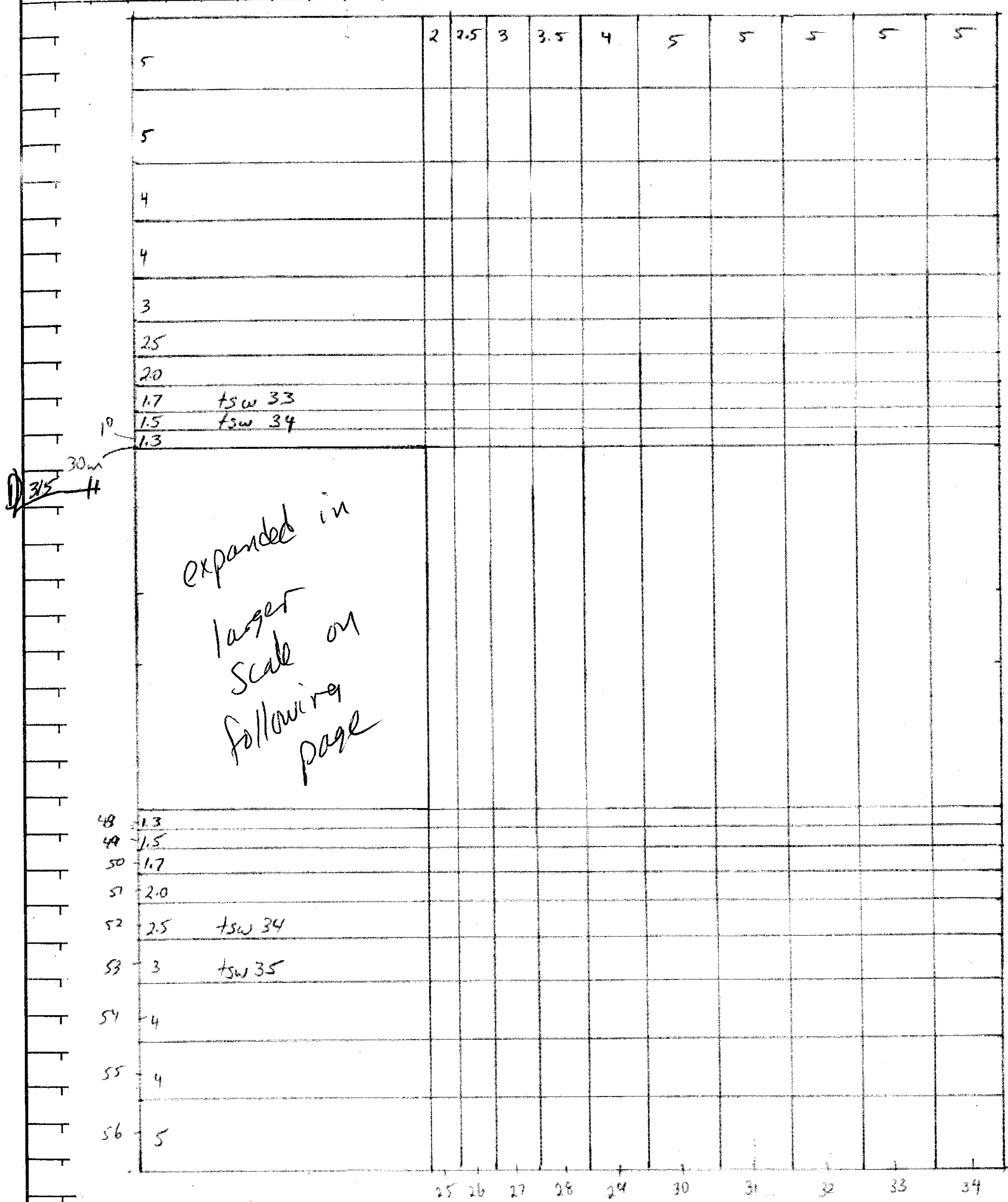

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Project No. 20-1402-661

Book No. 292 TITLE TEF

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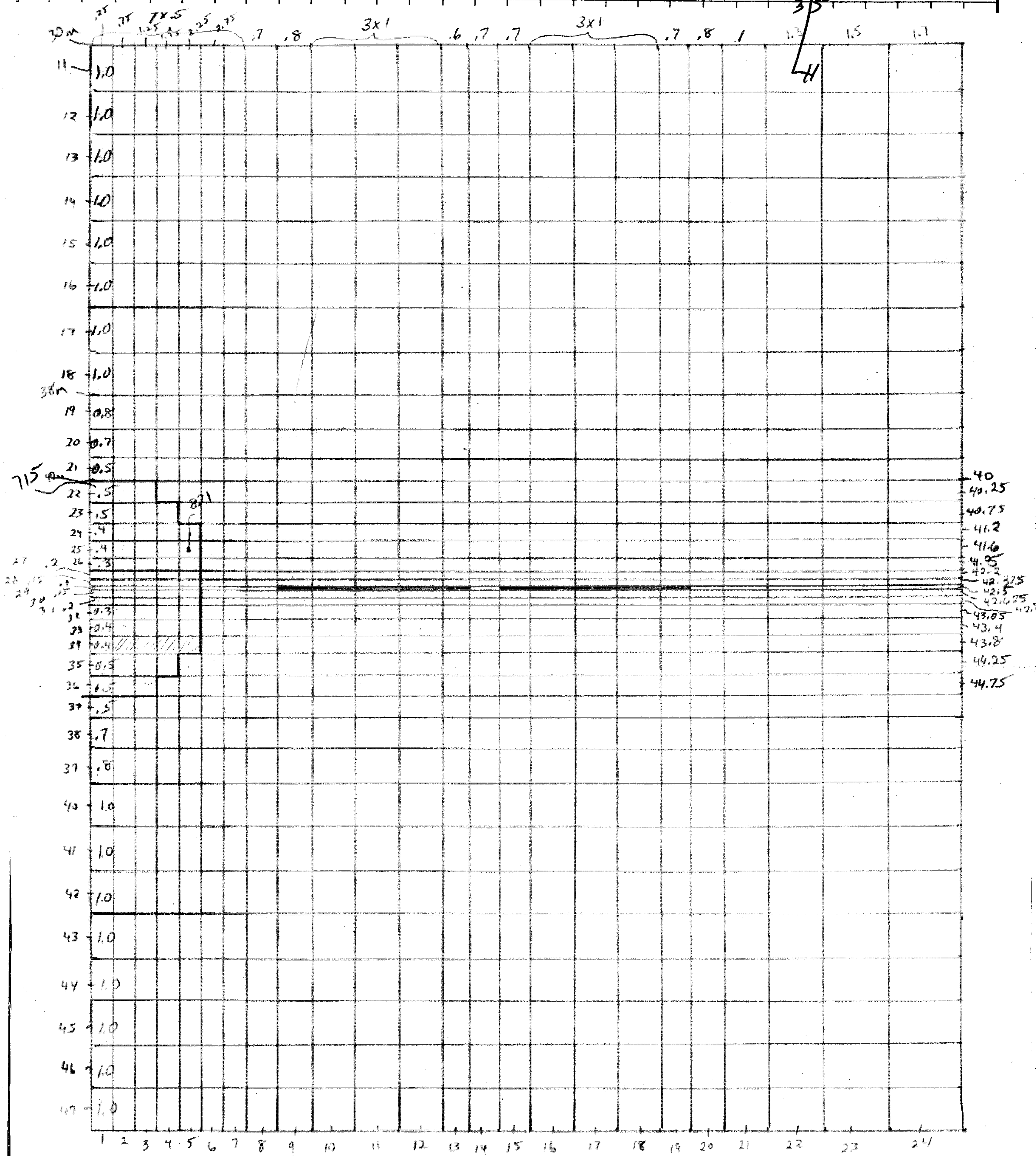

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Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by DH	Mar 5 1999

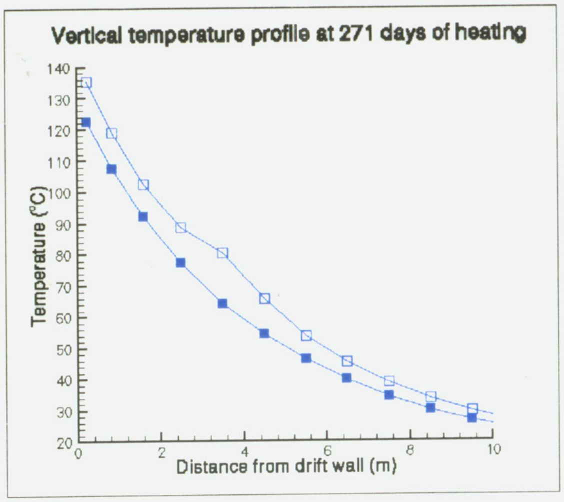


Figure 3

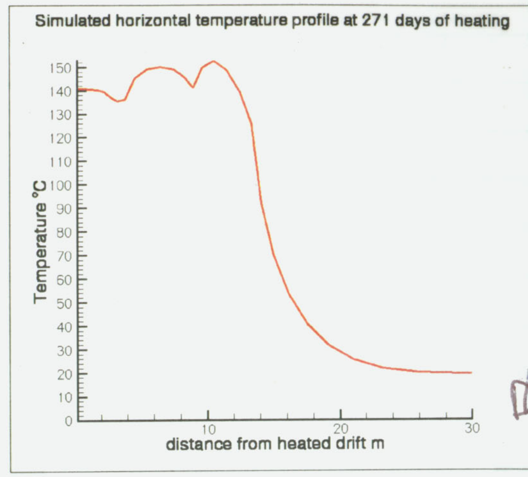


Figure 5

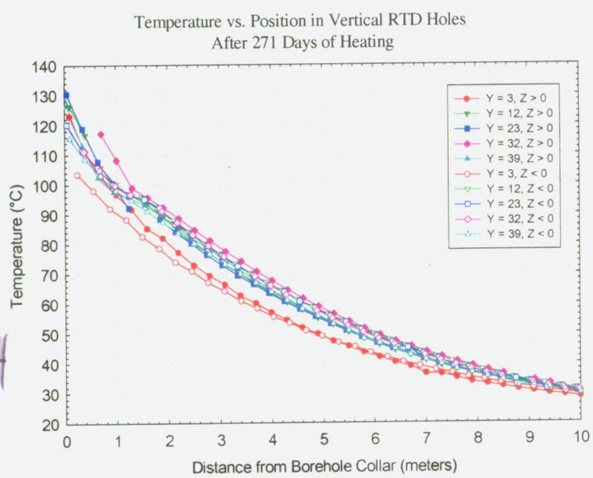
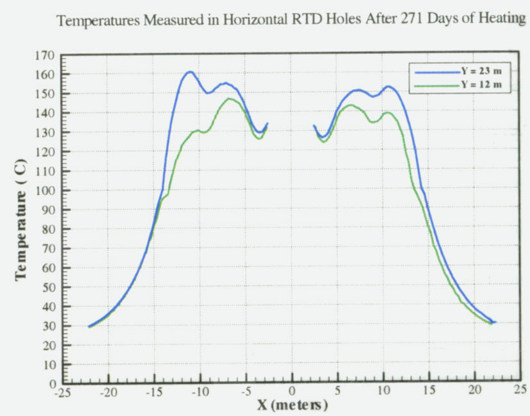
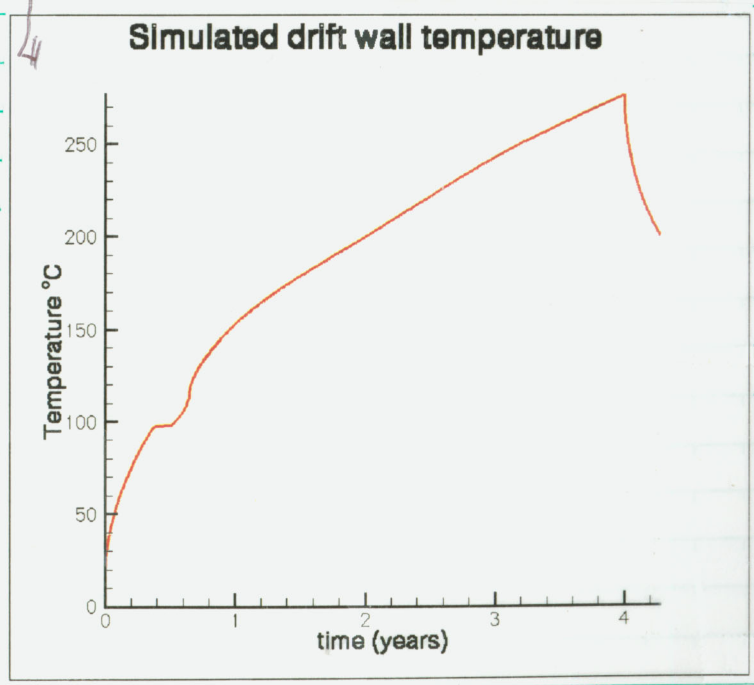


Figure 4





temperature measurements in RTD holes are from the thermal-mechanical Data from the Drift Scale Test 6/1/1998 – 8/31/1998 Sandia National Labs

Steve Sobolik
505-844-1131

Witnessed & Understood by me,	Date	Invented by	Date
		Recorded by DH	Mar 5 1999

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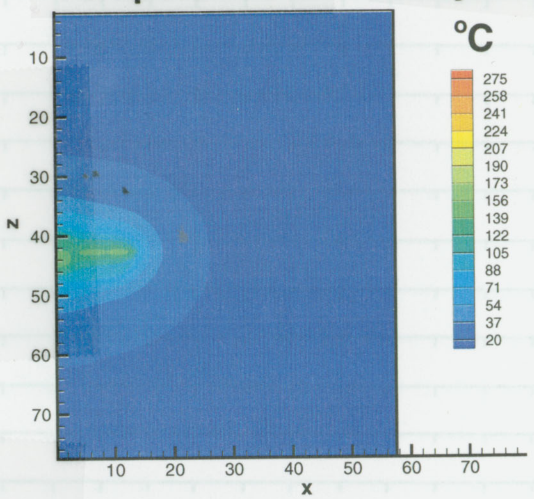
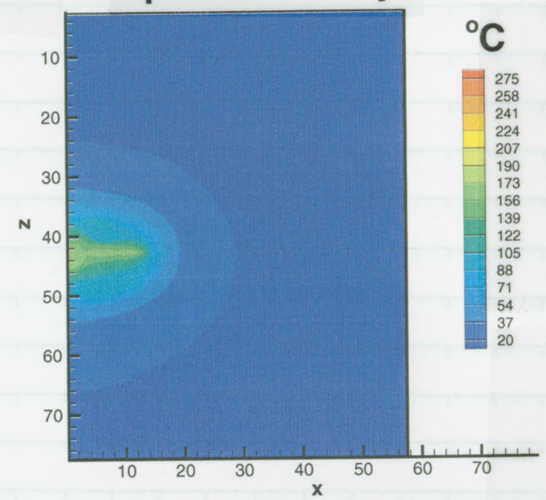
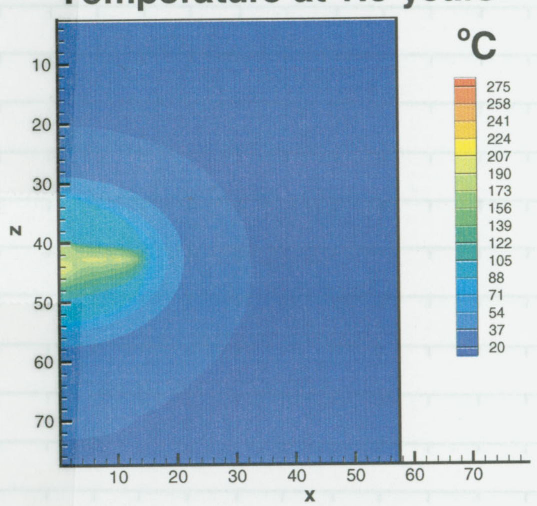
Temperature at 271 days



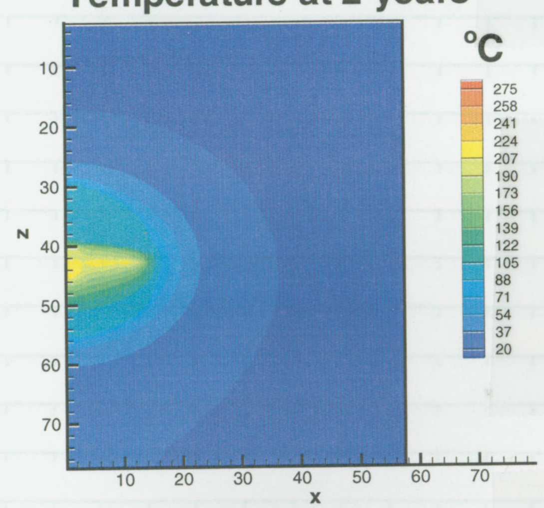
Temperature at 1 year



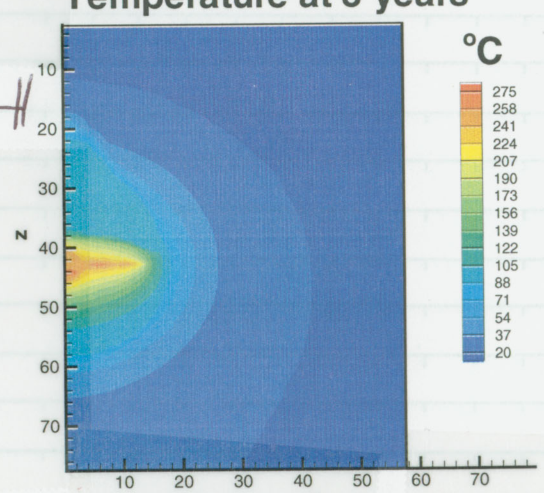
Temperature at 1.5 years



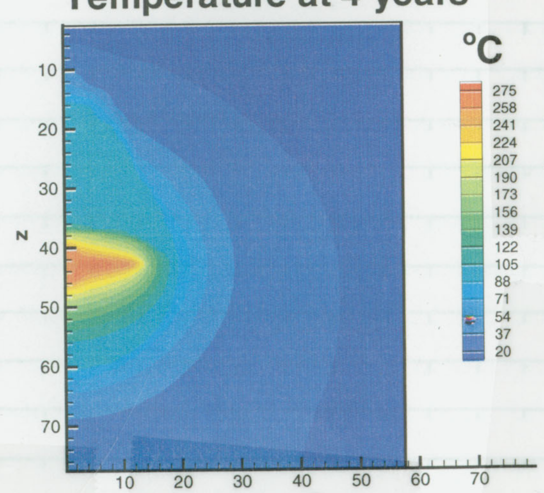
Temperature at 2 years



Temperature at 3 years



Temperature at 4 years



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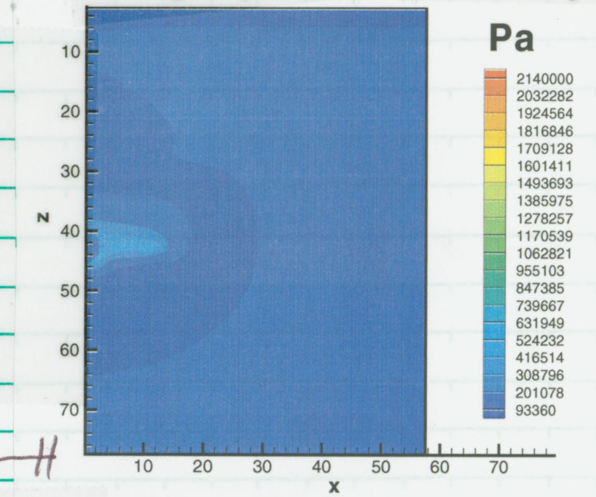
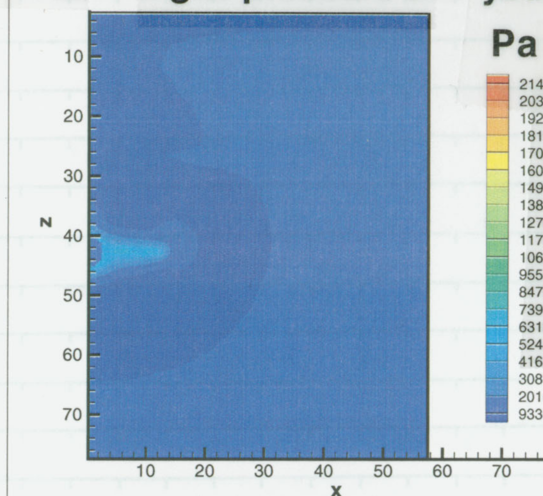
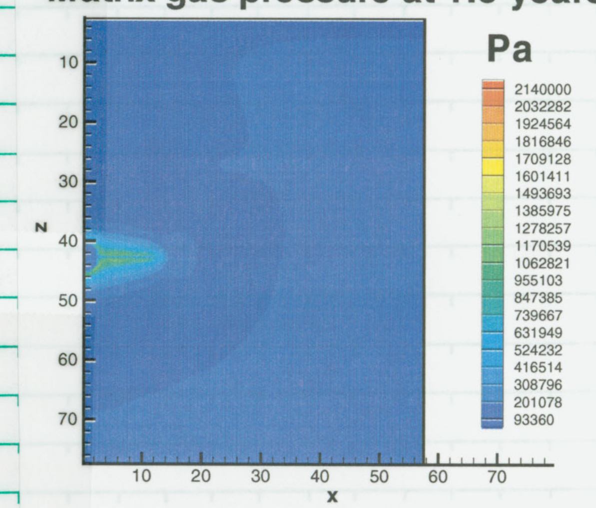
Matrix gas pressure at 271 days



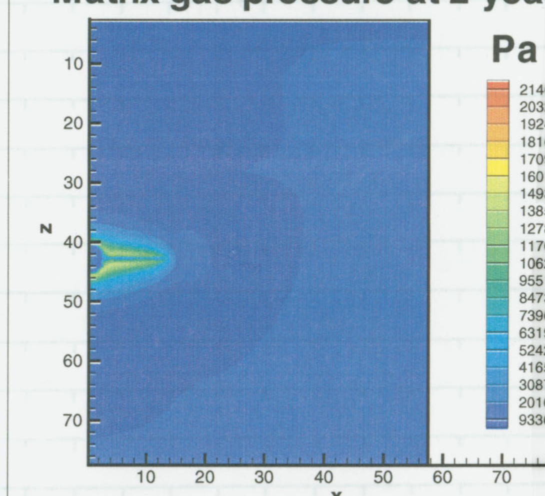
Matrix gas pressure at 1 year



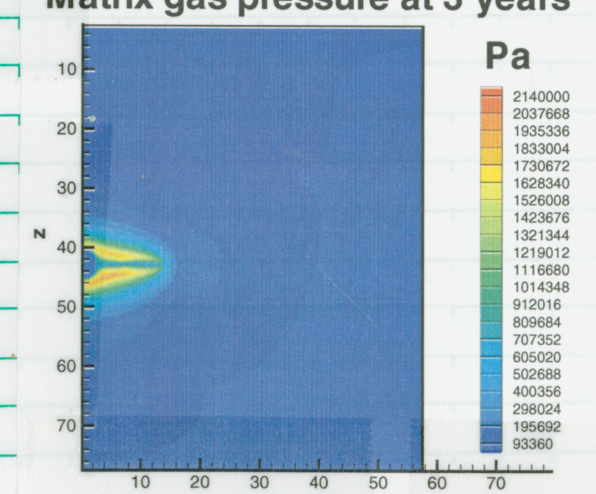
Matrix gas pressure at 1.5 years



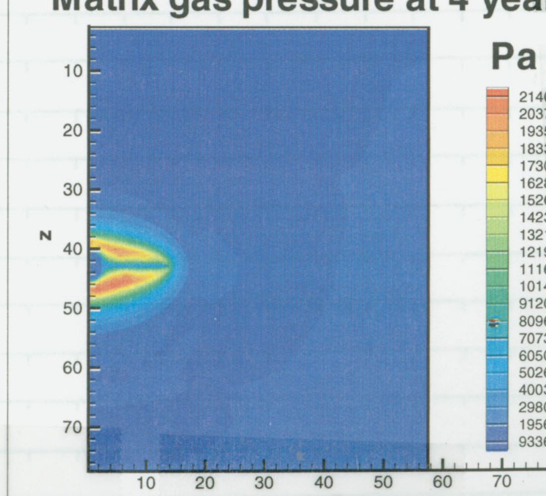
Matrix gas pressure at 2 years



Matrix gas pressure at 3 years



Matrix gas pressure at 4 years



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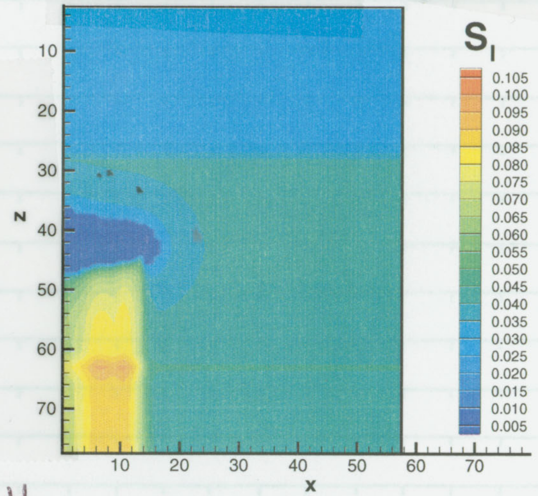
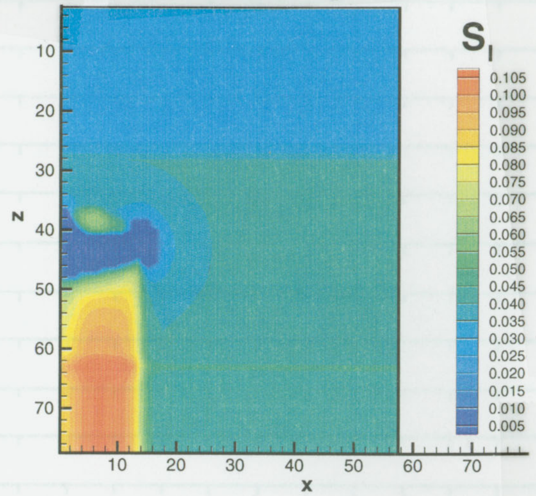
Saturation at 271 days

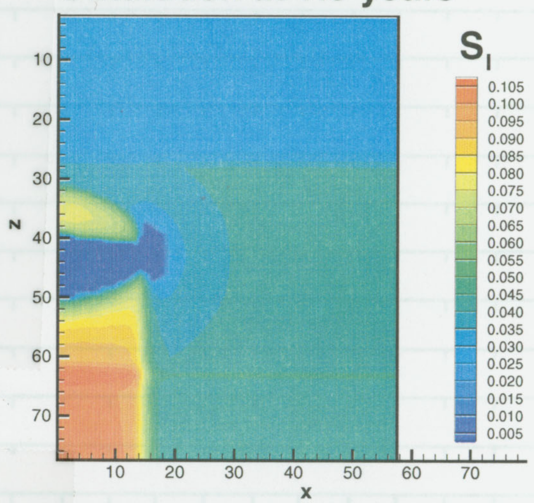


Saturation at 1 year

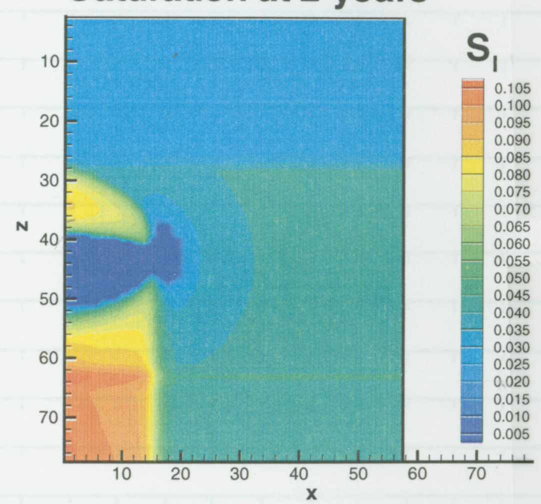


D-H

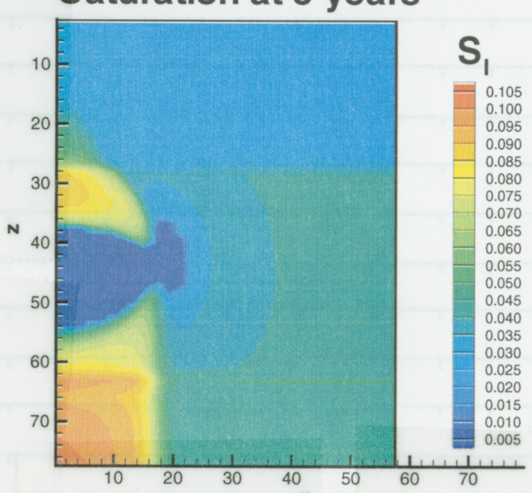
Saturation at 1.5 years



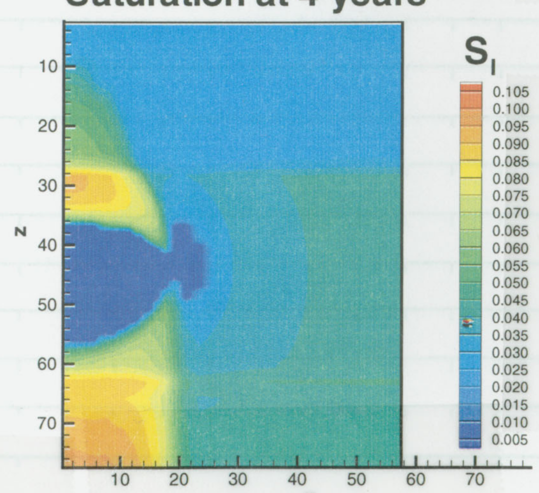
Saturation at 2 years



Saturation at 3 years



Saturation at 4 years



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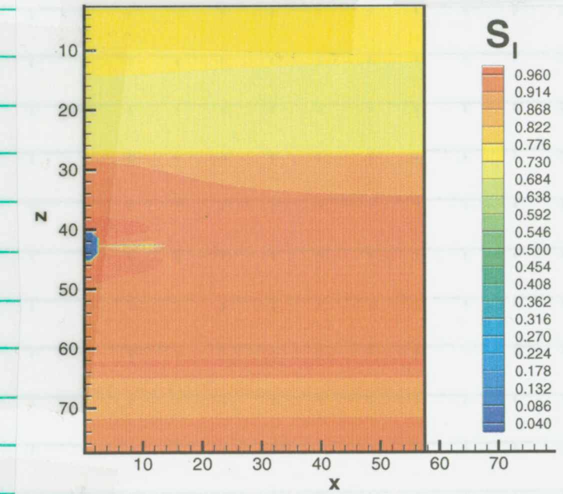
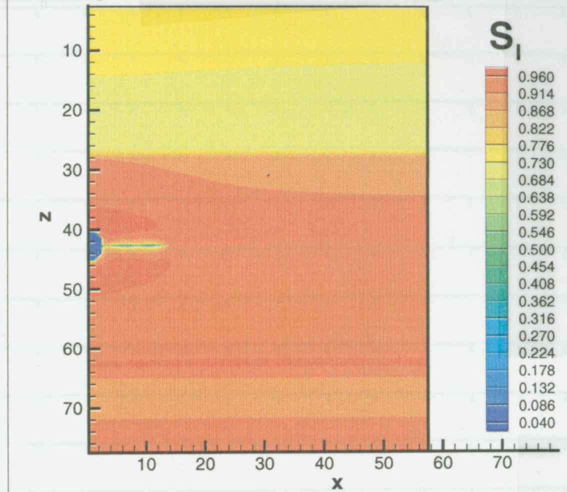
Matrix saturation at 271 days

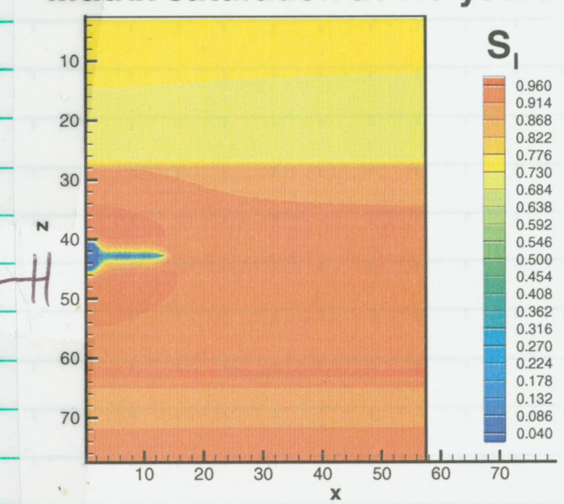


Matrix saturation at 1 year

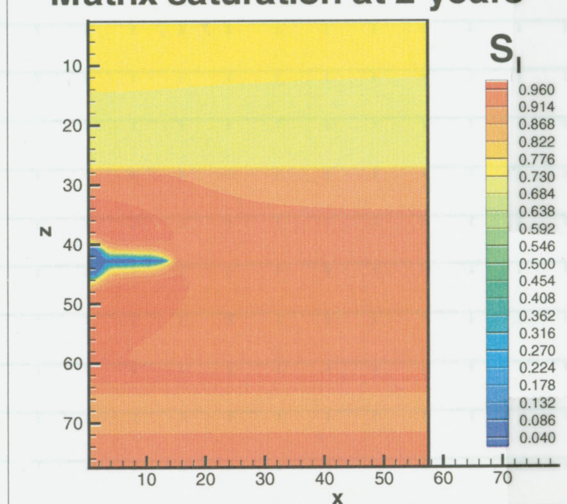


D-H

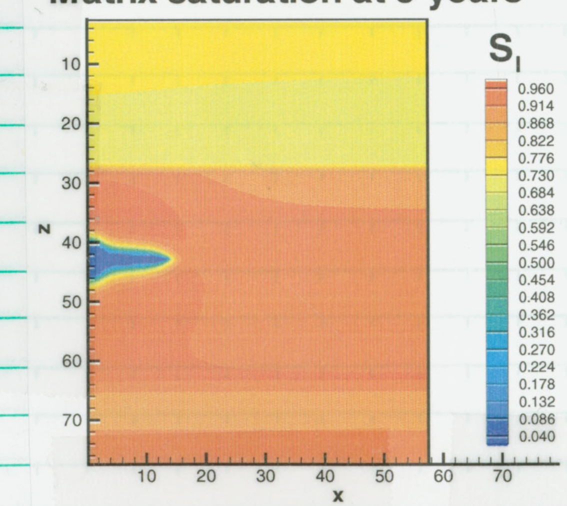
Matrix saturation at 1.5 years



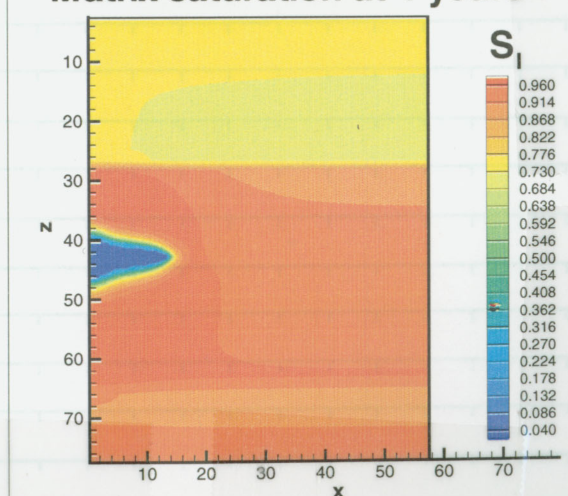
Matrix saturation at 2 years



Matrix saturation at 3 years



Matrix saturation at 4 years



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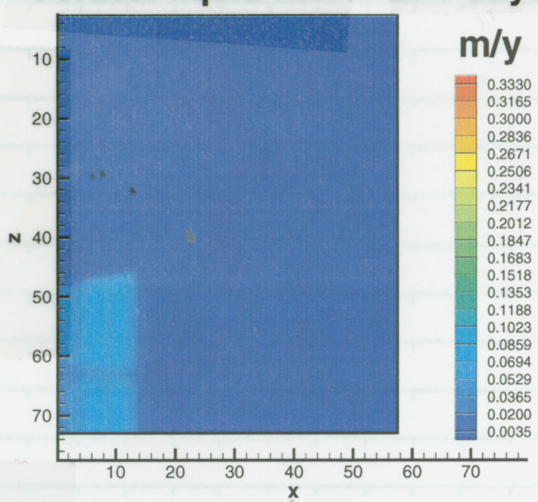
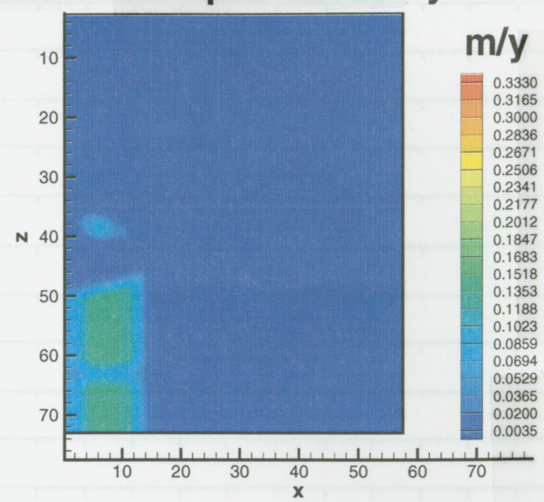
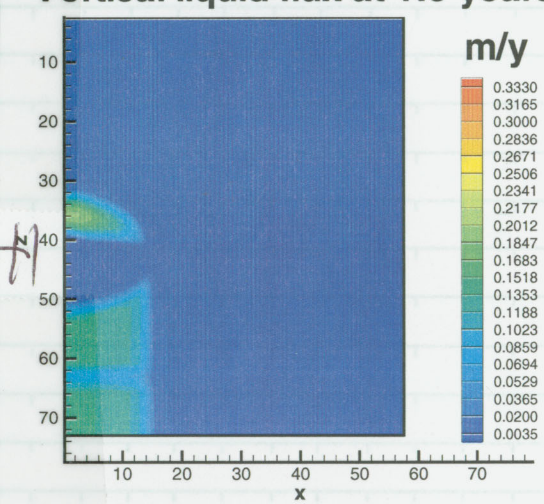
Vertical liquid flux at 271 days



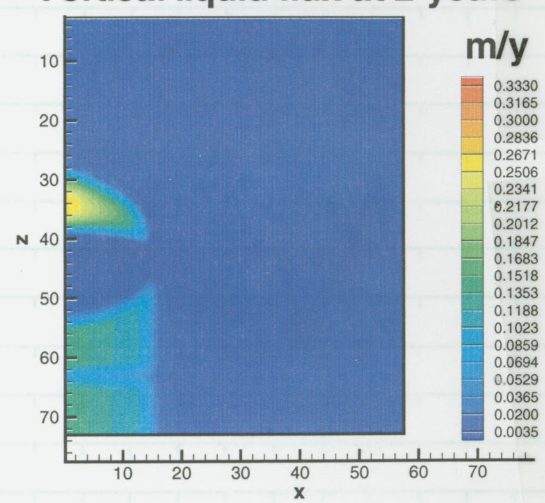
Vertical liquid flux at 1 year



Vertical liquid flux at 1.5 years

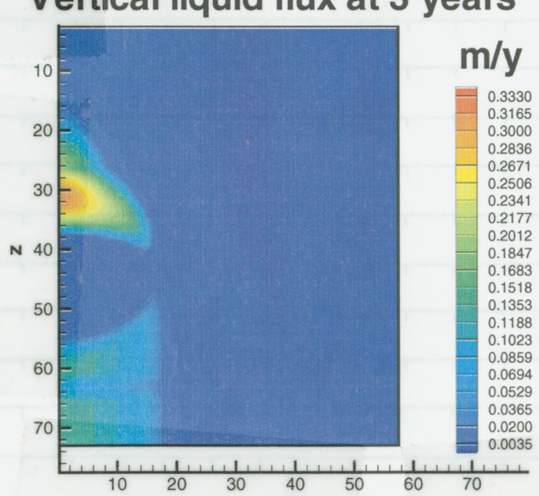


Vertical liquid flux at 2 years

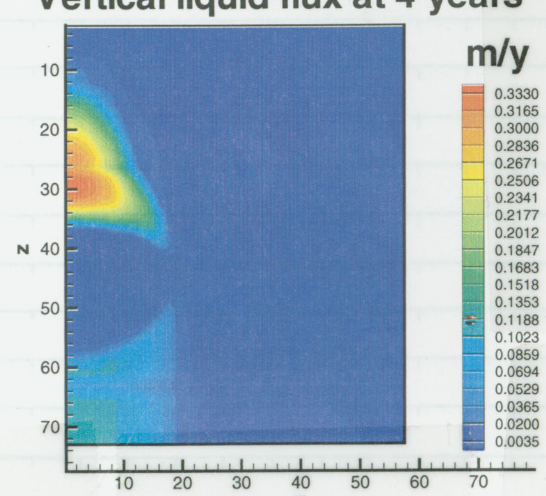


DH

Vertical liquid flux at 3 years



Vertical liquid flux at 4 years



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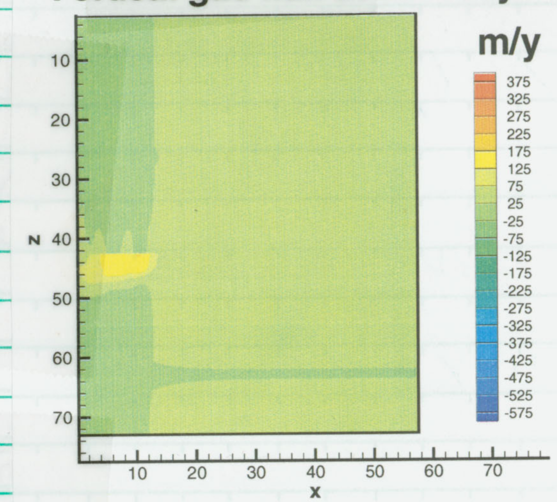
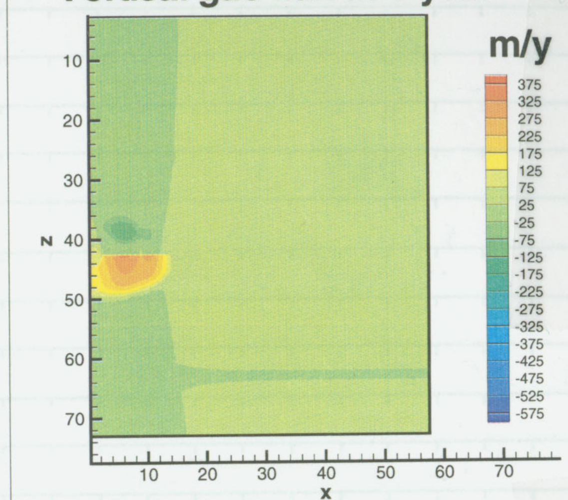
Vertical gas flux at 271 days

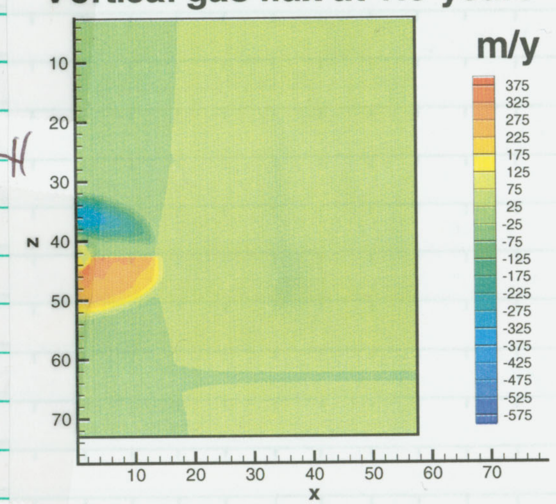


Vertical gas flux at 1 year

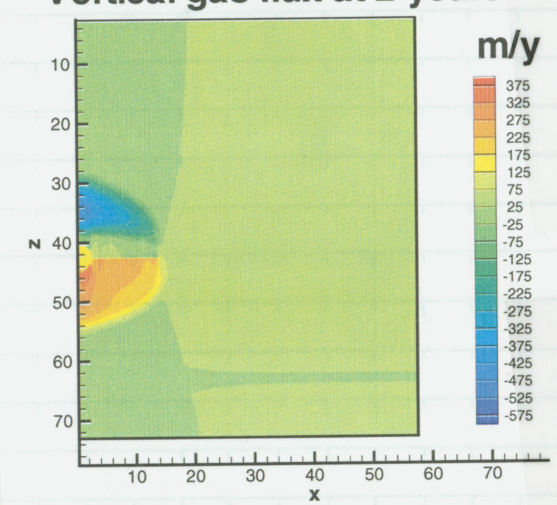


DH

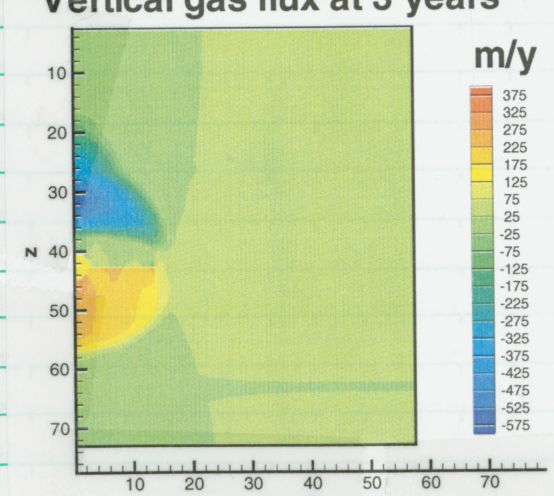
Vertical gas flux at 1.5 years



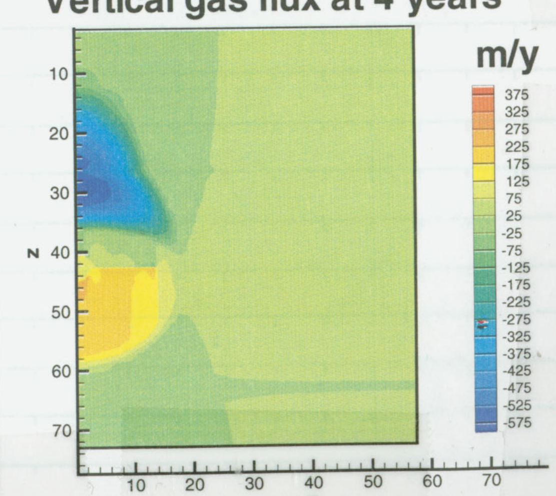
Vertical gas flux at 2 years



Vertical gas flux at 3 years



Vertical gas flux at 4 years



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Simulation results pg 21 — 32

in ~dhughson/multiflo/dst/4yrun/*

these results are part of the

IM Report for TEF ~~to~~ DH 3/16/99 to be

delivered March 30, 1999

Mar 15, 1999

Can a sink term be used to represent mass loss through the bulkhead

Aug 5 1998 600 mL/hr
Aug 26 1998 870 mL/hr
Aug 31, 1998 800 mL/hr ✓ Pick Aug 31, 1998

DH 3/16/99

~~(0.800 L/hr)~~ $= 2.2 \times 10^{-4}$ kg/s

$\left(800 \frac{mL}{hr}\right)\left(\frac{cm^3}{mL}\right)\left(\frac{m}{100cm}\right)^3\left(\frac{1000kg}{m^3}\right)$ ~~60m/hr~~ DH 3/16/99 $\frac{60}{}$ $\frac{hr}{60min}$ $\frac{min}{60s}$

Which occurs from 42.5 m — to say 50 m

For a 1 m slice $\frac{2.2 \times 10^{-4} \text{ kg/s}}{50 m} = 4.44 \times 10^{-6}$ kg/s/m

Divide by 2 for symmetry boundary & divide up into 3 blocks at drift crown

row 22 col 1,2,3 each 7.41×10^{-7} kg/s

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Sink of -7.41e-7 kg/s in each of 3 blocks at drift crown had negligible effects on fracture or matrix saturation
~dhughson/multiflo/dst/sink1

Increase by a factor of 10 and distribute over more of the drift ~

2.2×10^{-3} kg/s = 8000 mL/hr

divide by 50m (drift length), divide by 2 (symmetry)

= 2.22e-5 (kg/s)/m In 7 blocks

1	3	22	22
4	4	23	23
5	5	24	26

Rate for each grid block in region = 3.17e-6 kg/s

Dead at Runtime 0.6 ~ yrs

Try same arrangement with order of mag less
~ 800 mL/hr = 2.2×10^{-4} kg/s/m

With this arrangement there is a slight but noticeable shift upwards in the extent of the dryout zone above the drift.

Save this in ~dhughson/multiflo/dst/sink1

replacing results from the run at the top of this page and increase sink term by a factor of 2 to
4.4×10^{-4} kg/s/m

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7 blocks

Sink / block	Simulated Bulkhead loss	CASE
0		0
3.17e-7 kg/s	800 mL/hr	1
6.34e-7 kg/s	1600 mL/hr	2
12.7e-7 kg/s	3200 mL/hr	4
19.2e-7 kg/s	4838 mL/hr	6

Compare location at dry out zone above drift crown (x=0)

Interpolated between blocks

$$\frac{y-y_1^*}{x-x_1^*} = \frac{y_2^*-y_1^*}{x_2^*-x_1^*}$$

Fracture continuum - Drift Crown at 40m

BASE CASE SINK = 0

TIME	DISTANCE FROM CROWN TO S_l = 0.01			
271 days	3.55e1	2.7849e-2	36.14	3.86
	3.65e1	0		
1 year	3.55e1	2.1503e-2	36.03	3.965
	3.65e1	0		
1.5 year	3.915e1	2.8619e-2	39.54	0.46
	3.975e1	0		
2 year	3.84e1	5.1742e-2	39.0	.995
	3.915e1	0		
3 year	3.65e1	5.959e-2	37.33	2.67
	3.75e1	0		
4 year	3.55e1	5.659e-2	36.32	3.68
	3.65e1	0		
Sink 1 = 800 mL/hr 271 days	3.55e1	2.5408e-2	36.11	3.89
	3.65e1	0		
1 year	3.45e1	2.8293e-2	35.15	4.85
	3.55e1	0		
1.5 year	3.84e1	5.0427e-2	38.41	1.59
	3.915e1	0		
2 year	3.84e1	4.2277e-2	38.97	1.03
	3.915e1	0		
3 year	3.65e1	5.0833e-2	37.30	2.70
	3.75e1	0		

~~4 year~~

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	DISTANCE FROM CROWN TO SL = .01			
SINK 2 = 1600 mL/hr 271 days	3.55e1	2.1262e-2	36.03	3.97
	3.65e1	0		
1 year	3.45e1	2.4702e-2	35.10	4.90
	3.55e1	0		
1.5 year	3.75e1	5.5118e-2	38.24	1.76
	3.84e1	0		
2 year	3.75e1	5.7721e-2	38.24	1.76
	3.84e1	0		
3 year	3.65e1	3.6668e-2	37.23	2.77
	3.75e1	0		
SINK 4 = 3200 mL/hr 271 days	3.45e1	2.8843e-2	35.15	4.85
	3.55e1	0		
1 year	3.35e1	2.8413e-2	34.15	5.85
	3.45e1	0		
1.5 year	3.35e1	2.8063e-2	34.14	5.86
~~2 year~~ DH 3/22/99	3.45e1	0		
2 year	3.65e1	5.3342e-2	37.31	2.69
	3.75e1	0		
SINK 6 = 4838 mL/hr 271 days	3.45e1	2.3167e-2	35.07	4.93
	3.55e1	0		
1 yr	3.35e1	2.4653e-2	34.09	5.91
	3.45e1	0		
1.5 yr	3.25e1	2.3779e-2	33.08	6.92
	3.35e1	0		

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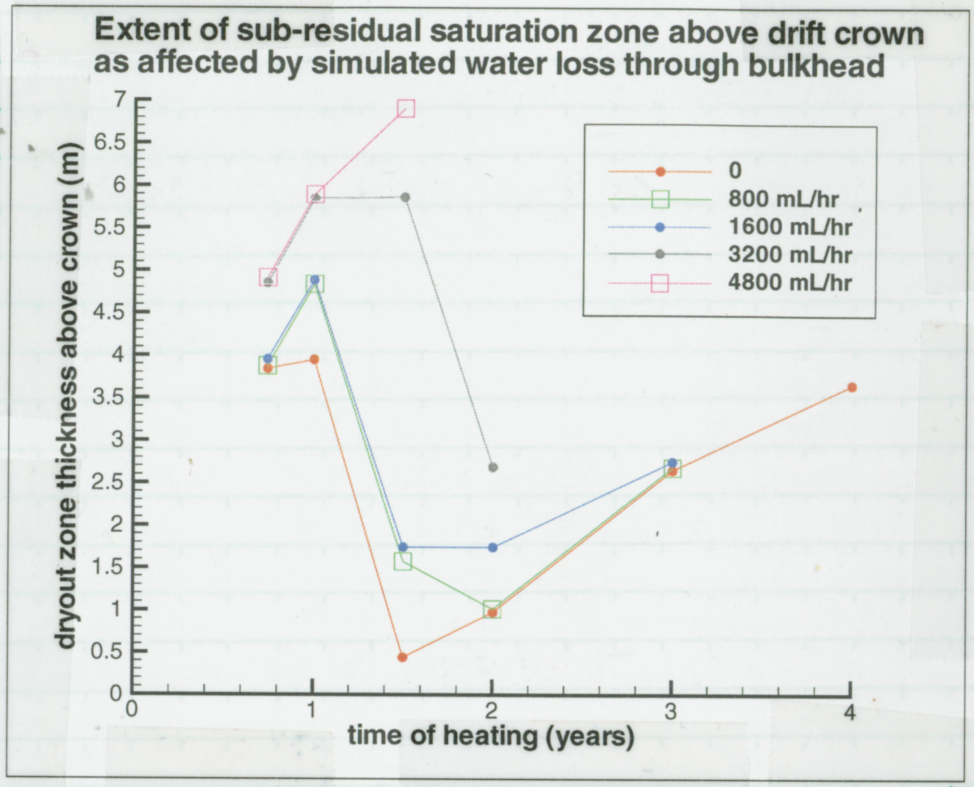

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Boiling Isotherm 95C

$$\frac{y-y_1^*}{x-x_1^*} = \frac{y_2^*-y_1^*}{x_2^*-x_1^*}$$

Drift Crown at 40m

$$y = \left(\frac{y_2^*-y_1^*}{x_2^*-x_1^*}\right)(x-x_1^*) + y_1^*$$

Base Case Sink = 0

DH 3/23/99

Time	Z	T	⊗	l
271 days 3/23/99	38.4	91.86	38.55	1.45
	39.15	107.4		
Sink = 800 mL/hr	38.4	91.85	38.55	1.45
271 days	39.15	107.4		
sink 1600 mL/hr	38.4	91.79	38.56	1.44
	39.15	107.3		
sink 3200 mL/hr	38.4	91.37	38.57	1.43
	39.15	107.1		
sink 4800 mL/hr	38.4	90.96	38.59	1.41
	39.15	107.1		

Time 1.5 yrs

	Z	T	⊗	l
Sink = 0	31.5	62.93	32.45	7.55
	32.5	96.79		
Sink = 800 mL/hr	32.5	83.92	33.31	6.69
	33.5	97.57		
sink = 1600 mL/hr	~~35.5~~ DH	~~89.34~~ DH 3/23/99	33.5 94.79 / 34.5 97.72	33.91 6.09
	~~36.5~~ DH	~~103.2~~ DH		
sink 3200 mL/hr	35.5	89.34	35.91	4.09
	36.5	103.2		
sink 4800 mL/hr	35.5	88.78	39.~~9~~95	4.05
	36.5	102.7		

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Time = 1.0 yr

	Z	T		
sink = 0	37.5	93.78	37.56	2.44
	38.4	110.8		
sink = 800 ml/hr	37.5	93.65	37.57	2.43
	38.4	110.7		
sink = 1600 ml/hr	37.5	93.57	37.58	~~2.48~~ 2.42 3/23/99 DH
	38.4	110.6		
sink = 3200 ml/hr	37.5	93.32	37.59	2.41
	38.4	110.3		
sink = 4800 ml/hr	37.5	92.53	37.61	2.37
	38.4	109.5		

Time = 2.0 yr

sink = 0	~~37.5~~	~~99.88~~ DH 3/23/99		
	~~38.4~~	~~97.88~~ DH 3/23/99		
	~~37.15~~ DH 3/23/99			
	27.95	57.5	29.29	10.71
	29.35	96.72		
sink = 800 ml/hr	29.35	89.07	30.14	9.86
	30.5	97.67		
sink = 1600 ml/hr	29.35	73.31	30.38	9.62
	30.5	97.42		
sink = 3200 ml/hr	31.5	93.06	31.92	8.08
	32.5	97.68		

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Time = 3 yr

DH 3/23/99

Sink = 0	~~22.25~~ 19.5	74.49	22.02	18.0
	22.25	96.89		
sink = 800 ml/hr	19.5	47.09	22.25	17.75
	22.25	95.04		
sink = 1600 ml/hr	22.25	83.76	24.16	15.84
	24.5	92.02		
Time = 4 yr	12.0	52.30	15.87	24.13
	16.0	96.48		

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Time to redo TH calculations with multiflo for the new EDA II Design.

Original in Book No 284 ~~based on~~ based on a section from the ~~Near~~ Near-Field/Altered-Zone Models report UCRL-ID-129179

Fig 3-13 b) at 233748 m N 170489 m E
stratigraphy simply scaled off figure

This was simply widened and the heat load reduced by M Hill for the Process- and System level sensitivity analyses status report Sept 1999 TEF NRC Deliverable

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New strategy: Locate according to Repository Layout

Get stratigraphy & contact elevations from Geologic Framework Model.

Correlate stratigraphy with hydrostratigraphy & assign properties from LBLN and LLNL tables.

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PREDECISIONAL

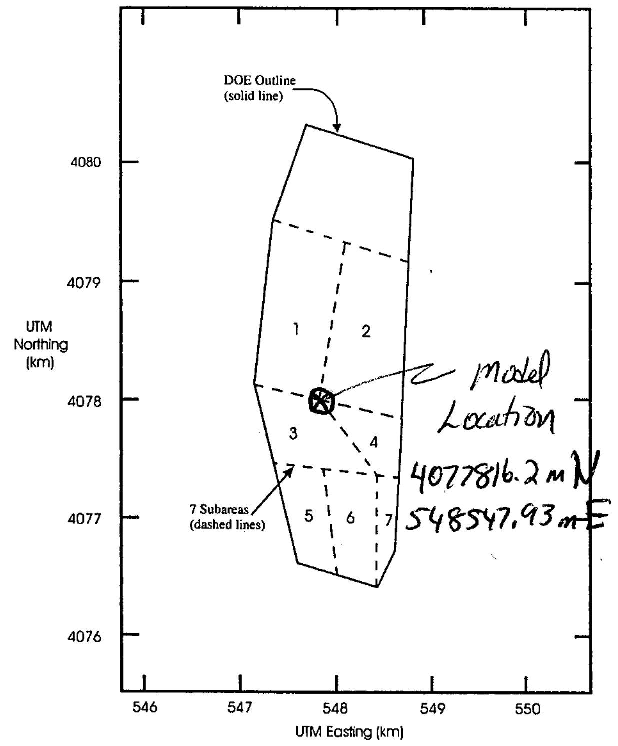

Figure 4-2. Boundary of proposed Yucca Mountain repository

4-6

From TPA location of corner common to subareas 1, 2, 3, and 4 in UTM coordinates

4077816.2 m N
548547.93 m E

Converted to State Plane Coordinates in feet using Army Corps of Engineers Program Corpscon

NAD 27
Zone 11
NAD 27
Nevada Central

Converts to 763279.74 ft N
559493.78 ft E

Stratigraphy from Geologic Framework Model
Elevations of Contacts from earthvision Annotation file

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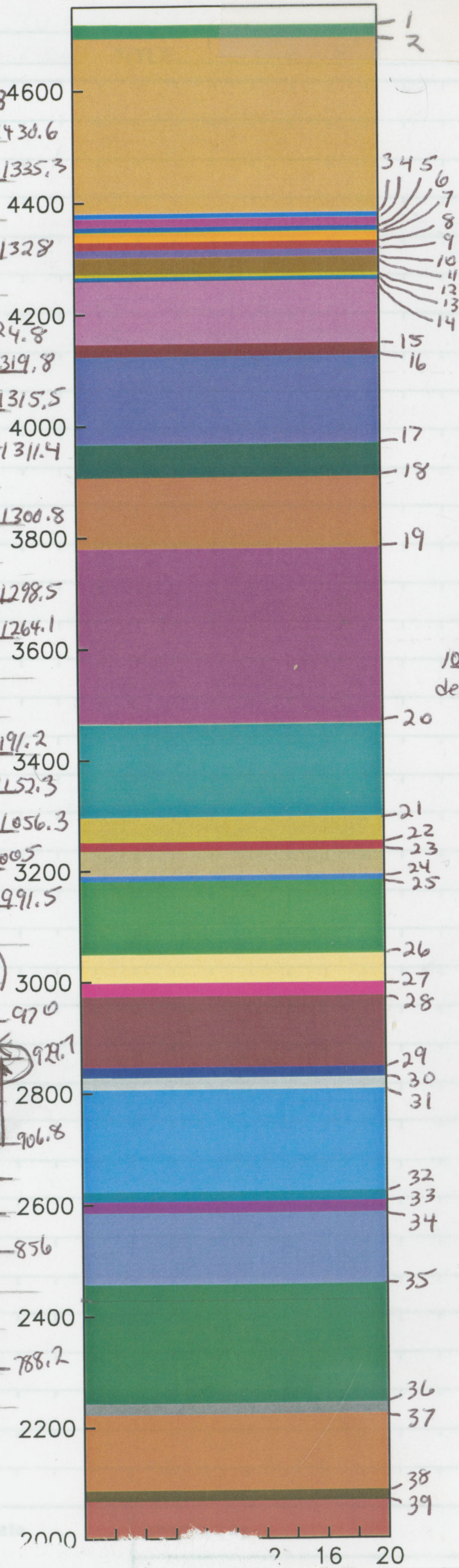
Unit	No.	Elev.	Layer	Value
	1	4717.1		1437.8
Tiva-Rainer	2	4693.5	tcw11	1430.6
Tpcp	3	4381	tcw12	1335.3
TpcLD	4	4372.6		
Tpcpv2	5	4356.8	tcw13	1328
Tpcpv1	6	4348.6	ptn21	
Tpbt4	7	4346.6		1324.8
Yucca	8	4330	ptn22	1319.8
Tpbt3_dc	9	4315.9	ptn23	1315.5
Pah	10	4302.4	ptn24	1311.4
Tpbt2	11	4273.1	ptn25	
Tptrv3	12	4267.8		1300.8
Tptrv2	13	4263.3	tsw31	
Tptrv1	14	4260.2		1298.5
Tptrn	15	4147.3	tsw32	1264.1
Tptrl	16	4124.3	tsw33	
Tptul	17	3967.6		
RHH	18	3908.2		1191.2
Tptpmn	19	3780.5	tsw34	1152.3
Tptpll	20	3465.7	tsw35	1056.3
Tptpln	21	3297.2	tsw36	1005
Tptpv3	22	3253	tsw37	991.5
Tptpv2	23	3236.6		
Tptpv1	24	3193.2	ch1(vc zc)	
Tpbt1	25	3182.5		970
Calico	26	3050.1	ch2(vc zc)	929.7
Calico bt	27	2998.9	ch3(vc zc)	
prow uv	28	2975.2	ch4(vc zc)	906.8
prow uc	29	2848.3		
prow md	30	2829.1	pp3vp	
prow lc	31	2808.4		856
prow lv	32	2624.5	pp2zp	
prow bt	33	2606.7		
bullfrog uv	34	2585.9		788.2
bullfrog md	35	2458.2	bf3vp	
▽		~~2428~~		740

1437.8 - 740 = 697.8



tcw12
102.5
tsw32 ~~198.7~~ 173.7
tsw33
~~251.0~~ 246.6
tsw34
~~290.5~~ 285.5
tsw35
1081.8 Heat
depth 356
~~437.8~~ 381.5
DH 9/27/99
tsw36
~~489.1~~ 432.8
~~502.0~~ tsw37 446.3
~~524.1~~ ch1 467.8
~~564.4~~ ch2 ch3 508.1
~~587.8~~ ch4 531
DH 9/27/99
pp3vp
~~638.1~~ 581.8
pp2zp
649.6
bf3vp
▽ 697.8

UTM 4077816.2m N
547847.27m E

State Plane
763279.74 ft N
559493.78 ft E

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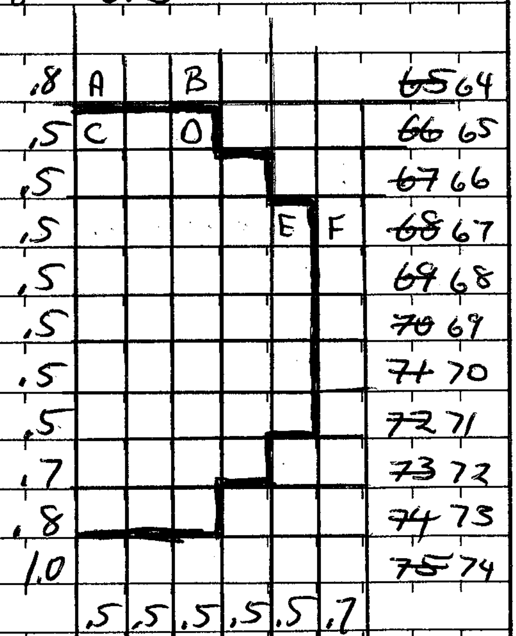
UNIT	ΔZ m	# of rows	row indices	Block dz top to bottom
tcw11	7.2	2	1:2	3.6 3.6
tcw12	95.3	12	3:14	4 6 8 10 10 10 10 10 10 7 6 4.3
tcw13	7.3 9/27/99	2	15:16 DH	3.7 3.6
ptn21	3.2 DH	1	17:17 9/27/99	3.2
ptn22	5 ~~4.3~~	1	18:18	5
ptn23	~~9.3~~ 4.3	~~2~~ 1	~~19:20~~ 20 20 19	~~4.7 4.6~~ 4.3
ptn24	4.1	1	~~21:21~~ 20 20	4.1
ptn25	10.6	3	~~22:24~~ 21,23	3.8 3.8 3
tsw31	2.3	1	~~25:25~~ 24,24	2.3
tsw32	34.4	6	~~26:31~~ 25 30	3.3.4 4 6 8 10
tsw33	72.9	8	~~32:39~~ 31 38	5x10 8 7.9 7
tsw34	38.9	4	~~40:43~~ 39 42	8.9 3x10
tsw35	~~38~~ ~~147.3~~	96	43:80 DH 9/27/99	10 9 8 7 6 5 4 3 2.2 1.5 11x1 .8 .5 6x.5 .7 .8 1
			81:86 ~~82:87~~	1.5 2 3 4 5 7
~~tsw36~~	~~51.3~~	~~6~~	~~82:87~~	8 9 10 10 8 6.3
~~ch1,2~~	~~21.5~~	~~3~~	~~90~~ DH 9/27/99 87,88	
tsw37	13.5	~~6~~ 2	~~88:89~~	6.7 6.8
ch1,2	21.5	3	~~90:92~~ 89 91	7 7 7.5
ch3	40.3	~~4~~5	92 ~~93~~:96	4 ~~3~~x8 8.3
ch4	22.9	2	97:98	10 12.9
pp3up	50.8	5	99:103	10.8 4x10
pp2zp	67.8	7	104:110	5x10 9 8.8
bf3up	48.2	5	111:115	8.2 4x10



Detail of drift in tsw35

A = ~~1025~~ 1009 DH 9/27/99
B = ~~1027~~ 1011
C = ~~1041~~ 1025
D = ~~1043~~ 1027
E = ~~1077~~ 1061
F = ~~1078~~ 1062

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HEAT LOAD

DH 10/29/99

$$\left(\frac{60\ MTU}{acre}\right)\left(\frac{1000\ W}{MTU}\right)\left(\frac{acre}{43560 ft^2}\right)\left(\frac{3.28 ft}{m}\right)^2 = 14.8\ W/m^2$$

x 40 m (for 80 m drift spacing = 593 W/m drift length

$\frac{63000\ MTU}{1050\ acre} = 60\ \frac{MTU}{acre}$ Total length of emplacement drifts = 113626 m

$$\left(\frac{63000\ MTU}{113626\ m}\right)\left(\frac{1000 W}{MTU}\right) = 555\ W/m \text{ drift length}$$

DH 10/29/99

Load used in 1 m deep 2D slice = ~~28~~ 599.8 W

input file & results ~dhughson/multiflo/therm2D/enfe

Results of TEF simulation at location UTM 4077816.2 m N 547847.3 m E. The heat load was approximately 60 MTU/acre of about 10 year old fuel placed with no ventilation in backfill having thermal properties identical to unit tsw35. So this probably represents a maximum temperature. Older fuel and ventilation will decrease the thermal load. Drifts are 81 m apart. Outline of the drift is shown on a closeup of the grid in the drift vicinity. Letters correspond to locations where state variables were monitored. Gas pressures in the matrix blocks are not realistic. They are artifacts of the multiflo implementation of the fracture-matrix interaction factor. Saturation inside the drift is an artifact of moisture retention properties used for the backfill.

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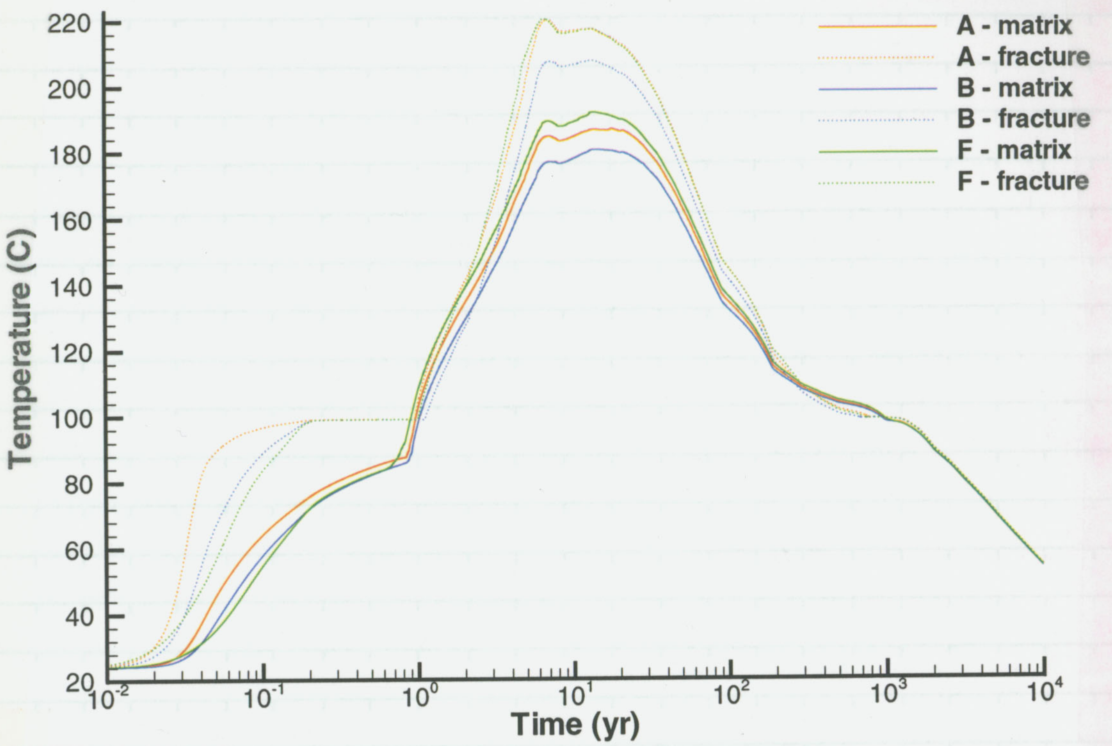
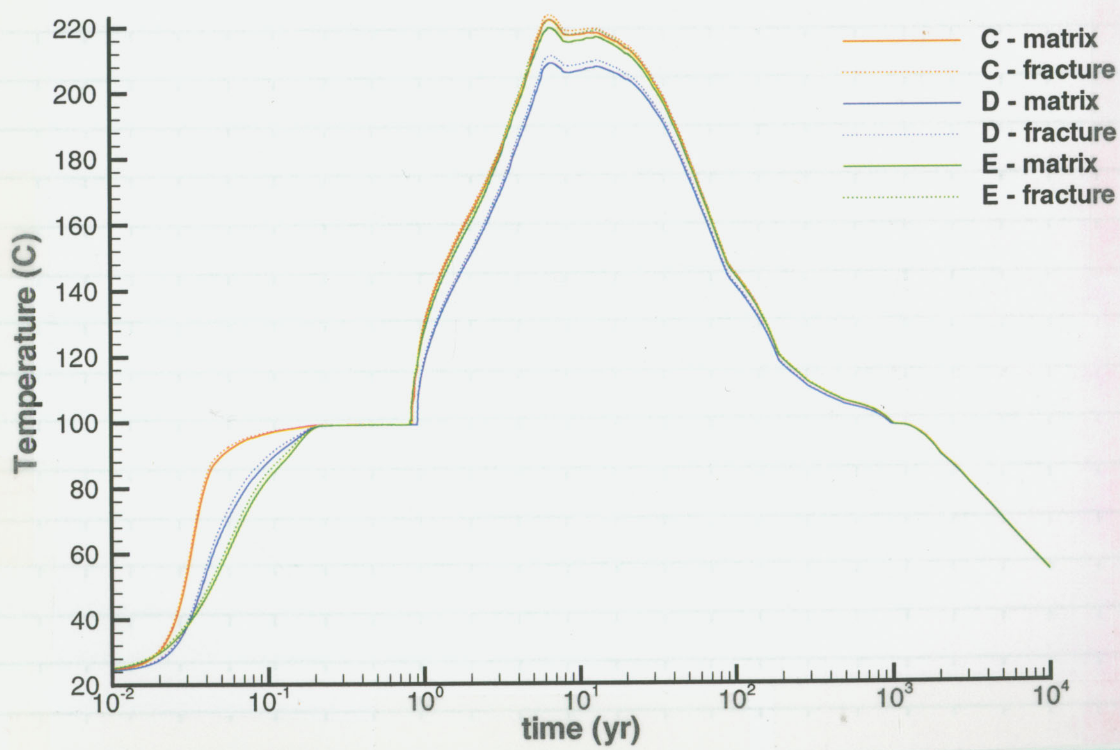
Tuff above the drift



Inside the drift near the wall



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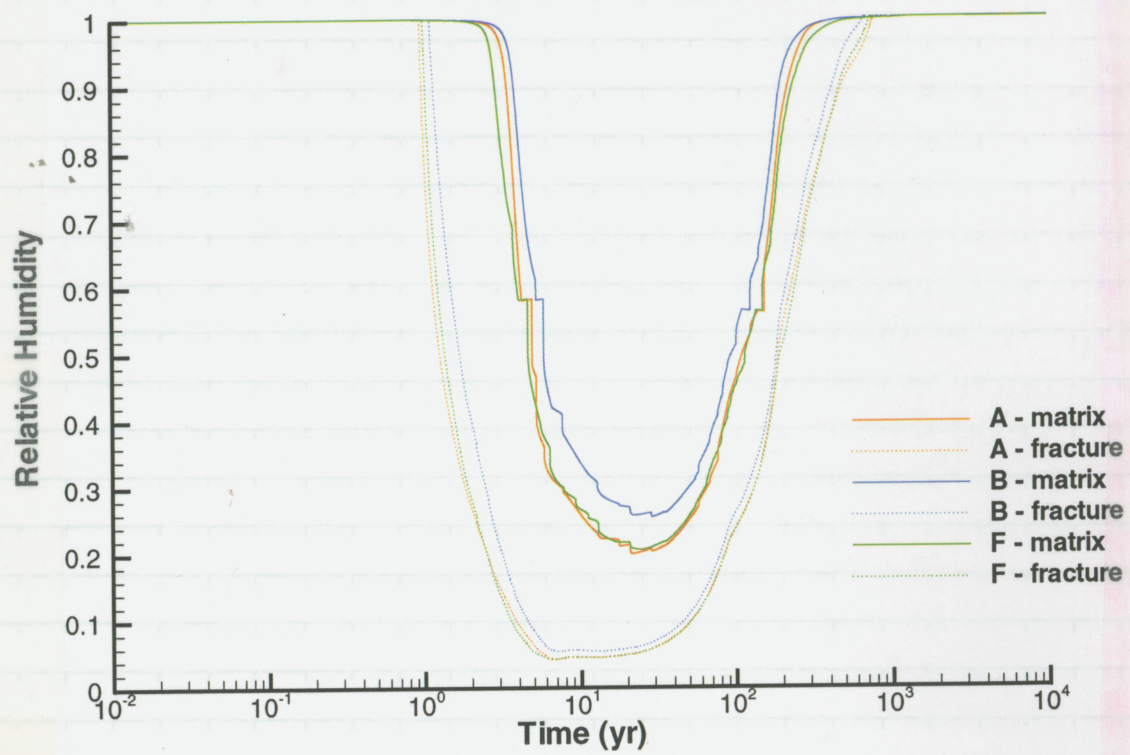
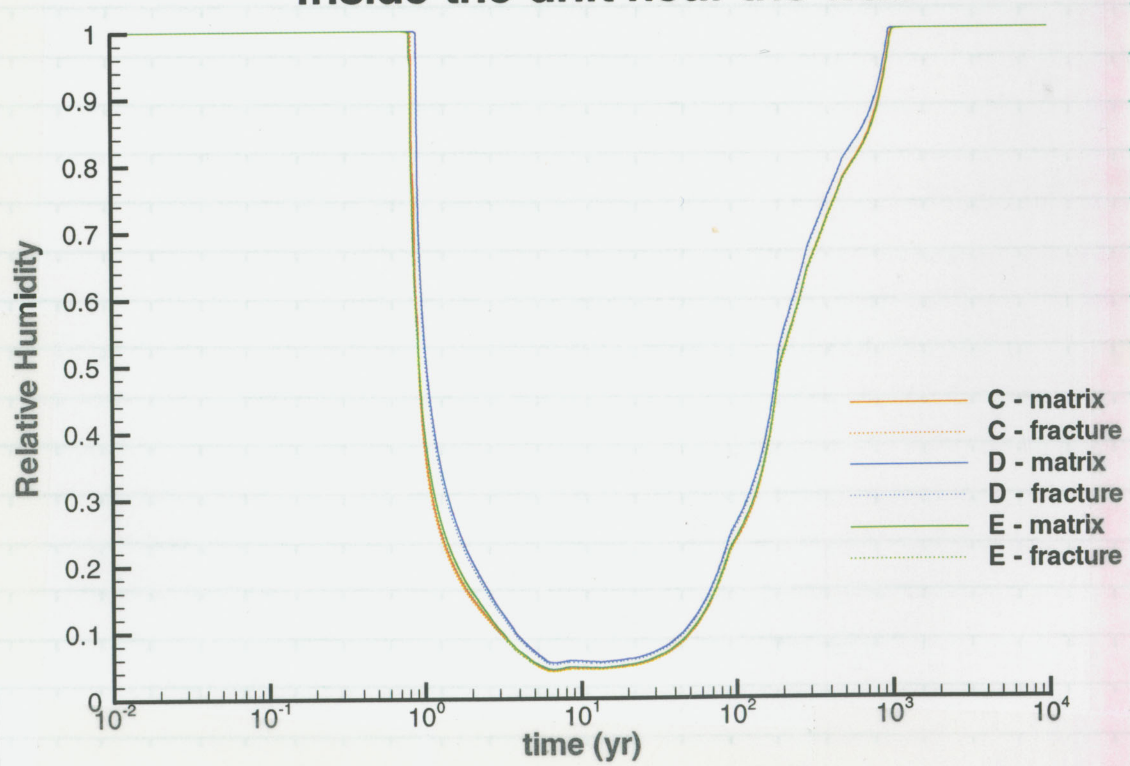
Tuff above the drift



Inside the drift near the wall



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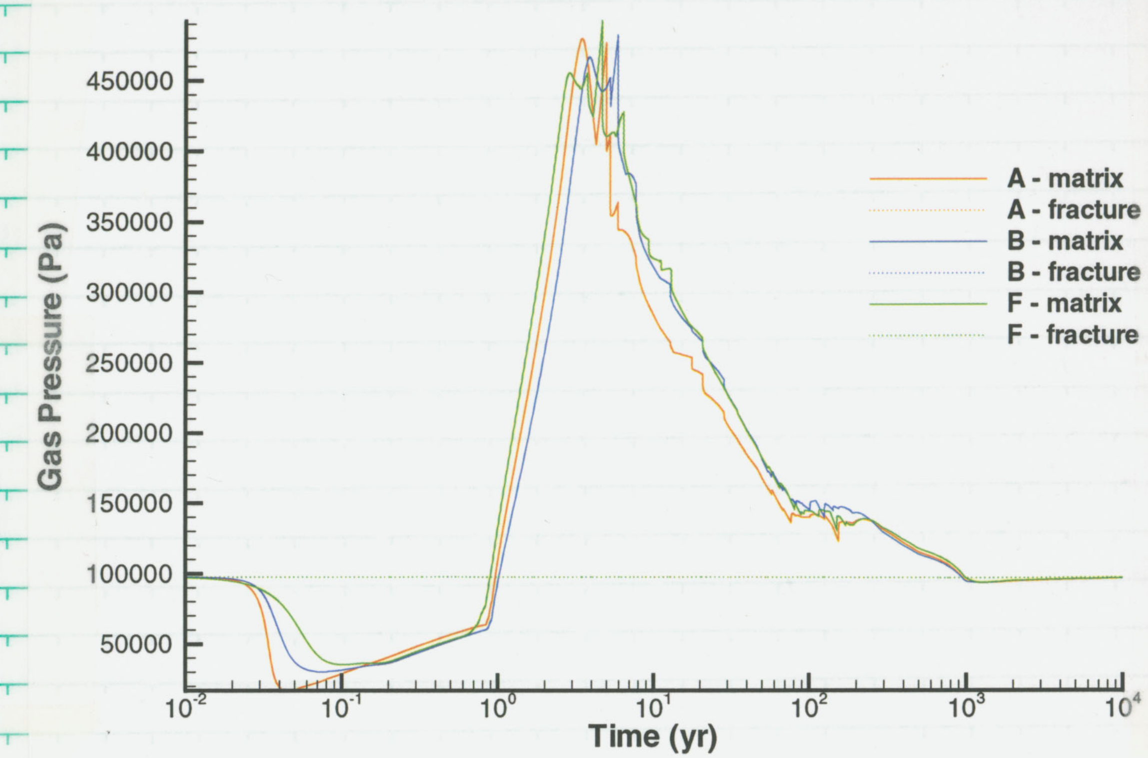
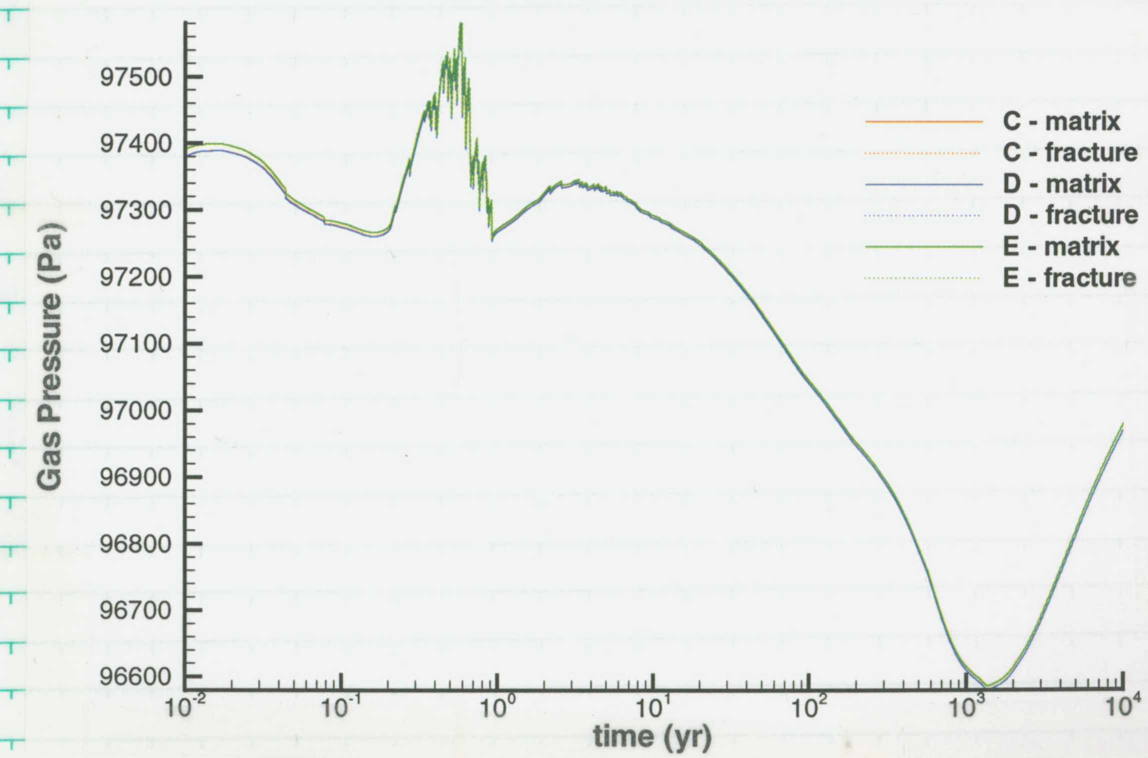
Tuff above the drift



Inside the drift near the wall



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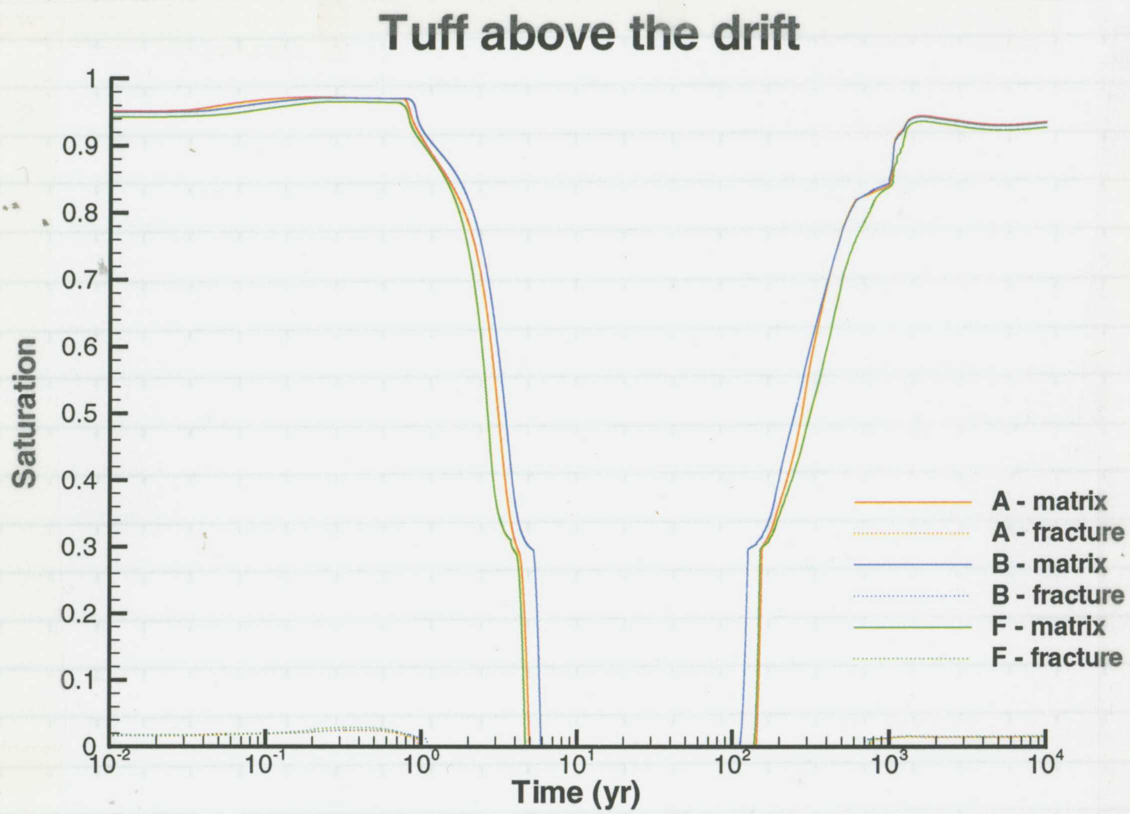
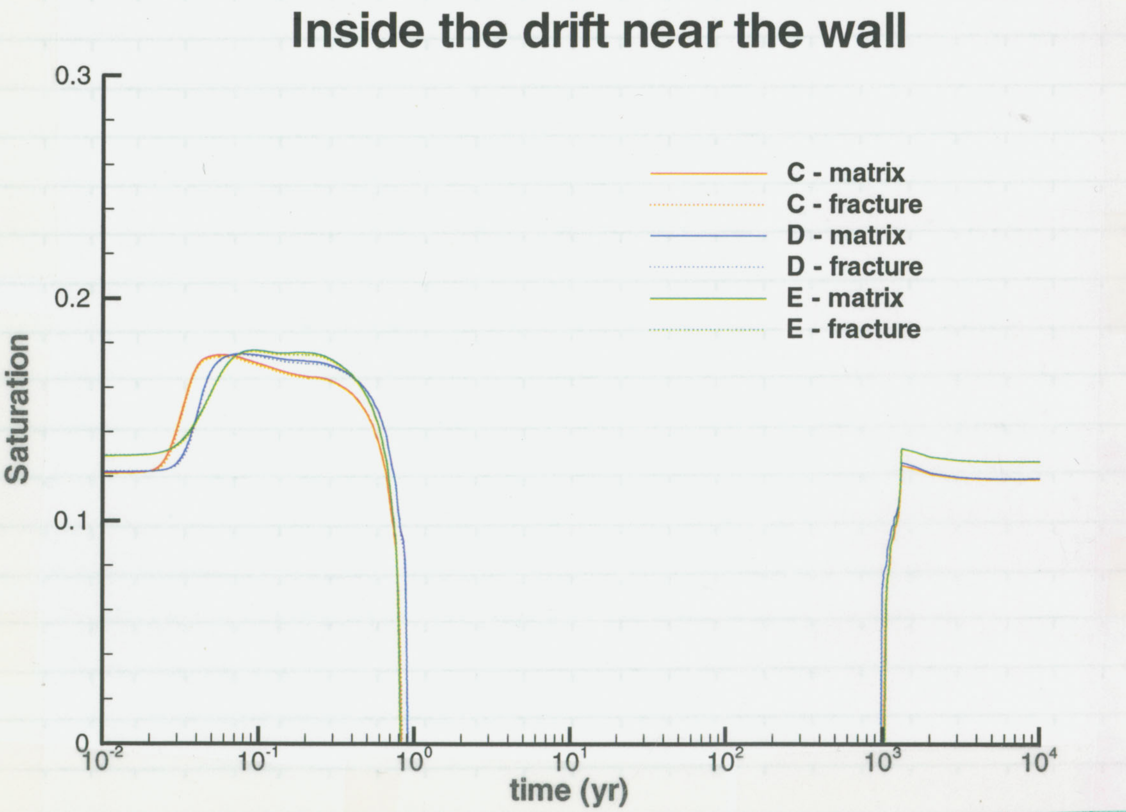
Tuff above the drift



Inside the drift near the wall



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Seepage Threshold as a function of Temperature

Grant, S.A. & A. Salehzadeh

Calculation of temperature effects on wetting coefficients of porous solids and their capillary pressure functions

WRR 32(2) p 261 - 270

Capillary Pressure $p_c = p^g - p^l = \frac{2\gamma^{lg}\cos\theta}{r(S_e)}$

wetting coefficient $K = \cos\theta = \frac{\gamma^{sg} - \gamma^{ls}}{\gamma^{lg}}$

$\gamma^{lg} = a + bT$ for CRC data linear regression range 20°C to 100°C

$a = 123.72$ dynes/cm/K $= 0.12372$ (N/m/K) $N m^{-1}$

$b = -0.17305$ dyne/cm $= -.00017305$ (N/m) $N m^{-1} K^{-1}$

DH Feb 6 2000

$$(aT + bT^2)\frac{dK}{dT} - aK = \Delta^{sl}_{sg} h^s = c + dT$$

for $d = 0$

$$K = \frac{-\Delta^{sl}_{sg} h^s + TC_1}{a + bT}$$

$$C_1 = \frac{\Delta^{sl}_{sg} h^s + aK(T=T_r) + bK(T=T_r)T_r}{T_r}$$

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If K not f(T) then

$$\frac{P_c(S_e)}{\left(\frac{\partial P_c(S_e)}{\partial T}\right)_{S_e}} = \frac{a}{b} + T$$

if K = f(T) then

$$\frac{P_c(S_e)}{\left(\frac{\partial P_c(S_e)}{\partial T}\right)_{S_e}} = -\frac{\Delta_{sg}^{sl} h^s}{C_1} + T = \beta_0 + \beta_1 T$$

$\beta_1 \approx 1$

$$\int_{P_c(T=T_r)}^{P_c(T=T_f)} \frac{dP_c}{P_c} = \int_{T_r}^{T_f} \frac{dT}{\beta_0 + T} \qquad P_c(T=T_f) = P_c(T=T_r)\left(\frac{\beta_0 + T_f}{\beta_0 + T_r}\right)$$

Gardner Model $K = K_0 \exp(\alpha P_c)$ $(T=T_r)$

$$K = K_0 \exp\left(\alpha P_c \left(\frac{\beta_0 + T_r}{\beta_0 + T_f}\right)\right) \qquad (T=T_f)$$

$$\beta_0 = \frac{-\Delta_{sg}^{sl} h^s T_r}{\Delta_{sg}^{sl} h^s + aK(T=T_r) + bK(T=T_r)T_r}$$

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Let T_r = 25C = 298.15 K and

assume ~~cos~~ [initials 4/10/2001] $\theta = 0$ $\cos\theta = K(T=T_r) = 1$

For silica & quartz

smallest $\Delta_{sg}^{sl} h^s = -0.67\ J/m^2$

largest $\Delta_{sg}^{sl} h^s = -0.12\ J/m^2$

theoretical maximum $\Delta_{sg}^{sl} h^s = -0.118\ J/m^2$

~~$$\beta_0 = \frac{-(-.67\ J/m^2)(298.15K)}{-0.67\ J/m^2 + (0.12372\ N/m/K) + (-.00017305\ N/m)(298.15K)}$$~~ [initials] Feb 16 2000

$$C_1 = \frac{\Delta_{sg}^{sl} h^s + aK(T=T_r) + bK(T=T_r)T_r}{T_r}$$

$$C_1 = \frac{-0.67\ J/m^2 + 0.12372\ N m^{-1} + (-.00017305\ N m^{-1} K^{-1})\ 298.15K}{298.15\ K}$$

$$C_1 = -.002\ N m^{-1}/K$$

$$\beta_0 = \frac{-\ 0.67\ J/m^2}{-.002\ N m^{-1}/K} = 334.1\ K$$ for small $\Delta_{sg}^{sl} h^s$

to $\beta_0 = 747.3$ K for large $\Delta_{sg}^{sl} h^s$

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From Page No. ___ Estimates for $\Delta^{sl}_{sy} h^3 = -0.67$ J/m² $\beta_0 = 334.1$ K

Need to change T_r to 20 C to make it easier given the water data in CRC, $\beta_0 = 329$ K

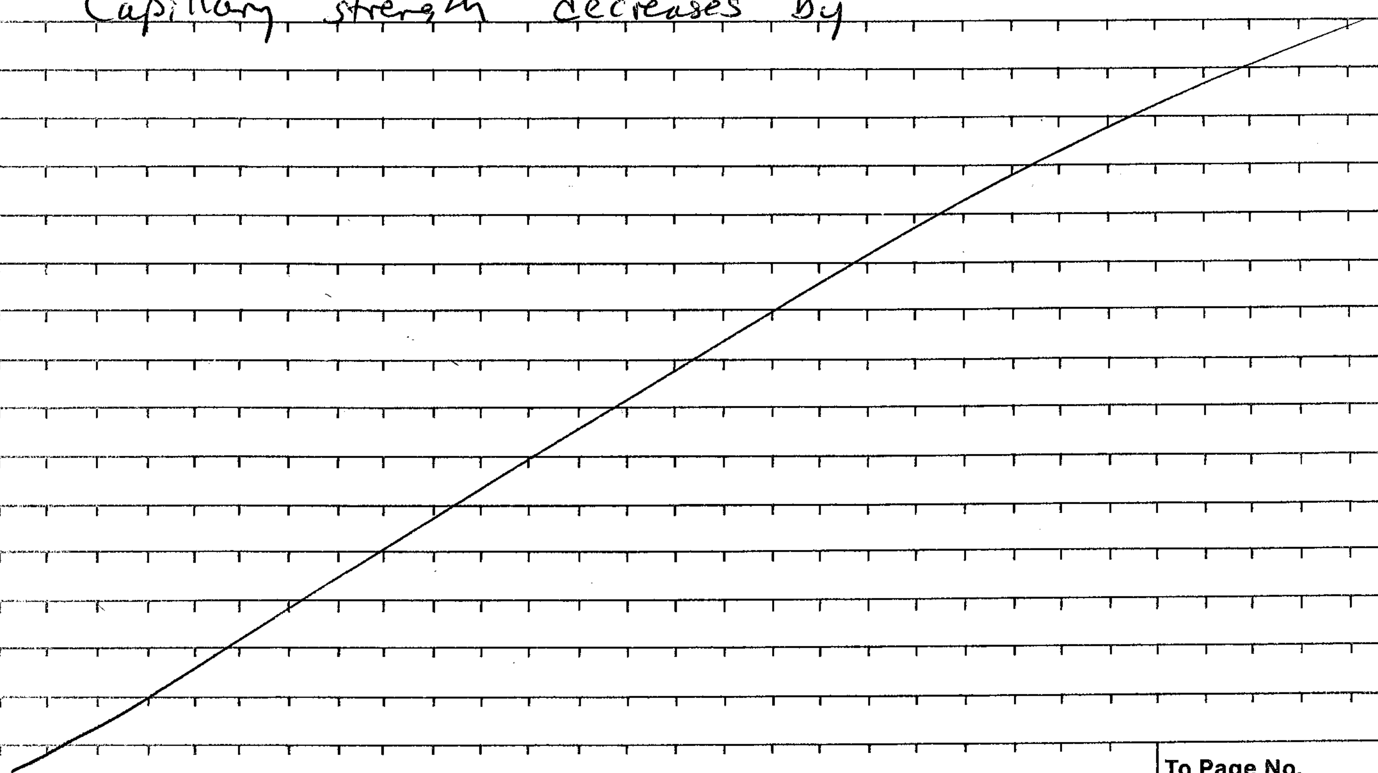
T (K)	ρ (kg/m³)	ν (μPa s)	ftrac	q^* (mm/yr)
20	998.21	1002	1	100.006
30	995.65	797.7	.984	~~123.641~~ 123.3
40	992.22	653.2	.9689	~~148.65~~ 147.8
50	988.03	547.0	.954	173.0
60	983.2	466.5	.9396	198.87
70	977.78	404.0	.9256	225.0
80	971.82	354.4	.912	251.2
90	965.35	314.5	.899	277.15

DH Feb 16 2000

for $\Delta^{sl}_{sy} h^3 = -0.12$ J/m² $\beta_0 = 748.3$ $T_{ref} = 20$ C

90 .937

Capillary strength decreases by



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IM 661-020 DST model, New DCM,

matrix saturation at ambient ~ .995 .998

TOO High. Set up small domain problem with structured & unstructured grids to compare

Structured grid nx=2 nz = 200 Δx=Δz=1m

tsw34 volf= 1.24e-4 areaf 1.23e-3

$$3 \text{ mm/yr} \left(\frac{m}{1000\,mm}\right)\left(\frac{yr}{60\,60\,24\,365\,s}\right)\left(\frac{998\,kg}{m^3}\right)\frac{1}{1.24e-4} = 7.656e-4$$

Unstructured ~dhughson/multiflo/green/testcase/unstruc/tu.dat

Structured ~dhughson/multiflo/green/testcase/struc/ts.dat

Appear to produce identical results
Ambient matrix saturation .9958 for tsw34

Structured grid velocities tsuz1.xyp

z= 99.5 x= 0.5 vlfz = 1.8903e+1
vlmz = 5.9064e-4

volf= 1.24e-4

x= 1.5 vlfz = 1.8902e+1
vlmz = 5.9064e-4

2.935 mm/yr

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$Z = 4.5$ $x = 0.5$ v/fz v/mz

volf 1.24e-4 2.3475e+1 8.5012e-5

$X = 1.5$ 2.3475e+1 8.5012e-5

2.996 mm/yr

$Z = 195.5$ $X = 0.5$ 1.5135e+1 9.4956e-4

1.5137e+1 9.4956e-4

2.83 mm/yr

If I change DCM parameters back to old way — should get higher matrix gas pressures

---

New DCM P areadmodf1 = 1.0 areamodf2 = 1.23e-3

Look at changing block size

X/m	max sat in matrix
0.5	.9958
0.1	.9997
1.0	.9852
2.0	0.9594
4.0	0.9175

$F = 5/9\,C$

$9F = 5C$

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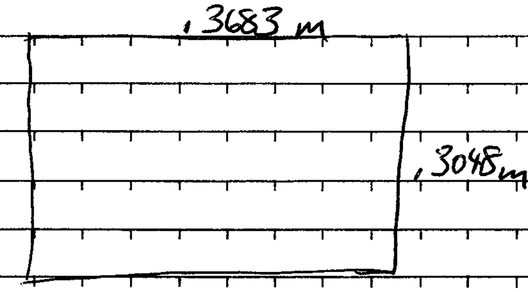
From Page No. Some Notes on preliminary modeling of heated glass fracture.

Plates 12" x 14.5"



$12\text{ in}\left(\frac{m}{39.37\text{ in}}\right) = .3048\,m$

$14.5\text{ in} = .3683\,m$

$0.5\text{ in} = .0127\,m$ $3/8" =$

Capillary rise ~ 2 cm = .02 m

$h = \frac{2\sigma\cos\alpha}{\rho g b}$ $\sigma = .072\ N/m$ $\rho = 997\ kg/m^3$ $g = 9.81\ m/s^2$

$K = \frac{b^2}{12}$ $= 4.5e{-8}$

$b = \frac{2\left(.072\ \frac{kg\,m/s^2}{m}\right)}{(997\ kg/m^3)(9.81\ m/s^2)(.02\,m)} = 7.36e{-4}\ m \cong .03\text{ in}$

Lexan density $\left(.044\ \frac{lb}{in^3}\right)\left(\frac{.4536\,kg}{lb}\right)\left(\frac{39.37\,in}{m}\right)^3 = 1218\ \frac{kg}{m^3}$

$\left(1.34\ \frac{BTU\cdot in/hr}{ft^2\cdot{}^\circ F}\right)\left(\frac{.2931\ W}{BTU/hr}\right)\left(\frac{ft}{12\text{ in}}\right)\left(\frac{3.28\,ft}{m}\right)\left(\frac{9F}{5C}\right) = .193\ \frac{W}{mC}$

Glass $\left(31.5\times10^4\ \frac{cal\ cm}{cm^2\,s\,C}\right)\left(4.1868\ \frac{W}{cal/s}\right)\frac{100\,cm}{m} = 1.3e8\ \frac{W}{mC}$

$2.6\ g/cm^3$

This can't be right

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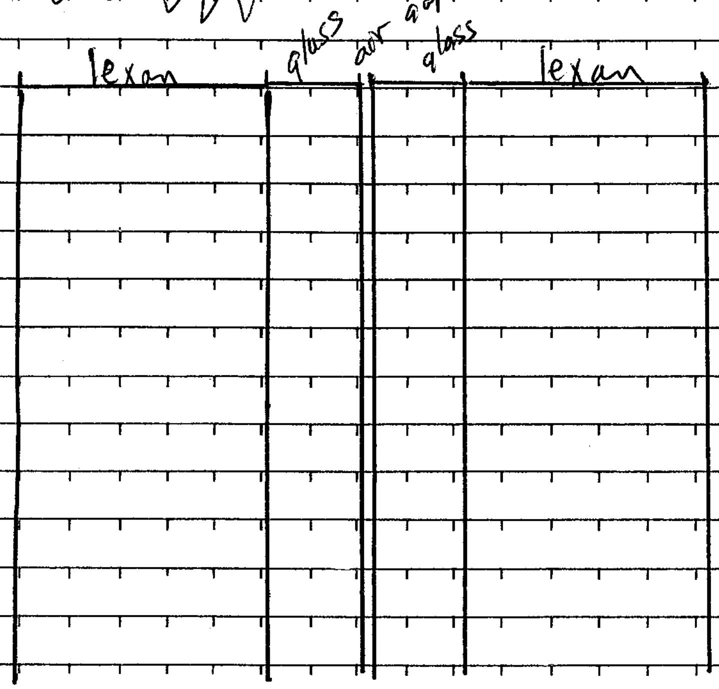
Glass 5.5 $\frac{BTU/hr}{ft^2}\frac{in}{F}$ = $.8\frac{W}{m\,C}$

$2.6\frac{g}{cm^3}\;\frac{kg}{1000g}\left(\frac{100cm}{m}\right)^3 = 2600\frac{kg}{m^3}$

~~[scribble]~~ DH 4/24/2000



2.38 e-3 m
7.14 e-3 m

Raw data from Jim Prikryl in Excel worksheets

D:\documents\tef\661-050\data\tempdata*.xls
D:\documents\tef\661-050\data\face_heatflux.xls
face_temps.xls
finger_plot.xls
finger_summary.xls
glass_TC_summary.xls

Backed up to zip disk to accompany this notebook

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Data from Jim Prikryl ΔT Q measured L

From CRC ρ_l at boiling ~ 960 kg/m^3
h = 2.258 e+6 J/kg

$$L = \left(\frac{\rho_l Q h}{K_m \beta}\right)^{1/2}$$

ΔT in $5\frac{C}{in}\;\frac{in}{2.54cm}\;\frac{100cm}{m}$

Q in $\frac{0.3\,ml}{min}\;\frac{cm^3}{ml}\left(\frac{m}{100cm}\right)^3\frac{min}{60s}$

L in inches $\left(\frac{2.54cm}{inch}\right)\left(\frac{m}{100cm}\right)$

Look at Initial T gradient from 126-138

Following section on modeling of flow through heated Hele-Shaw cell glass plate fracture model for ~~deter~~ DH 4/24/2000 deliverable IM 20.01402.661-050

Data from Jim Prikryl some work from Frank Dodge recorded here.

Due in author final Technical review Sept 9, 2000

DH 4/24/2000

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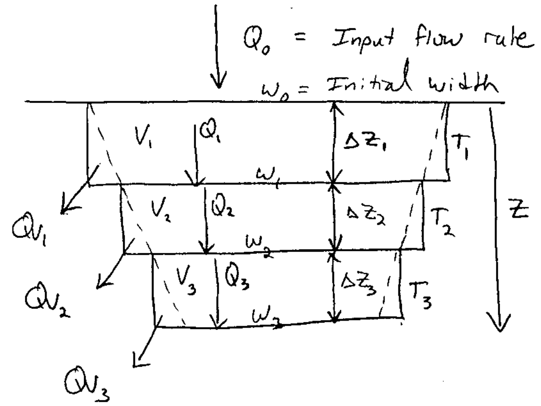
(1)



Q_0 = Input flow rate

w_0 = Initial width

b = aperture

T_b = Boiling temp = 0

$\beta = \frac{dT}{dz} > 0$

ρ = density

h = enthalpy

$\Delta z_1 = \frac{Q_0 \Delta t}{w_0 b}$ $\qquad T_1 = \beta \Delta z_1$

Flow of heat into volume 1 $(V_1) = f_1 = A_1 K_m\left(\frac{T_1 - T_b}{d}\right)$

A = area of water contacting the heat source

d = thickness of glass

K_m = thermal conductivity of glass

Let $K = \frac{K_m}{d}$ $\qquad A_1 \cong w_0 \Delta z_1$

$$f_1 = w_0 \Delta z_1 K T_1 = w_0 \Delta z_1 K \beta \Delta z_1$$

vaporization rate $Q_{v_1} = \frac{f_1}{\rho h} = \frac{w_0 K \beta (\Delta z_1)^2}{\rho h}$

$$Q_1 = Q_0 - Q_{v_1} = Q_0 - \frac{w_0 K \beta (\Delta z_1)^2}{\rho h}$$

$\Delta z_2 = \frac{Q_1 \Delta t}{w_1 b}$ $\qquad T_2 = \beta(\Delta z_1 + \Delta z_2)$

$$Q_{v_2} = \frac{w_1 \Delta z_2 K \beta (\Delta z_1 + \Delta z_2)}{\rho h}$$

$$Q_2 = Q_1 - Q_{v_2} = Q_1 - \frac{w_1 \Delta z_2 K \beta (\Delta z_1 + \Delta z_2)}{\rho h}$$

DH 8/24/2000

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(2)

$$Q_2 = Q_0 - \frac{w_0 K \beta (\Delta z_1)^2}{\rho h} - \frac{w_1 K \beta \Delta z_2 (\Delta z_1 + \Delta z_2)}{\rho h}$$

$$Q_{v_3} = \frac{w_2 \Delta z_3 K \beta (\Delta z_1 + \Delta z_2 + \Delta z_3)}{\rho h}$$

$$Q_3 = Q_2 - Q_{v_3}$$

$$Q_3 = Q_0 - \frac{w_0 K \beta (\Delta z_1)^2}{\rho h} - \frac{w_1 K \beta \Delta z_2 (\Delta z_1 + \Delta z_2)}{\rho h} - \frac{w_2 \Delta z_3 K \beta (\Delta z_1 + \Delta z_2 + \Delta z_3)}{\rho h}$$

Eventually the flow is gone $Q_{v_n} \geq Q_{n-1}$

so $Q_n = 0$ and $\sum_{i=1}^{n} \Delta z_i = L$

$$Q_n = 0 = Q_0 - \frac{w_0 K \beta (\Delta z_1)^2}{\rho h} - \frac{w_1 K \beta \Delta z_2 (\Delta z_1 + \Delta z_2)}{\rho h} - \dots - \frac{w_n K \beta \Delta z_n L}{\rho h}$$

$$\frac{Q_0 \rho h}{K \beta} = w_0 (z_1)^2 + w_1 \Delta z_2 (\Delta z_1 + \Delta z_2) + \dots + w_n \Delta z_n L$$

$$\frac{Q_0 \rho h}{K \beta} = \sum_{i=1}^{n-1} w_{i-1} \Delta z_i \sum_{j=1}^{i} \Delta z_j + w_n \Delta z_n L$$

$$L = \frac{1}{w_n z_n} \left(\frac{Q_0 \rho h}{K \beta} - \sum_{i=1}^{n-1} w_{i-1} \Delta z_i \sum_{j=1}^{i} \Delta z_j \right)$$

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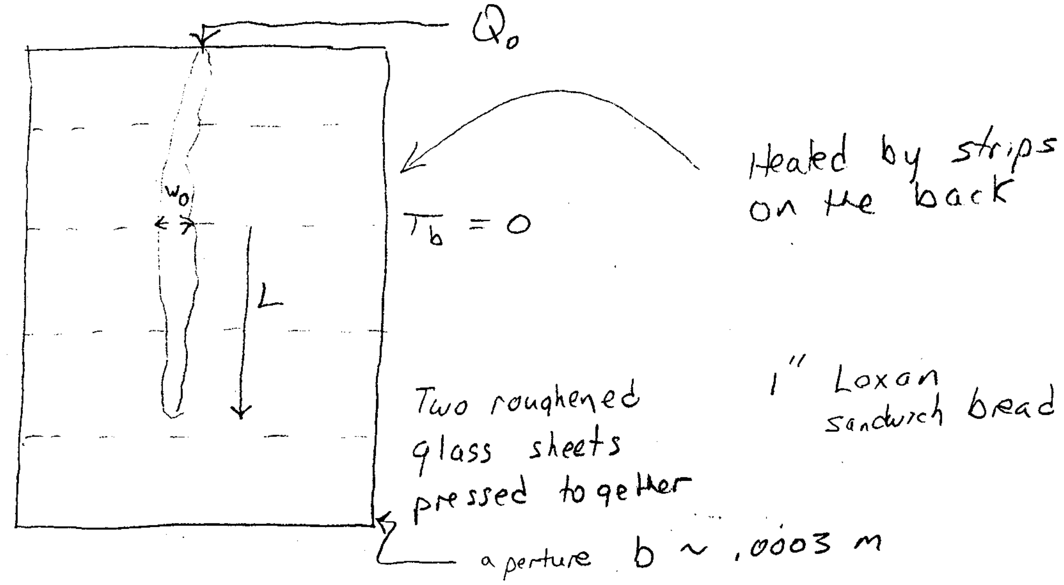
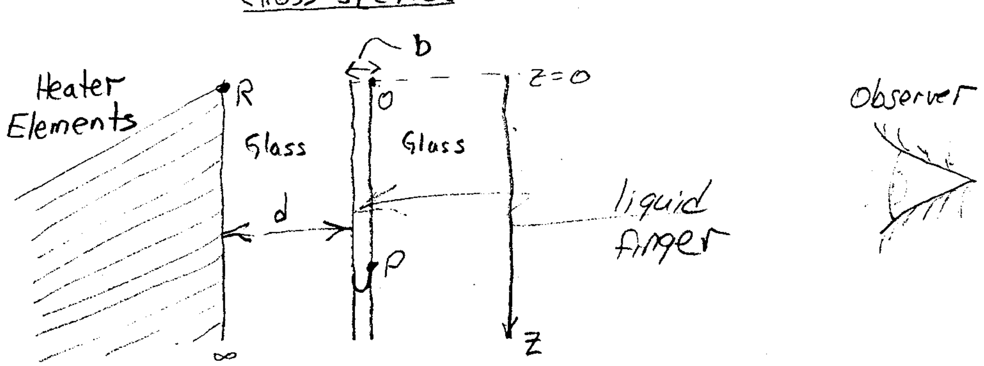
Finger Flow in a heated Hele-Shaw cell   DH Aug 2 2000



Suppose:



$T(z)$ along the line $\overline{OP} = T_b$

$T(z)$ along the line $\overline{R\infty}$ $\quad T(z) = \beta z$

Heat flow into finger $\quad f(z) = \dfrac{A K (T(z) - T_b)}{d}$

K = Thermal conductivity $\left(\text{Units } \dfrac{J}{s\, m\, °C} = \dfrac{W}{m\, °C}\right)$

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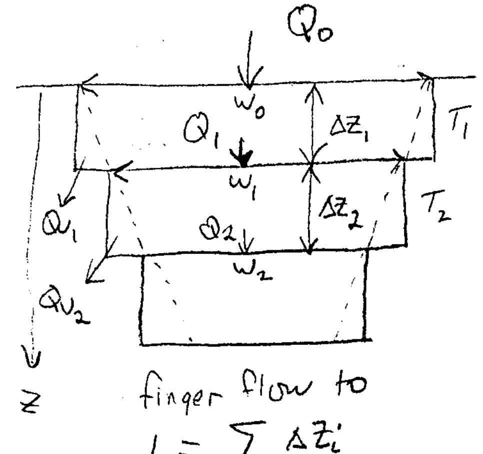


finger flow to $L = \sum_i \Delta Z_i$

$z = 0 \quad T = T_b = 0$

Assume porosity $n \approx 1$

Choose an arbitrarily small Δt

$$q_0 = \frac{Q_0}{w_0 b} = \frac{\Delta Z_1}{\Delta t}$$

Flow of heat into water parcel

$$f_1 = A_1 K \frac{(T_1 - T_b)}{d} \qquad \text{Let } K_m = \frac{K}{d}$$

DH 8/24/00

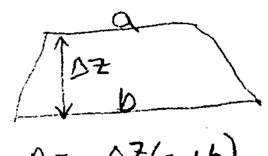
Rate of vaporization $\quad Qv_1 = \dfrac{f_1}{\rho h} \quad$ ρ = density, h = enthalpy

$$Q_1 = Q_0 - Qv_1 = Q_0 - \frac{A_1 K_m T_1}{\rho h} \qquad T_1 = \beta \Delta Z_1$$

$$T_2 = \beta(\Delta Z_1 + \Delta Z_2)$$

$$\Delta Z_1 = \frac{Q_0 \Delta t}{w_0 b} \qquad A_1 = w_0 \Delta Z_1$$

Area of trapezoid $\quad (Q_0 - Q_1)\Delta t = b\dfrac{\Delta Z_1}{2}(w_0 + w_1)$



$A = \dfrac{\Delta z}{2}(a+b)$

$$Qv_2 = \frac{w_1 \Delta Z_2 K_m \beta(\Delta Z_1 + \Delta Z_2)}{\rho h}$$

$Q_2 = Q_1 - Qv_2$ and so on

Last drop$_n$ $\quad w_n \le b$

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```
* First crack time stepping model for finger flow through a boiling
fracture
* August 1, 2000
* Input required
* Q0 Initial flow rate in mL/min
* w0 Initial finger width
* bf Aperture width
* Bt Temperature gradient positive in z
* Fk Parameter for heat flow
*
      real Q0,w0,bf,Bt,Fk,delt
* enthalpy of boiling J/kg, density kg/m^3
      h=2.26E+6
      p=997.
* fracture aperture m
      bf=.0003
      write(*,*)'Enter in the following order'
      write(*,*)' '
      write(*,*)'Flow rate in mL/min'
      write(*,*)'Initial finger width in cm'
      write(*,*)'Temperature gradient in C/m'
      write(*,*)'Heat constant (K/d) in J/(sCm^2)'
      write(*,*)'Time step in sec'
      read(*,*) Q0,w0,Bt,Fk,delt
* convert units to kg,m,s
      Q0=Q0/1000000./60.
      w0=w0/100.
*
      Q=Q0
      w=w0
      z=0.
      open(unit=29,file='stepmod.out')
*
      do while(w.ge.bf)
         delz=(Q*delt)/(w*bf)
         z=z+delz
         T=Bt*z
* area of incremental slice m^2
         A=w*delz
* flow of heat to incremental slice J/s
         fw=A*Fk*T
* rate of vaporization from heat flow m^3/s
         Qv=fw/(p*h)
* liquid flow rate remaining m^3/s
         Q=Q-Qv
* new finger width based on area of a trapezoid m
         wi=(2*delt*Q)/(bf*delz)-w
         write(29,*) z,-wi/2.,wi/2
         w=wi
      enddo
      write(*,*) 'L = ',z,' meters'
      close(29)
      end
```

Modified slightly — see page 81

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	measured data			K calibrated to run 2	model	measured
	Q mL/min	w cm	β °C/m	K (J/(sCm²))	L	(meas)
run 2	.3	.965	213.4	1035	.222	(.222)
run 3	.2	.965	191.2	1035	.192	(.197)
run 4	.1	.914	216.5	1035	.129	(.140)
run 6	.025	.965	208.8	1035	.065	(.076)
run 10	.1	1.143	98.3	1035	.183	(.171)
run 11	.05	1.092	98.05	1035	.131	(.127)
run 13	.2	1.194	113.6	1035	.238	(.235)
run 15	.2	.864	320.6	1035	.151	(.165)
run 16	.3	.914	323.9	1035	.182	(.191)
run 17	.1	.914	324.3	1035	0.105	(.127)

DH 8/24/00

$K_{glass} \approx 0.8 \frac{W}{mC}$ $d = 3/8'' = .95cm$

$K = \frac{K_{glass}}{d} = \frac{0.8 \frac{J}{smC}}{.95cm \frac{m}{100cm}} = 84 \frac{J}{sCm^2}$

Higher Temps? More area?

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Experiment ID	Duration in min (approximate)	Temperature Gradient (°C/inch)	Flow rate (ml/min)	Max penetration depth (inches)		Width of finger (inches)
Finger_run_2	112	5	0.3	8.75	6.5	0.38
Finger_run_3	60	5	0.2	7.75	5	0.38
Finger_run_4	60	5	0.1	5.5	3.4	0.36
Finger_run_5	60	5	0.05	4	1.9	
Finger_run_6	60	5	0.025	3	1.3	0.38
Finger_run_7	93	5	0.01	2.25	—	
Finger_run_9	60	2.5	0.2			
Finger_run_10	60	2.5	0.1	6.75	2.4	0.45
Finger_run_11	60	2.5	0.05	5	.5	0.43
Finger_run_12	90	2.5	0.025	3.25	—	
Finger_run_13	74	2.5	0.2	9.25	5	0.47
Finger_run_14	246	2.5	0.01	2.25	—	
Finger_run_15	60	7	0.2	6.5	4.8	0.34
Finger_run_16	60	7	0.3	7.5	5.6	0.36
Finger_run_17	60	7	0.1	5	4.6	0.36
Finger_run_18	110	7	0.2	6.5		
Finger_run_19	60	7	0.4	8.75	6.75	
Finger_run_20	60	7	0.05	3.75	2.1	
Finger_run_21	60	7	0.025	3	.9	
Finger_run_22	60	7	0.01	1.5		

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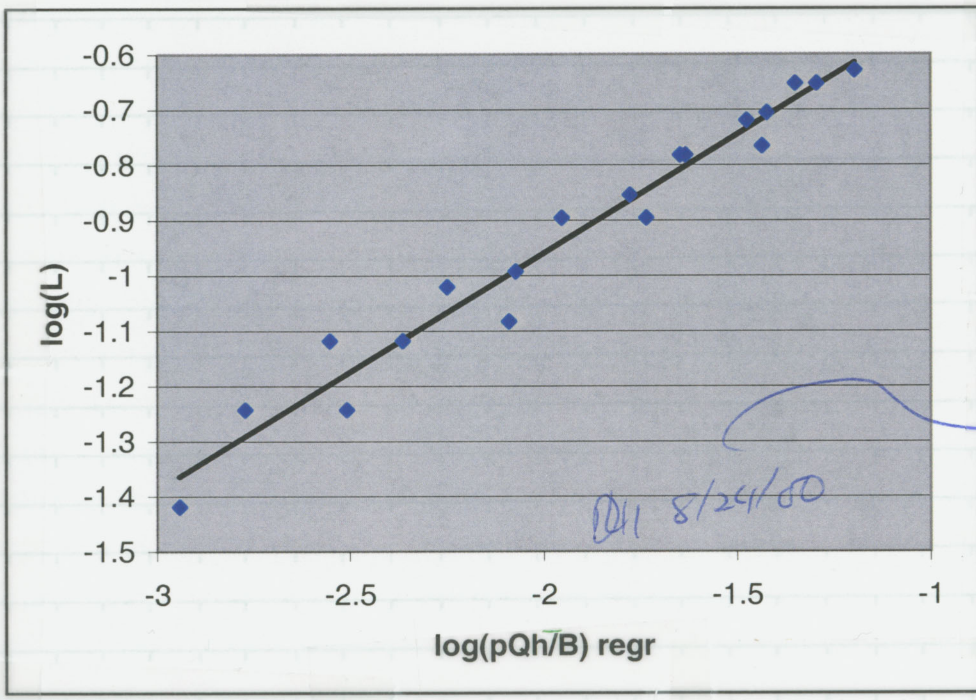
From OM Phillips

$$L = \left(\frac{\rho Q h}{K_m \beta}\right)^{1/2} \qquad Log(L) = \frac{1}{2} Log\left(\frac{\rho Q h}{\beta}\right) - \frac{\log K_m}{2}$$

DH 8/24/00

Find β ~~fo~~ by linear regression on channels 126-138 in excel spreadsheet

O:\documents\tef\661-050\data\km-l.xls



slope = .4293 intercept = -.101

$r^2 = .964$

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How does the model compare ?

DH 8/24/00

Simulations of L — β from regression on channels 126-138

b = .0003 m   Δt = .01 s

K = calibrated from measured data run 2

Q mL/min	W_0 cm	β C/m	K $\frac{J}{s m^2 C}$	L m
.3	.965	213.4	1035	.222
.2	.965	191.2	1035	.192
.1	.965	216.5	1035	.127
.05	.965	213.9	1035	.091
.025	.965	208.8	1035	.064
.01	.965	213.8	1035	.041
.2	1.143	98.3	1035	.258
.1	1.143	98.1	1035	.183
.05	1.143	111.1	1035	.122
.025	1.143	113.6	1035	.085
.2	1.143	116.4	1035	.238
.01	1.143	~110	1035	.055
.2	.889	320.6	1035	.150
.3	.889	323.9	1035	.183
.1	.889	324.3	1035	.106
.2	.889	310.4	1035	.153
.4	.889	322.5	1035	.212
.05	.889	320.6	1035	.075
.025	.889	322.3	1035	.053
.01	.889	316.6	1035	.034

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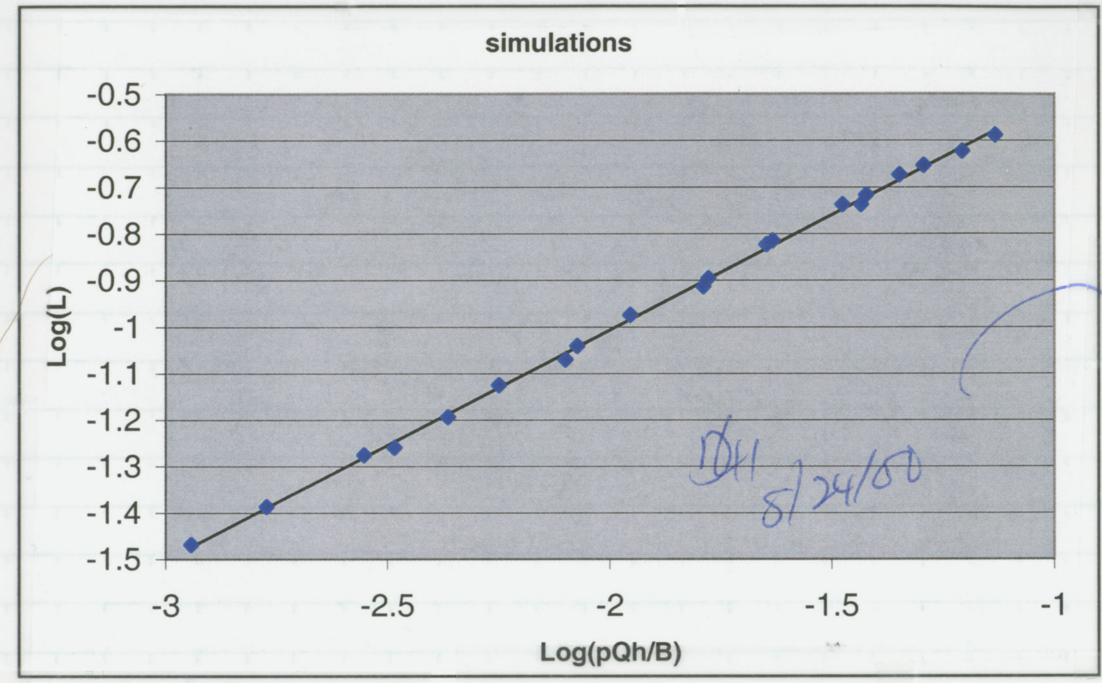

slope = .495　　intercept = -.0169

r^2 = .9989

Numbers and calculations in

D:\documents\tef\661-050\data\adjusted-L.xls

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Jim's measurement of L are from the base of the condensate zone. Have to readjust these using the x-y coordinate system of the temp sensors.

Definition Z = 0 is where T = 100°C inside the air gap prior to injecting water.

Interpolate temps to air gap -
Orient finger in coordinate system -
Recalculate length L -
Also the widths given on 63 and 64 and 66 are wrong.
recalculate temp gradient based on interpolated temps at heater

D:\documents\tef\661-050\data\run_2.xls
run_2
Q_0 = 0.3 m³/min w_0 = 1.8 cm β = 222.7 °/m L = 0.166 m
6.5"

D:\documents\tef\661-050\data\run_3.xls
run_3
Q_0 = 0.2 m³/min w_0 = 1.96 cm β = 200.2 °/m L = 0.126 m
4.96"

same path run_4.xls
run_4
Q_0 = 0.1 m³/min w_0 = 0.90 cm β = 226.0 °/m L = .087 m
3.4"

path run_5.xls
run_5
Q_0 = 0.05 m³/min w_0 = ~~0.84~~ .85 cm (dlh 8/24/00) β = 224.1 °/m L = .047 m
1.87"

path run_6.xls
run_6
Q_0 = 0.025 m³/min w_0 = ~~0.30~~ cm 0.75 cm (dlh 8/23/2000) β = 218.2 °/m L = 0.034 m
1.33"

path run_7.xls
run_7
Q_0 = 0.01 m³/min —— β = 223.7 °/m ——

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D:\documents\tef\661-050\data\ ~~run_8.xls~~ run_10.xls
Q_0 = 0.1 m³/min w_0 = ~~0.2~~ = 0.61 cm (dh 8/23/2000) β = 101.9 °/m L = 0.061 m
2.41"

path run_11.xls
Q_0 = 0.05 m³/min W_0 = 0.71 cm β = 101.2 °/m L = 0.013 m
0.52"

path run_12.xls
Q_0 = 0.025 m³/min w_0 = —— β = 113.4 °/m L = ——

path run_13.xls
Q_0 = 0.2 m³/min w_0 = ~~0.408~~ 1.19 (dlh 8/24/2000) β = 113.4 L = 0.126 m
4.97"

path run_14.xls
Q_0 = 0.01 m³/min ~~scratch~~

path run_15.xls
Q_0 = 0.2 m³/min w_0 = 1.91 cm β = 326.1 L = 0.121
4.76"

path run_16.xls
Q_0 = 0.3 m³/min w_0 = 1.58 β = 329.4 L = 0.142
5.6"

path run_17.xls
Q_0 = 0.1 m³/min w_0 = 2.92 β = 330.2 L = 0.117
4.6"

path run_19.xls
Q_0 = 0.4 m³/min w_0 = 1.13 β = 326.4 L = 0.171
6.75"

path run_20.xls
Q_0 = 0.05 m³/min w_0 = 0.9 cm β = 324.1 L = 0.053
2.1"

path run_21.xls
Q_0 = 0.025 m³/min W_0 = 0.67 β = 324.7 L = 0.022
.86"

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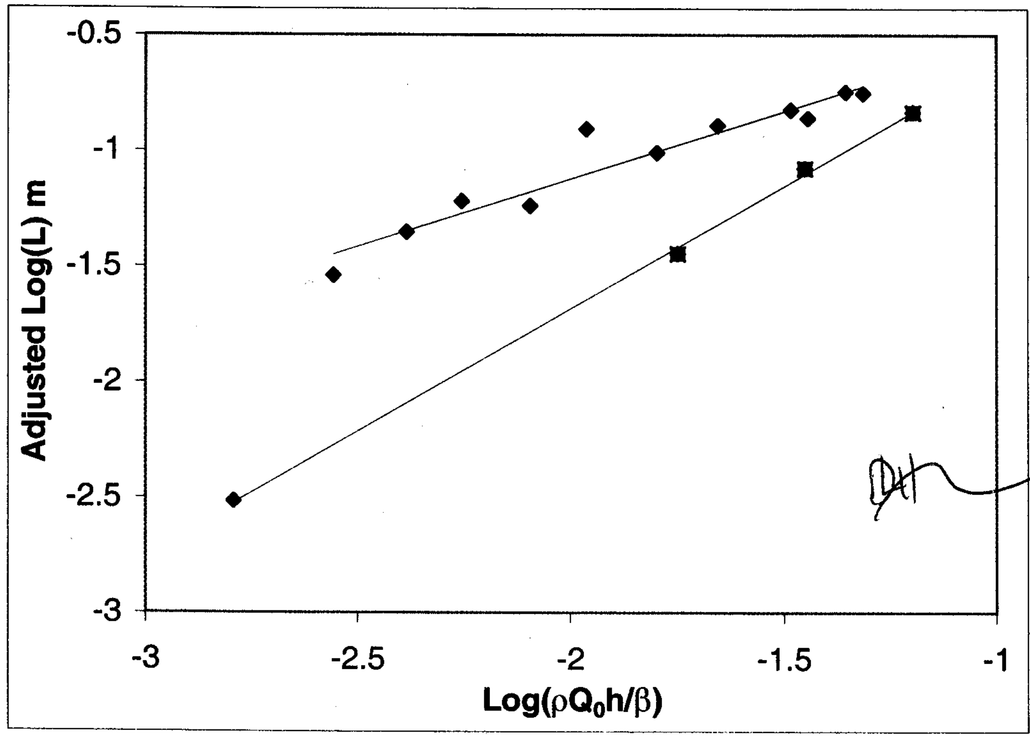
Regressions on Temp data – Interpolations of width data & all other computations specific for each individual run are in a series of Excel worksheets

D:\documents\tef\data\

run_2, run_3, run_4, run_5, run_6, run_7, run_10, run_11, run_12, run_13, run_15, run_16, run_17, run_19, run_20, run_21



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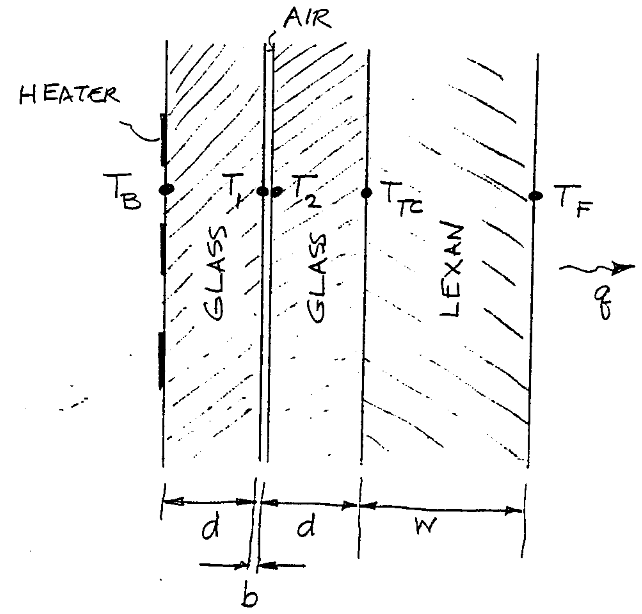
ESTIMATE OF HEATER TEMPERATURE
– TO ALLOW MORE ACCURATE HEAT FLOW PREDICTIONS



T_B = temperature at back face of glass (heater side)
T_F = temperature at front face of Lexan
T_{TC} = temperature of thermocouple (known!)
T_1, T_2 = temperature across air gap

$d \simeq 0.0095$ m (0.375 in)
$b \simeq 0.0001$ m (approx)
$w \simeq 0.0254$ m (1 in)

$K_G \simeq 1.04 \frac{watt}{m\text{-}°C}$ (from Debra)
$K_{air} \simeq 0.03 \frac{watt}{m\text{-}°C}$ (handbook)
$K_L \simeq 0.19 \frac{watt}{m\text{-}°C}$ (manufacturer)

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For natural convection from a vertical plate to air, for a plate < 2 ft. high, :

$$h = 1.58(T_F - T_{air}) \ \frac{\text{watt}}{m^2 \cdot °C}$$

Assume 1-d heat flow. then:

$$q = \frac{K_G}{d}(T_B - T_1) = \frac{K_{air}}{b}(T_1 - T_2) = \frac{K_G}{d}(T_2 - T_{TC}) \quad (1)$$

$$= \frac{K_L}{W}(T_{TC} - T_F) = h(T_F - T_{air})$$

OR

$$q\left[\frac{d}{K_G} + \frac{b}{K_{air}} + \frac{d}{K_G}\right] = T_B - T_{TC} \quad (2)$$

~~so $\frac{K_G}{d} + \frac{K_{air}}{b} + \frac{K_G}{d} = \frac{K_{G\text{-}air\text{-}G}}{2d+b}$~~ DH Sept 11 2000   ~~[i.e., $q = \frac{K_{G\text{-}air\text{-}G}}{2d+b}(T_2 - T_{TC})$]~~ DH Sept 11 2000

~~From measurements $K_{G\text{-}air\text{-}G} \simeq 0.885 \ \frac{\text{watt}}{m\text{-}°C}$~~ DH Sept 11 2000

so

$$q = \frac{T_B - T_{TC}}{\frac{d}{K_G} + \frac{b}{K_{air}} + \frac{d}{K_G}} \equiv \frac{K_{G\text{-}air\text{-}G}}{2d + b}\left[T_B - T_{TC}\right]$$

Thus

$$K_{G\text{-}air\text{-}G} = \frac{2d + b}{\frac{2d}{K_G} + \frac{b}{K_{air}}} = \frac{0.0191 \text{ m}}{\frac{0.019}{1.04} + \frac{0.0001}{0.03}}$$

$$K_{G\text{-}air\text{-}G} = 0.884 \ \frac{\text{watt}}{m\text{-}°C}$$ DH

From measurements $K_{G\text{-}air\text{-}G} \simeq 0.885 \ \frac{\text{watt}}{m\text{-}°C}$ ← CHECK

Also, from Eq. (1)

$$q\left(\frac{W}{K_L} + \frac{1}{h}\right) = T_{TC} - T_{air} \quad (3)$$

From Eq. (2) & Eq. (3)

$$T_B = T_{TC} + q\left[\frac{d}{K_G} + \frac{b}{K_{air}} + \frac{d}{K_G}\right]$$

$$T_B = T_{TC} + \left(\frac{d/K_G + b/K_{air} + d/K_G}{W/K_L + 1/h}\right)(T_{TC} - T_{air}) \quad (4)$$

- T_{TC} & T_{air} are known
- however, $h = 1.58(T_F - T_{air})^{0.25}$ & $T_F = ?$

Because of the 0.25 exponent, we don't need to know T_F precisely, so make some reasonable calculations

From Eq. (1)

$$(T_{TC} - T_F)\frac{K_L}{W} = h(T_F - T_{air})$$

let $T_{TC} \simeq 100°C$ $T_{air} \simeq 20°C$

$$(100 - T_F)\frac{0.19}{0.0254} = 1.58(T_F - 20)^{1.25}$$

$$\Rightarrow T_F \simeq 71°C$$

or in general

$$T_F \simeq T_{TC} - 30°C$$

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Put this into Eq. (4), with

$$\frac{d}{K_G} + \frac{b}{K_{air}} + \frac{d}{K_G} = \frac{2d+b}{K_{G-air-G}} \quad \frac{m^2\cdot°C}{watts}$$

$$h = 1.58\,(50°C)^{0.25} \simeq 4.2 \quad \left[T_F - T_{air} \simeq (100-30)-20 \simeq 50°C\right]$$

So
$$T_B = T_{TC} + \left[\frac{0.0191/0.885}{\left(\frac{0.0254}{0.18} + \frac{1}{4.2}\right)}\right]\left[T_{TC} - 20°C\right]$$

$$= T_{TC} + 0.058\,(T_{TC} - 20°C)$$

or
$$\boxed{T_B = 1.058\,T_{TC} - 1.0°C}$$

CHECK HEAT FLOW [Eq. (2)]

$$q = \frac{T_B - T_{TC}}{\frac{d}{K_G} + \frac{b}{K_{air}} + \frac{d}{K_G}} = \frac{0.058\,T_{TC} - 1.0}{\frac{0.0191}{0.885}}$$

let $T_{TC} \simeq 100°C$

$$q = \frac{4.8}{0.0216} = 222 \text{ watts/m}^2$$

VERY CLOSE!

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Sept 11 2000

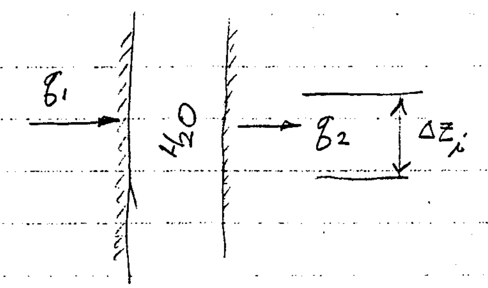
[crossed out] DH Sept 11 2000

$$T_B(z) = 1.058\,T_{TC}(z) - 1.0 \quad °C$$

let $\theta = T - 100°C$

$$\therefore \theta_B(z) = 1.058\,\theta_{TC}(z) + 4.8\ °C$$

$$\theta_{TC}(z) = \beta z$$



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$\theta_{H_2O} = 0$ $\qquad$ $W_i(z)$ = width of finger

$$\boxed{\frac{K_G}{d}(\theta_{B_i} - \theta_{H_2O})\,\Delta z_i W_i = \dot{m}_{evap_i} h_{fg} + \frac{K_G}{d}(\theta_{H_2O} - \theta_{TC_i})\,\Delta z_i W_i}$$

From Page No.

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Assume water falls at constant velocity (is this needed?)

$$\dot{m} = \rho Q_0 - \Sigma \dot{m}_{evap} = \rho Q$$

$$Q_0 = W_0 V_{fall} \qquad Q = W(z) V_{fall} = Q_0 \left[\frac{W(z)}{W_0}\right]$$

W_0, Q_0, and $V_{fall} = \frac{Q_0}{W_0}$ = KNOWN

~~$\frac{K_G}{d}\left[\theta_{B_i} - \theta_{H_2O} - \theta_{H_2O} + \theta_{TC_i}\right]\Delta z_i W_i$~~ DH Sept 11 2000

$$\dot{m}_{evap_i} = \rho Q_{i+1} - \rho Q_i = \rho \frac{dQ}{dz}\Delta z_i$$

$$\frac{dQ}{dz} = \frac{Q_0}{W_0}\frac{dW}{dz}$$

So

$$\frac{K_G}{d} W_i\left[\theta_{B_i} - \theta_{H_2O} - \theta_{H_2O} + \theta_{TC_i}\right] = \rho\left[\frac{Q_0}{W_0}\frac{dW_i}{dz}\right]$$

or

$$\boxed{\frac{dW}{dz} = \frac{W_0}{Q_0}\left[\theta_B(z) + \theta_{TC}(z)\right]\left(\frac{K_G}{d}\right)W}$$

Solve numerically!

NOTE: $\theta_{TC}(z) < 0$

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Conservation Eq.

$$\frac{\partial(\rho Q)}{\partial z} = -E$$ rate of mass loss per unit fracture length

Heat Flow

$$\frac{\partial\theta}{\partial t} = K\nabla^2\theta$$

OM Phillips

$$L^2 = \frac{2}{\pi}\frac{\rho Q_0 h}{K_m \beta}$$

$\rho(Q(z+\Delta z) - Q(z)) = \dot{m}$

heat flow rate / unit / h

For the fracture model

$$\rho\frac{(Q_{i+1} - Q_i)\Delta z}{\Delta z} = -\frac{w\Delta z K}{h}\frac{(T_h - T_0)}{d}$$

$$\rho\frac{\partial Q}{\partial z} = -\frac{wK}{h}\frac{\partial\theta}{\partial x}$$ Is this right??

$\theta(x,z)$

Let $T_0 = 0$ $\quad T_h = \beta z$

$$\rho\frac{\partial Q}{\partial z} = -w\frac{K}{d}\beta z \qquad \int_{Q_0}^{0}\rho\, dQ = \int_{z=0}^{L} -\frac{wK\beta}{d} z\, dz$$

Find the geometric factor

$w = w_0$

$w = w_0 e^{\alpha z}$

$w = w_0 e^{\alpha z^2 + \beta z}$

$$L^2 = (\text{Geom})\frac{\rho Q_0 h}{K_m \beta}$$

For fracture model vs. Mountain

$$L^2 = (\text{Geom})\frac{\rho Q_0 h}{K_G \beta}$$

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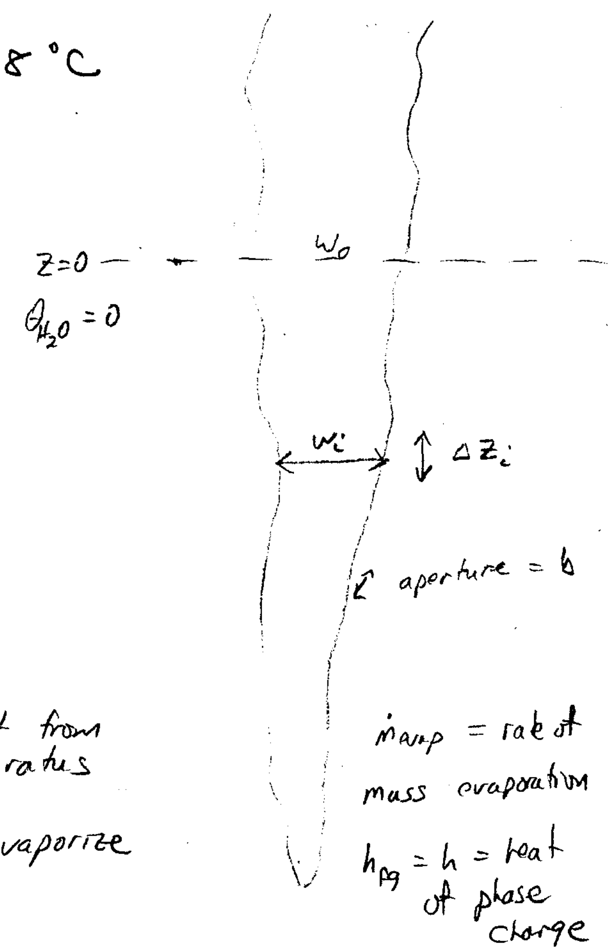
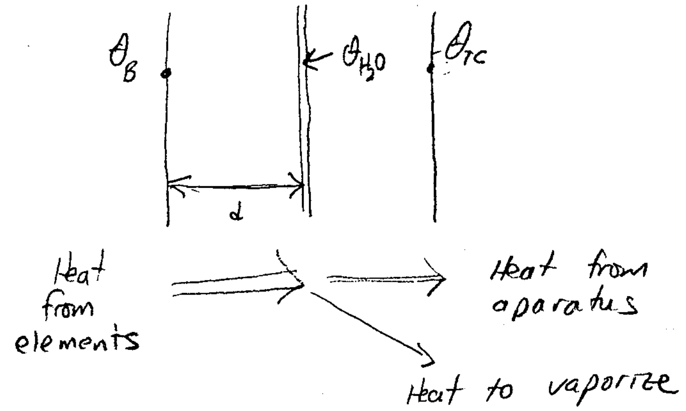
$$\theta_B(z) = 1.058\,\theta_{TC}(z) + 4.8\ ^\circ C$$
$$= a_1 \theta_{TC} + a_2$$
$$\theta_{TC}(z) = \beta z$$



Heat Flux



$$\frac{K_G}{d}(\theta_{B_i} - \theta_{H_2O})\Delta z_i\, w_i = -\dot{m}_{evap_i} h_{fg} + \frac{K_G}{d}(\theta_{H_2O} - \theta_{T_i})\Delta z_i\, w_i$$

$$-\dot{m}_{evap_i} = \rho Q_i - \rho Q_{i-1} = \rho \frac{dQ}{dz}\Delta z_i$$

$$\frac{dQ}{dz} = \frac{Q_0}{w_0 b}\frac{dw}{dz}$$

$$-\dot{m}_{evap_i} = \rho \frac{Q_0}{w_0 b}\frac{dw}{dz}\Delta z_i$$

513
4790

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$$\frac{K_G}{d}\theta_{B_i}\Delta z_i w_i = -\frac{\rho Q_0}{w_0 b}\frac{dw}{dz}\Delta z_i h - \frac{K_G}{d}\theta_{TC_i}\Delta z_i w_i$$

$$\frac{K_G}{d}(\theta_{B_i} + \theta_{TC_i}) w_i = -\frac{\rho Q h}{w_0 b}\frac{dw}{dz}$$

$$\theta_B = a_1\theta_{TC} + a_2 \qquad \theta_{TC} = \beta z$$

$$\frac{K_G}{d}(a_1\beta z + a_2 + \beta z)\, w = -\frac{\rho Q h}{w_0 b}\frac{dw}{dz}$$

$$\frac{K_G}{d}(a_0\beta z + a_2)\, w = -\frac{\rho Q h}{w_0 b}\frac{dw}{dz}$$

$$\int \frac{dw}{w} = \int \frac{K_G}{d}\frac{w_0 b}{\rho Q h}(a_0\beta z + a_2)\, dz$$

$$\ln w = -\frac{K_G w_0 b}{d\rho Q h}\left(\frac{a_0\beta z^2}{2} + a_2 z\right) + C_1$$

$$w = \exp\left[-\frac{K_G w_0 b}{d\rho Q h}\left(\frac{a_0\beta z^2}{2} + a_2 z\right) + C_1\right] = w_0 \exp\left[\frac{K_G w_0 b}{d\rho Q h}\left(\frac{a_0\beta z^2}{2} + a_2 z\right)\right]$$

$$w(z=0) = w_0 = \exp[C_1]$$

$$w = w_0 \exp\left[-\frac{K_G w_0 b}{d\rho Q h}\left(\frac{a_0\beta z^2}{2} + a_2 z\right)\right]$$

check to data Aug 21 2000

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$$\frac{K}{d}(T_h - T_b)\,w\,dz = -\frac{\rho Q_0 h}{w_0}\frac{dw}{dz}dt + \frac{K}{d}(T_b - T_f)\,w\,dz$$

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$\beta \geq 0$ $a \geq 0$

$$\frac{K}{d}\beta z\, w\, dz = -\frac{\rho Q_0 h}{w_0}\frac{dw}{dz}dz + \frac{K}{d}\left(-(a_1 z + a_2)\right)w\,dz$$

$$\frac{K}{d}(\beta z + a_1 z + a_2)w = -\frac{\rho Q_0 h}{w_0}\frac{dw}{dz}$$

$$\frac{dw}{dz} = -\frac{w_0 K}{\rho Q_0 h d}\, w(\beta z + a_1 z + a_2)$$

$-\mathcal{B}$

$$w(z) = w_0 \exp\left(-\frac{w_0 K}{\rho Q_0 h d}\left((\beta + a_1)\frac{z^2}{2} + a_2 z\right)\right)$$

$$w(z) = w_0 \exp\left(-\mathcal{B}\left[(\alpha+\beta)\frac{z^2}{2} + (c_1 + c_2)z\right]\right)$$

$$\ln(w(z)) = \ln(w_0) - \mathcal{B}\left[(\alpha+\beta)\frac{z^2}{2} + (c_1+c_2)z\right]$$

$$\mathcal{B}\frac{(\alpha+\beta)}{2}L^2 + \mathcal{B}(c_1+c_2)L = \ln(w_0) - \ln(w_L)$$

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top line

$$\frac{K}{d}(T_h - T_b)\,w\,dz = -\frac{\rho Q_0 h}{w_0}\frac{dw}{dz}dz + \frac{K}{d}(T_b - T_f)\,w\,dz$$

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```
* First crack time stepping model for finger flow through a boiling
fracture
* August 1, 2000
* Input required
* Q0 Initial flow rate in mL/min
* w0 Initial finger width
* bf Aperture width
* Bt Temperature gradient positive in z
* Fk Parameter for heat flow
*
      real Q0,w0,bf,Bt,Fk,delt
* enthalpy of boiling J/kg, density kg/m^3
      h=2.258E+6
      p=960.
* fracture aperture m
      bf=.0001
      write(*,*)'Enter in the following order'
      write(*,*)' '
      write(*,*)'Flow rate in mL/min'
      write(*,*)'Initial finger width in cm'
      write(*,*)'finger tip width in cm'
      write(*,*)'Temperature gradient in C/m'
      write(*,*)'Heat constant (K/d) in J/(sCm^2)'
      write(*,*)'Time step in sec'
      read(*,*) Q0,w0,wl,Bt,Fk,delt
* convert units to kg,m,s
      Q0=Q0/1000000./60.
      w0=w0/100.
      wl=wl/100.
*
      Q=Q0
      w=w0
      z=0.
      open(unit=29,file='stepmod.out')
*
      do while(w.ge.wl)
         delz=(Q*delt)/(w*bf)
         z=z+delz
         T=Bt*z
* area of incremental slice m^2
         A=w*delz
* flow of heat to incremental slice J/s
         fw=A*Fk*T
* rate of vaporization from heat flow m^3/s
         Qv=fw/(p*h)
* liquid flow rate remaining m^3/s
         Q=Q-Qv
* new finger width based on area of a trapezoid m
         wi=(2*delt*Q)/(bf*delz)-w
         write(29,*) z,w
         w=wi
      enddo
      write(*,*) 'L = ',z,' meters'
      close(29)
      end
```

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modified slightly from page 62

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Review comment #12
Discussion of the assumption $\frac{dQ}{dz} = \frac{Q_0}{w_0}\frac{dw}{dz}$

Volumetric Flow Rate $Q = vwb$ $\left[\frac{L^3}{T}\right]$

v = liquid velocity
w = finger width
b = fracture aperture

$dQ = d(vwb) = (vw)db + (vb)dw + (wb)dv$

assume b = constant
v = constant

then $dQ = vb\,dw$

if v = constant = $V_0 = \frac{Q_0}{w_0 b}$

then $dQ = \frac{Q_0}{w_0} dw$

and $\frac{dQ}{dz} = \frac{Q_0}{w_0}\frac{dw}{dz}$

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Is v = constant a reasonable assumption?

Cubic Law for flow between parallel plates

$Q = \frac{\rho g b^2}{12\mu}(bw)\frac{\partial h}{\partial z}$

ρ = density
g = gravity
μ = viscosity
P = pressure

$h = \frac{P}{\rho g} + z$

For porosity $n = 1$

$\frac{Q}{bwn} = \frac{q}{n} = v = \frac{\rho g b^2}{12\mu}\frac{\partial h}{\partial z}$

Water pressure $P \approx$ constant
(open to atmosphere & no water column)

so $\frac{\partial h}{\partial z} = \frac{\partial}{\partial z}\left(\frac{P}{\rho g} + z\right) = 1$

and $v = \frac{\rho g b^2}{12\mu}$ = constant

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Sept 14 2000

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Debra Hughson

From: FDodge@swri.edu
Sent: Wednesday, September 13, 2000 4:38 PM
To: dhughson@swri.edu
Cc: FDodge@swri.edu
Subject: Review comment #12

Debra:

This is my explanation of the "assumption" that dQ = (Qo/wo)dw.

At any point, the volumetric flow rate of liquid in the finger is Q = (V)(w)(b), where V = vertical fall velocity (averaged over the cross section of the finger) of the liquid at that point, w = the finger width at that point, and b = fixed distance between the glass plates. Consequently, the most general change in the flow rate is dQ = (Vb)dw + (wb)dV.

The flow rate at the top of the finger before any liquid evaporates is Qo = (Vo)(wo)(b). So eliminating "b" between the Qo and the dQ expressions gives:
dQ = Qo(w/wo)(dV/Vo) + Qo(V/Vo)(dw/wo).
The assumption that V = constant then makes dQ = Qo(dw/wo). But this is a good assumption (i.e., V = constant). What makes the liquid fall is the gravity body force. This force is restrained by the viscous stresses at the wall, and these stresses are linearly proportional to the average velocity V for a creeping flow, so the velocity has to take on a value where the viscous stresses just balance the gravity body force. Since gravity doesn't change, neither does the velocity -- that is, the velocity is constant. There is some initial part when the flow starts from rest where the liquid accelerates up to the velocity that balances the downward gravity force. Below this point, however, the velocity remain constants. Presumably the acceleration length of the finger is above the point where the finger starts to evaporate (the acceleration length is very very short, of the order of the finger width). Thus, throughout the evaporating length of the finger the velocity must be consta!
nt and equal to the initial velocity Vo.

Therefore, the "assumption" that dQ = Qo(dw/wo) is valid so long as a one-dimensional flow model is allowed.

I hope this discussion satisfies comment #12. All the "hand waving" above can be turned into differential equations if we need to prove mathematically the physical arguments given above.

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Run MULTIFLO simulations to get reflux liquid velocities

Metra input files & runs in directories

~dhughson/multiflo/mhill/ noblow50
maxheat
25y50u

Were all set up to run quickly. These I used for deliverables ~~604~~ DH Oct 25 2000 1402.661.040 and 050

But now using ~spainter/bin/metra

none of these files run. I suspect this is because a few changes were made to the code, probably for bug fixes

Input File found that runs OK in

~dhughson/multiflo/mhill/dry thick

moved to location

~dhughson/multiflo/vel4frac/wall5

as a working directory

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Output from ~dhughson/multiflo/vel4frac/walk

Need to find height of 97°C isotherm above drift crown

Heater at 386.25 m = z

Time	From matrix field xyp Z(m) interpolated	97°C
60	380.7	1.8
70	379.5	3
80	377.8	4.7
90	375.5	7
100	375.2	7.3
200	372.0	10.5
300	371.7	10.8
400	371.6	10.9
500	371.6	10.9
600	371.6	10.9
700	371.4	11.1
800	371.4	11.1
900	371.7	10.8
1000	372.1	10.4
1200	372.6	9.9
1400	373.5	9
1600	375.3	7.2
1800	376.7	5.8
2000	379.2	3.3

dlh Oct 30 2000

2.5	377.75	
2	380	
1.5	381.75	
	382.5	CROWN
1	383	DRIFT
1	384	DRIFT
1	385	DRIFT
.5	385.75	DRIFT
.5	386.25	HEATER
1	387	INVERT

spreadsheet

D:\documents\Tef\661-050\Gsa 2000\drst2boil

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β = thermal gradient interpolated from matrix .xyp files ~dhughson/multiflo/vel4frac/walk

Time = 80 yr file = 13csfldm9.xyp

377.75	~~96.54~~ 96.87 dlh Nov 7 2000
380.0	108.2

β = ~~5.2~~ 5.0 °C/m dlh Nov 7 2000

Time = 200 yr file = 13csfldm12.xyp β = 0.54

Time	β
80	5.0
90	1.0
100	2.0
200	~~.05~~ 0.54 dlh Nov 7 2000
300	.785
400	0.96
500	0.965
600	0.96
700	0.9
800	0.84
900	0.72
1000	0.58
1200	0.4
1400	0.27
1600	0.63
1800	0.39
2000	0.46

60

70 ~~3.6~~ dlh Nov 7 2000

$$L = \left(\frac{\rho Q h}{\beta K}\right)^{1/2}$$

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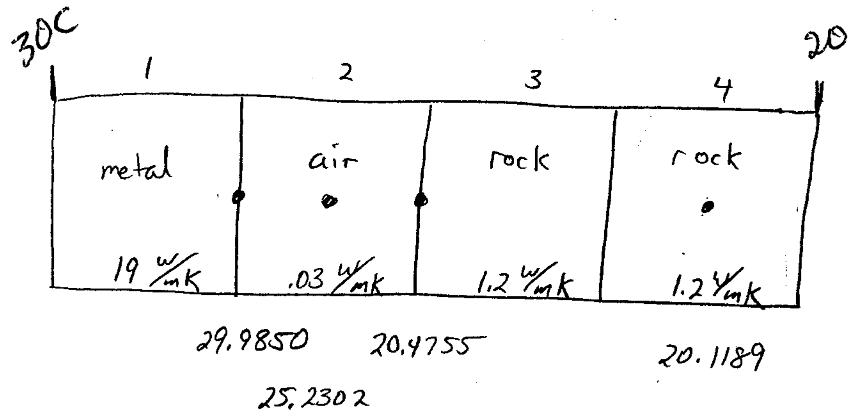
Check of radiation heat transport in MULTIFLO



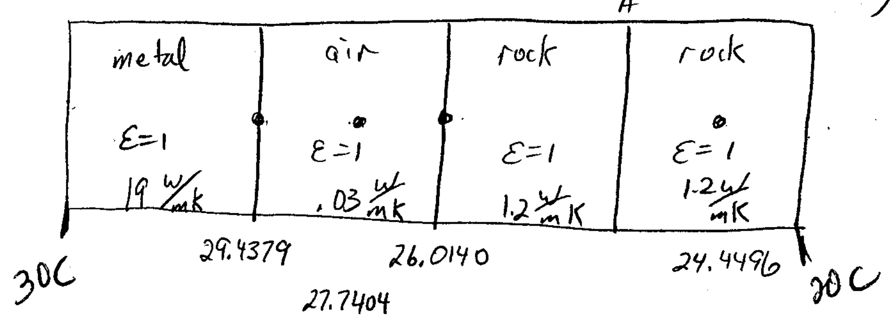
cond_un.dat

$f = KA\frac{(T_1 - T_2)}{\Delta}$

Fluxe = .2853 W conduction only

radiation only with no conduction gives run time over flow

$\sigma = 1.37e{-12}\ \frac{cal}{cm^2 s} = 5.67 \times 10^{-8}\ \frac{W}{m^2 K^4}$ $\frac{f^*}{A} = \varepsilon\sigma(T_1^4 - T_2^4)$ $A = 1 m^2$



Fluxe = 10.68

f	10.68	0.1	.1	1.25	10.68
f*	3.54 / ?	10.58 / 10.68	10.58 / 10.68	9.43 / 10.68	26.01 / ?

DH 02/01/01

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Top (left) shows conduction only – unstructured grid node log

Steady state temps check with Fourier's law of heat cond

Emissivity from BC = 0 for unstruc grid
no heat trans by radiation from BC

Radiation only w/ no conduction gives overflow

Bottom (left) Heat conduction by radiation and cond

Heat trans in far left (block 1) and far right (block 2)
by conduction only due to lack of radiation
from BC in unstructured grid

middle two blocks (2 and 3) stefan-boltzman
plus fourier sums to 10.68 W

1) Heat transfer in 1D by radiation and conduction works OK

2) Radiation from BC in unstructured grid does not work. Does work, however, in the structured grid

files DH Jan 2 2001

~~~dhugh~~ ~dhughson/multiflo/tpa5/testemis/multi.dat

and subdirectory testcases

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This scientific notebook complies with CNWRA QA requirements. The material recorded in this notebook is sufficient in scope and detail to allow a skilled practitioner to replicate the studies described in the Table of Contents.

Gordon Wittmeyer

4/12/2001

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Operating System: (including version number)	Windows NT, Version 4
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Media Type: (CDs, 3 1/2, 5 1/4 disks, etc.)	Iomega Zip 250 (original) CD
File Types: (.exe, .bat, .zip, etc.)	wpd, ai, xls, ppt, tif
Remarks: (computer runs, etc.)	Media contains text files and figure files for a presentation on the Hele-Shaw model of rivulet formations in a heated fracture.