Knight Piesold
Elko Roundtable 2014
Drain Down from Waste Rock and Heap Leach Piles

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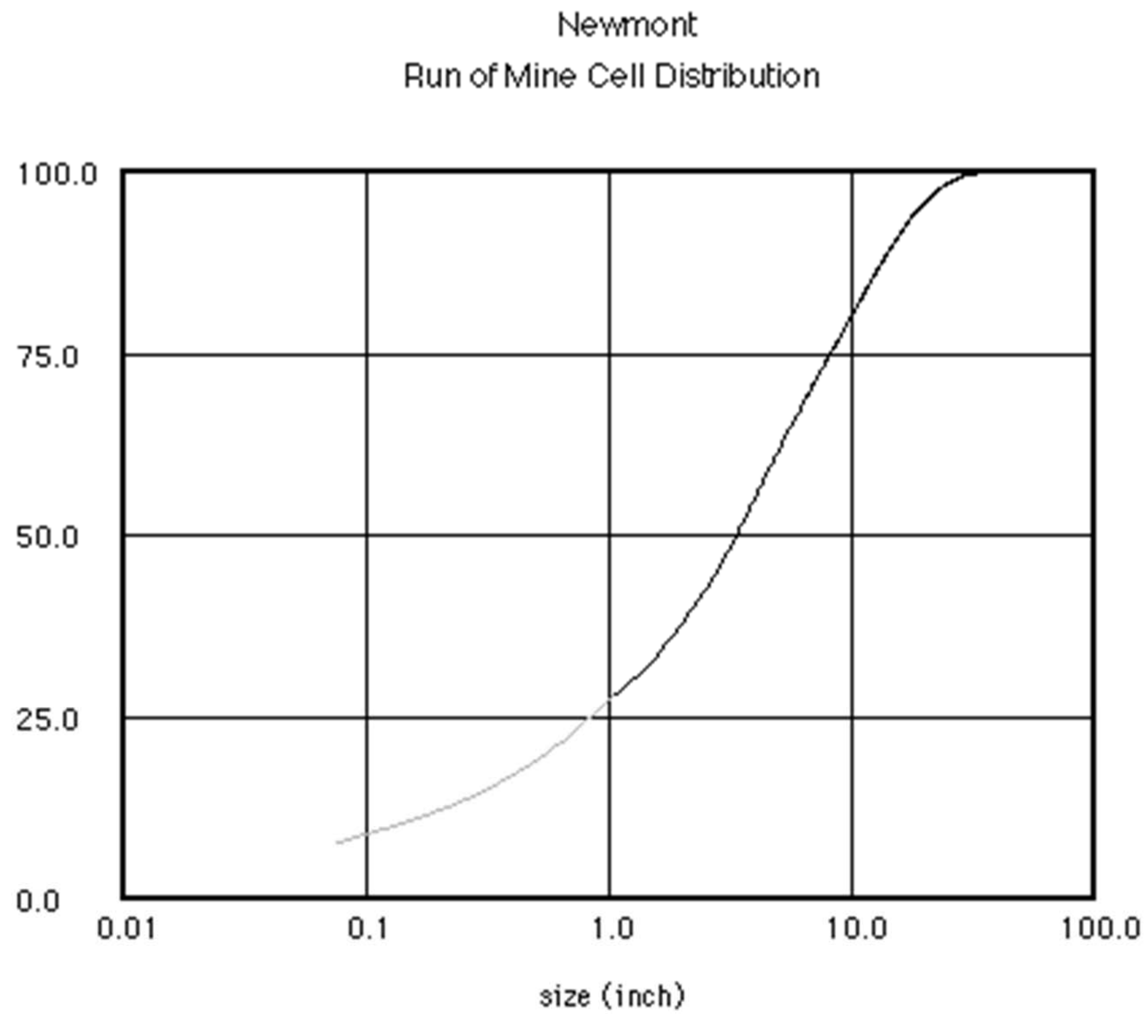
Outline

- Introduction - Heaps & Dumps
- ROM Physical Properties
- Capillary Physics
- Drain Down
- Air Flow in Piles
- How do we solve the drain down issue?

ROM

- Blasted Material is Run of Mine (ROM)

ROM



size (inches)	% finer
0.079	8.01
0.187	11.81
0.250	13.62
0.375	16.68
0.500	19.25
0.750	23.61
1.000	27.29
1.500	32.70
2.000	37.92
4.000	55.17
6.000	66.85
8.000	74.56
10.000	80.36
15.000	90.41
25.000	98.52
50.000	100.00
75.000	100.00

P20 size (inch) 0.54
P50 size (inch) 3.36
P80 size (inch) 9.86
topsize (inch) 29.10

Bulk Density

A. Equations:

$\acute{\omega}$ = Voidage in Percent

- Bulk Density = $\frac{\text{Mass + Voids}}{\text{Volume}}$ = D(1- $\acute{\omega}$)
- Bulk SG = $\frac{\text{Mass + Voids}}{\text{Volume}}$ = SG(1- $\acute{\omega}$)
- $\acute{\omega}$ = Volume of Voids/Total Volume
- $\acute{\omega} = \frac{\text{Volume of Voids}}{\text{(Void Volume + Solid Volume)}}$
- $\acute{\omega}$ = 1 - Bulk Density/Density of Solids
- $\acute{\omega}$ = 1 – BSG/SG

Voidage

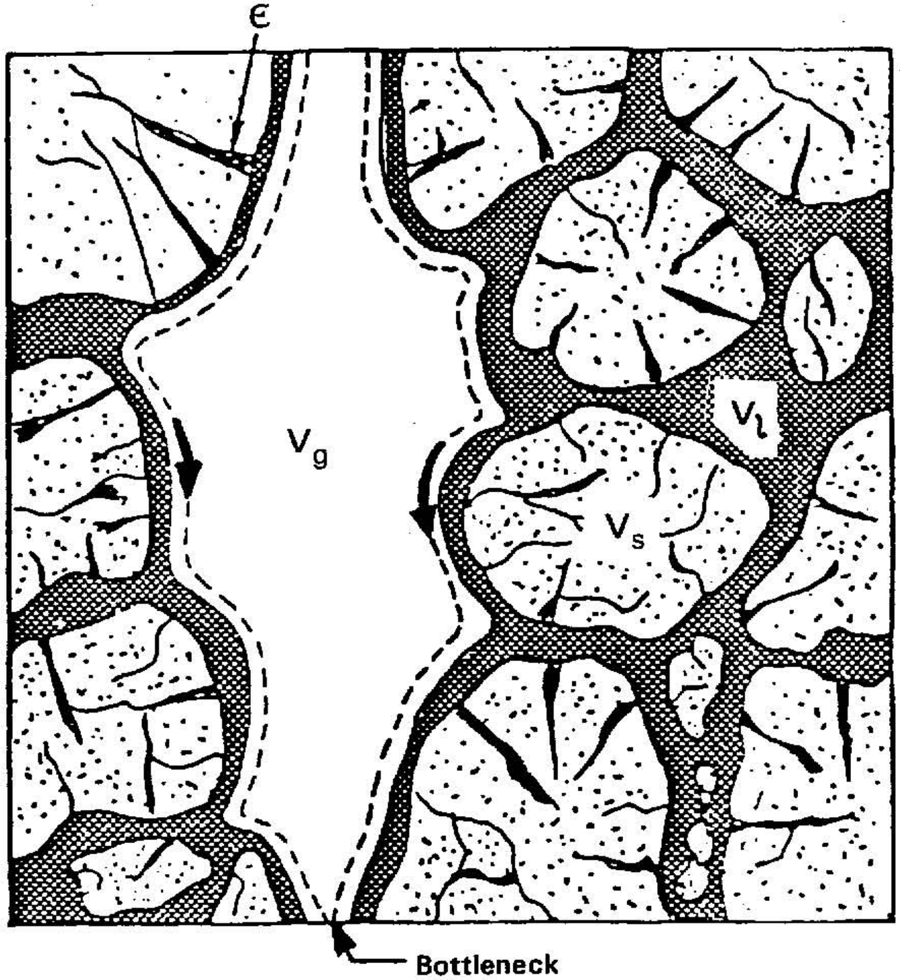


Figure 7.1. Schematic section of a heap showing space occupied by solids (v_s), rock microporosity (ε), solution void space (v_l) and air void space (v_g) (Schlitt, 1984).

Voidage

Table 7.1 Phase Regions in a Fragmented Ore Heap—Flow-Test Column (Schlitt, 1984).

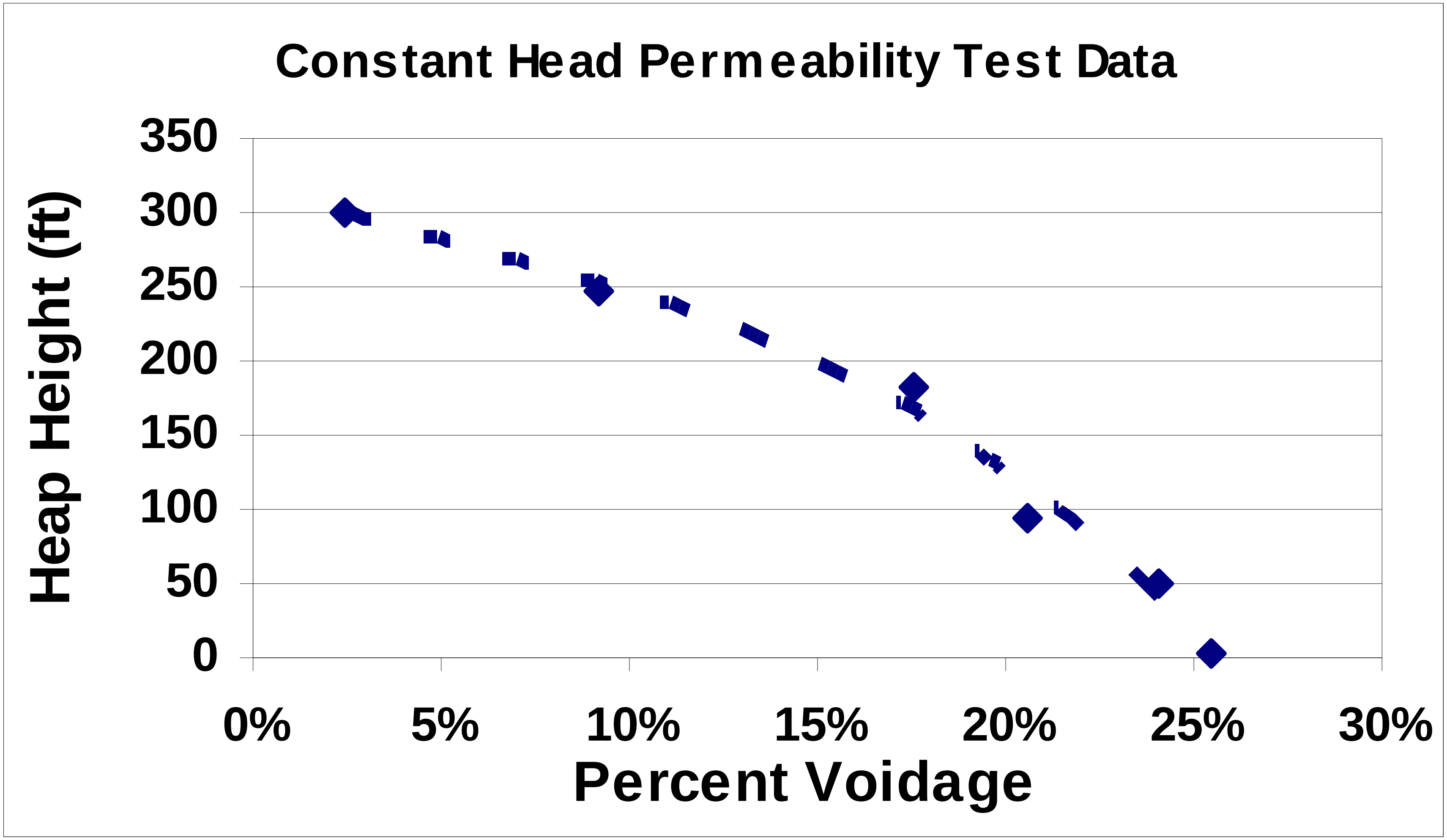
Phase	Symbol	Stagnant or Mobile	Measured Vol Pct in Test Volume
Solid rocks including closed pores	ν_s	Stagnant (dead space)	59.0%
Open microporosity within rocks	ε	Stagnant (dead space)	2.4%
Solution void space between rocks	ν_l	Mobile (water flow)	19.0–21.5%
Air void space between rocks	ν_g	Mobile (air flow) and trapped air pockets	18.1–19.6%

Heap & Dumps

- **Voidage: 2 to 40% voids in a ROM Heap**
- **Voidage in -6" crushed material stacked**

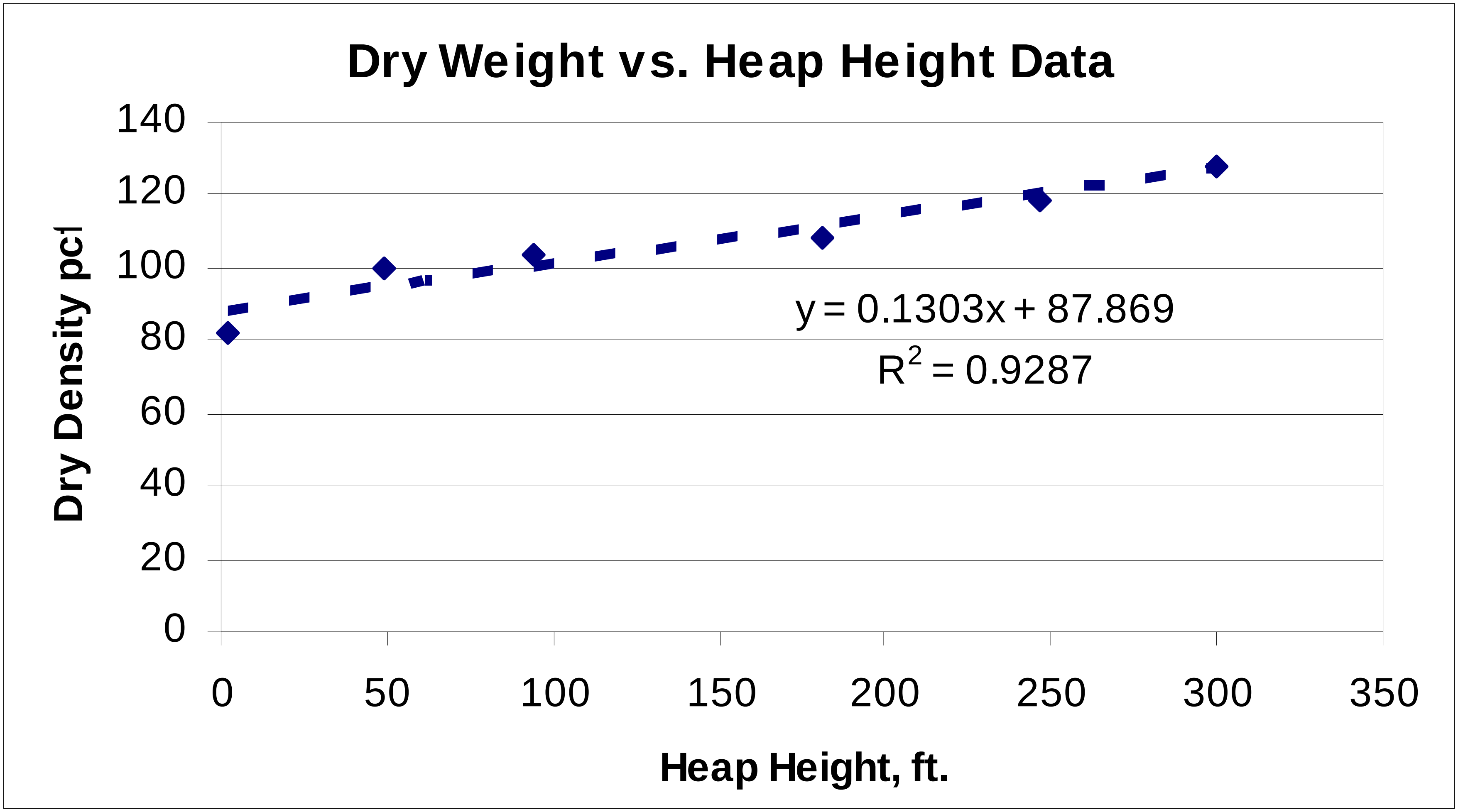
Ore Properties:	Knight Piesold				% Moisture	11%	131.10	#/ft^3	
Feet	Normal Stress-Wet		**Wet Density**			**dry Density**	**Voidage**	Permeability:	
Down	psf	psi	#/f^{t3}	g/cm^3	ft^3/ton	#/ft^3	%	K=cm/sec	
2	144	1	82.9	1.33	24.1	82.49	25.48%	0.011	1.10E-02
49	5,500	38.2	111.9	1.79	17.9	99.59	24.03%	0.007	7.00E-03
94	11,000	76.4	116.9	1.87	17.1	104.04	20.64%	0.0034	3.40E-03
181	22,000	152.8	121.4	1.94	16.5	108.05	17.58%	0.00078	7.80E-04
247	33,000	229.2	133.7	2.14	15.0	118.99	9.23%	0.00024	2.40E-04
300	39,059	271.2	143.6	2.30	13.9	127.85	2.48%	0.000111	1.11E-04

Heap & Dumps



Constant Head Permeability Test Data
Heap Height (ft)
350
300
250
200
150
100
50
0
0%
5%
10%
15%
20%
25%
30%
Percent Voidage

Heap & Dumps



Dry Weight vs. Heap Height Data
140
120
100
80
60
40
20
0
Dry Density pcf
y = 0.1303x + 87.869
R2 = 0.9287
0
50
100
150
200
250
300
350
Heap Height, ft.

Solution Retention and Capillarity

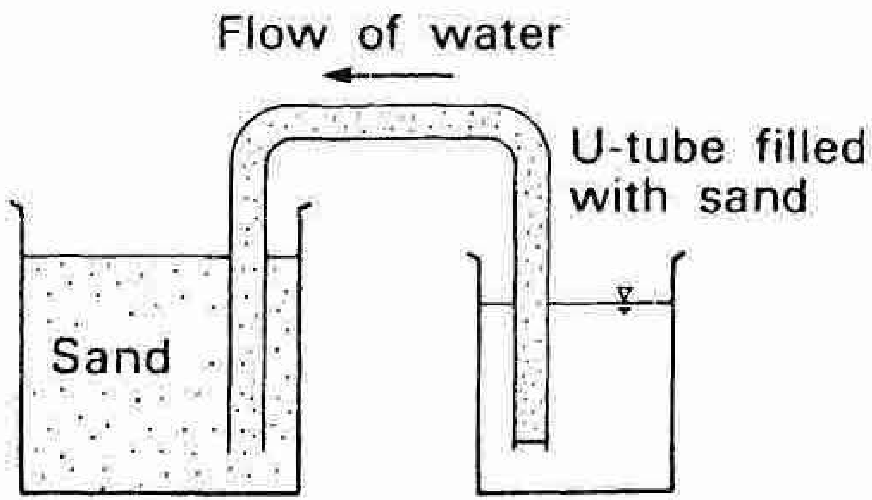
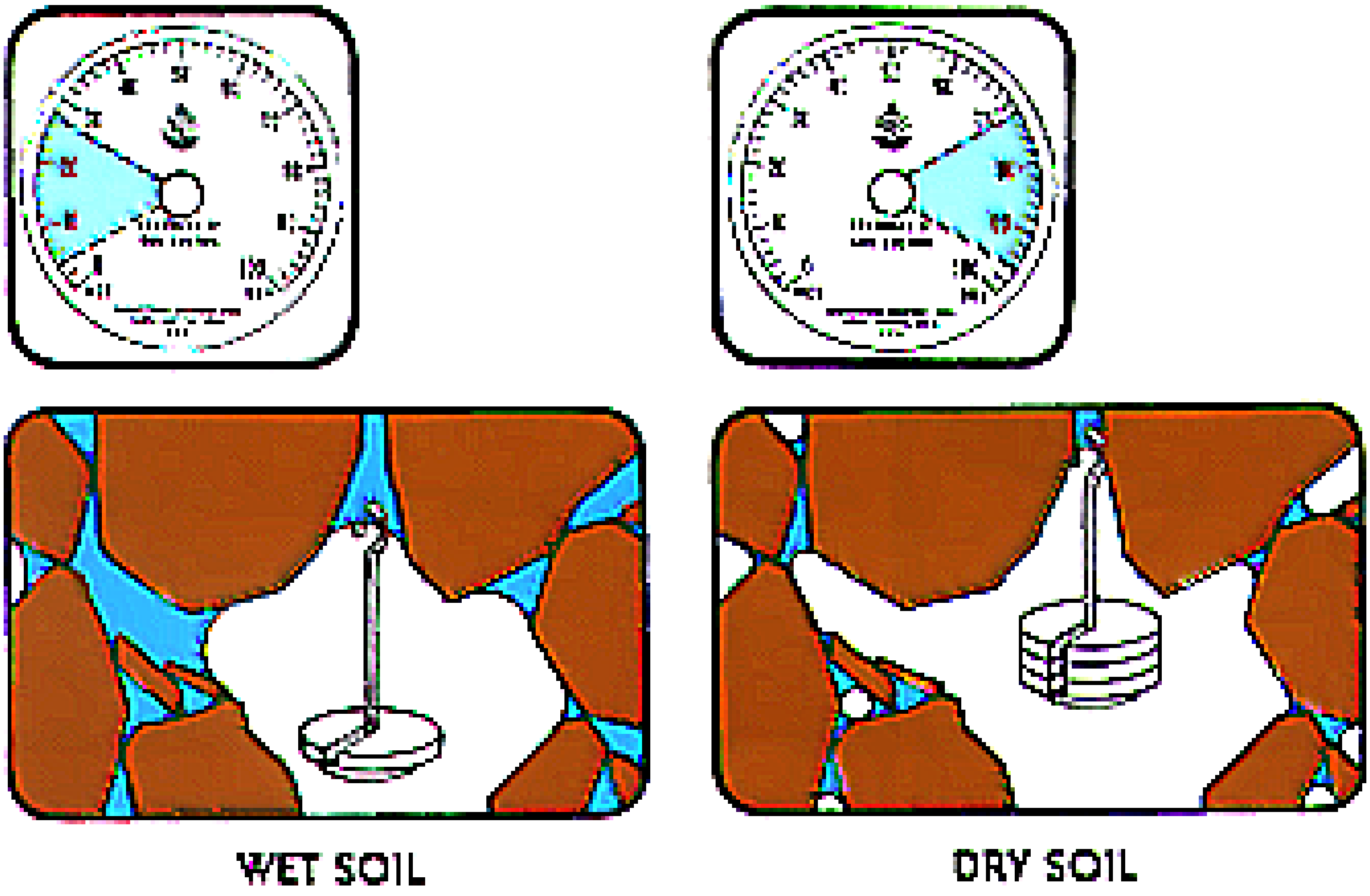


Figure 1.23 Beaker and sand-filled glass tube for demonstrating the phenomenon of capillary flow through a sand (from Hogentogler and Barber).

Solution Retention and Capillarity



Solution Retention and Capillarity

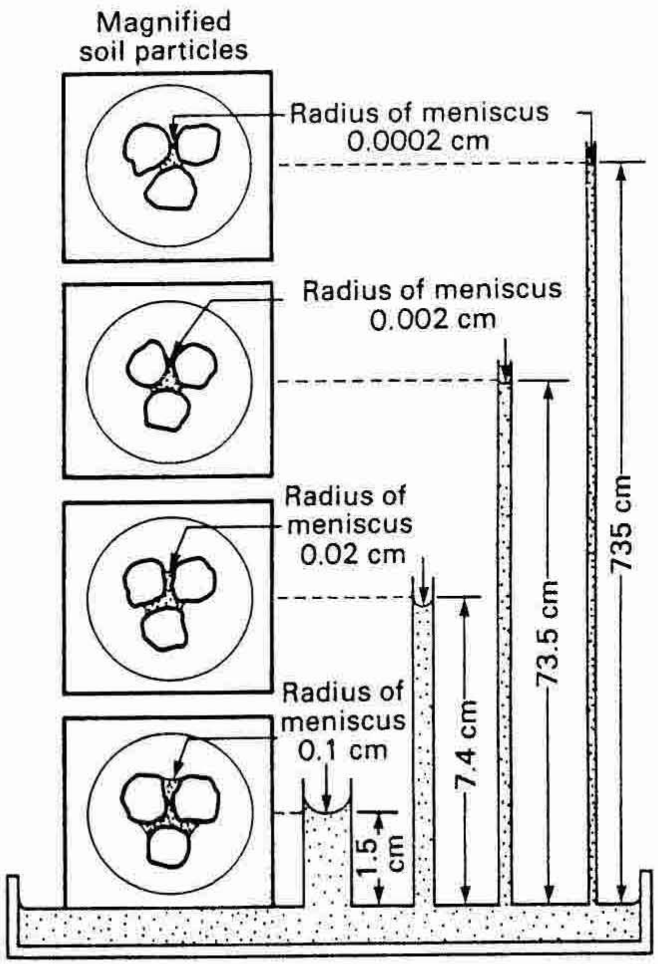


Figure 4.3 Capillary tubes showing the air–water interfaces at different radii of curvatuve (from Janssen and Dempsey, 1980).

Drain Down Physics

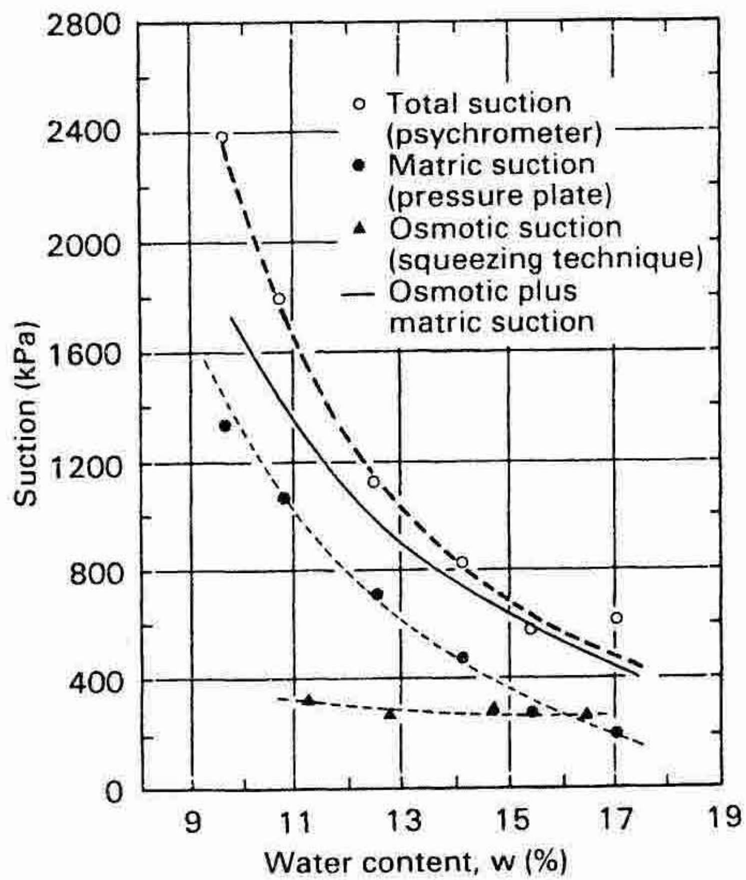
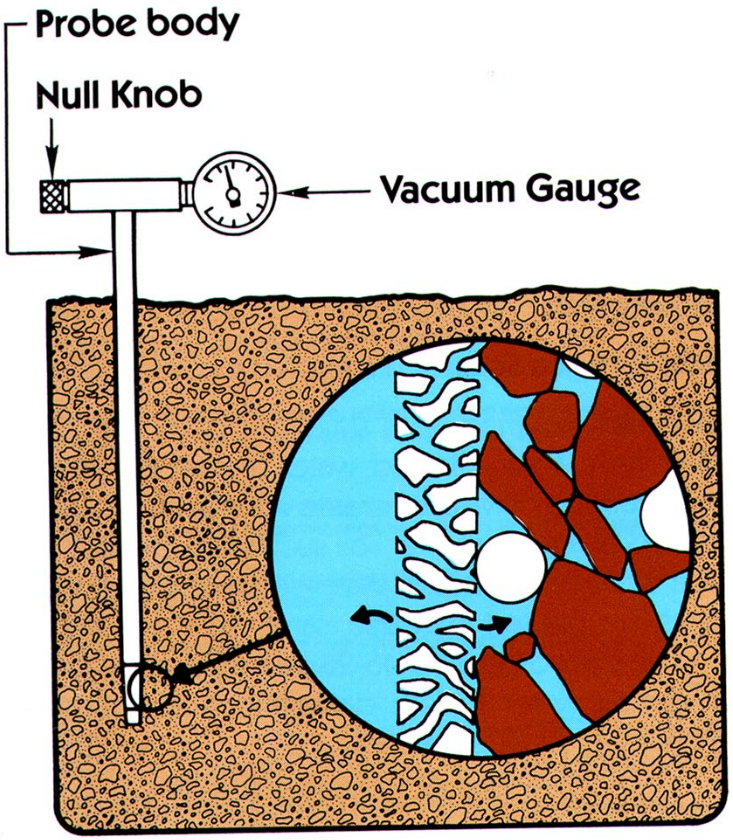
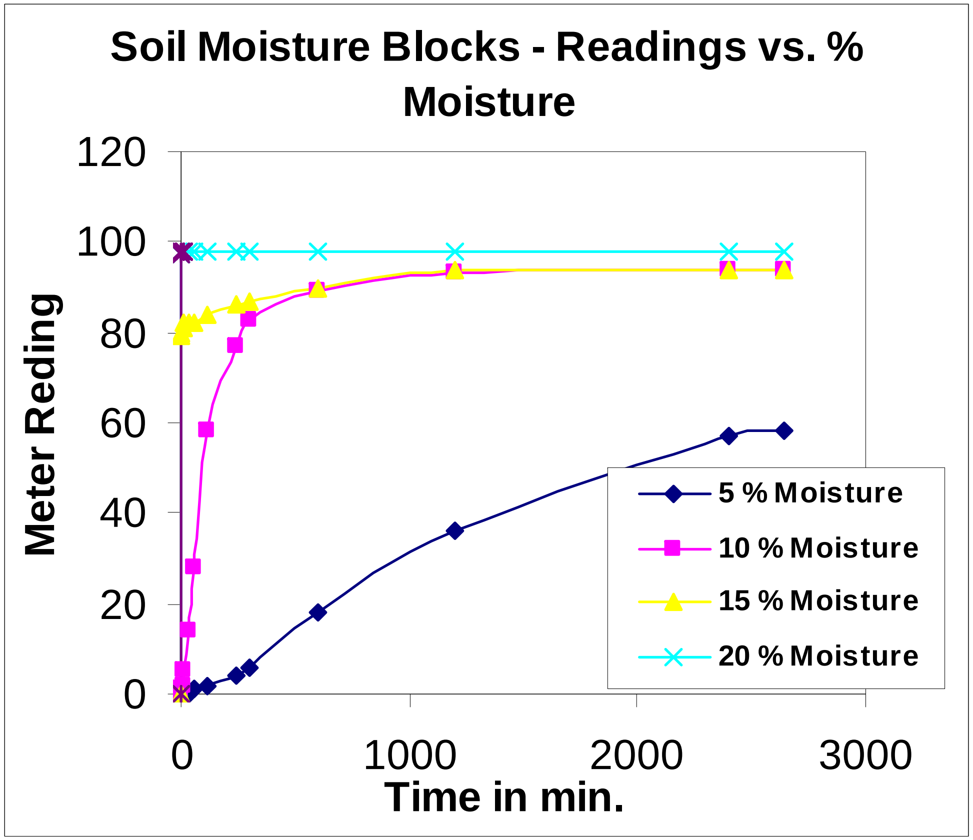


Figure 4.4 Total, matric, and osmotic suctions for glacial till (from Krahn and Fredlund, 1972).

Solution Retention and Capillarity





Drain Down Physics

- 3 forces, gravity, surface tension and atmospheric pressure
- Surface tension is the molecular attraction that causes water to preferentially adhere to solid surfaces over air and thereby displace air from both internal microporosity and void space.
- Hydroscopic water is the water that clings to the particles in the heap.
- Solution will drain until gravity = surface tension
- As particle size decreases the capillary rise will increase

Drain Down Physics

- Clays (ultra fine particles with a lot of void space) tend to be saturated with water unless evaporated
- Solution fills all void space for rock sizes less than 48 mesh (0.3 mm) and will exclude air
- Rocks coarser than 10-20 mesh (1 mm) drainage will be almost complete and most of the void space will be filled with air
- Solution is retained in minus 40 mesh rock without exterior heating force

Drain Down Physics

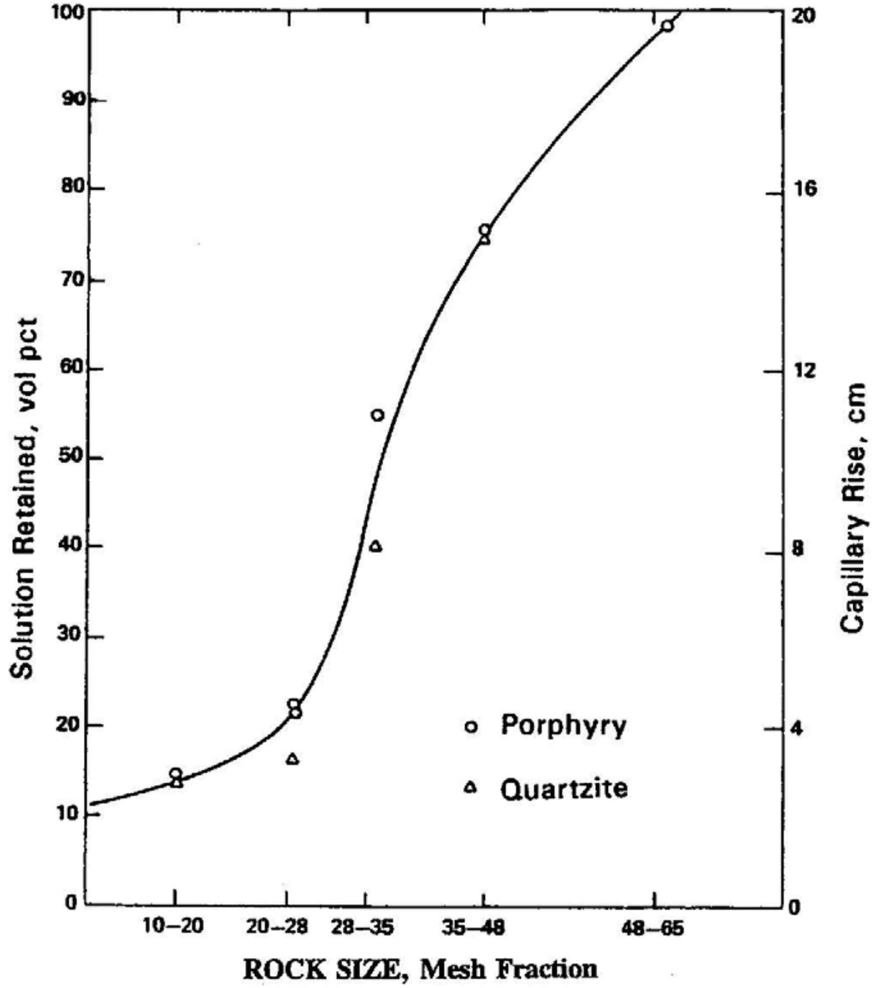
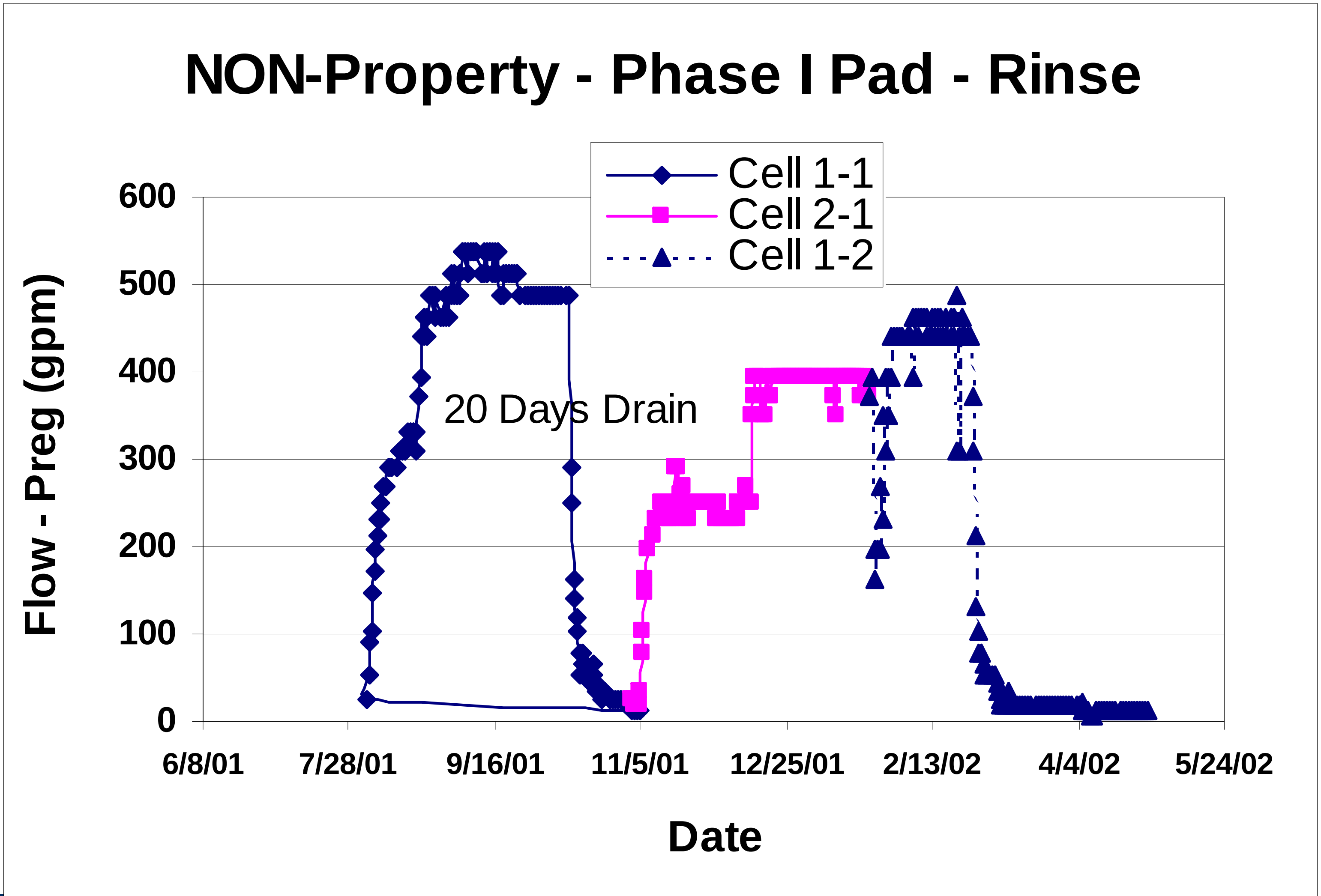


Figure 7.2. Solution retention and capillary rise as a function of rock fragment size (Schlitt, 1984).

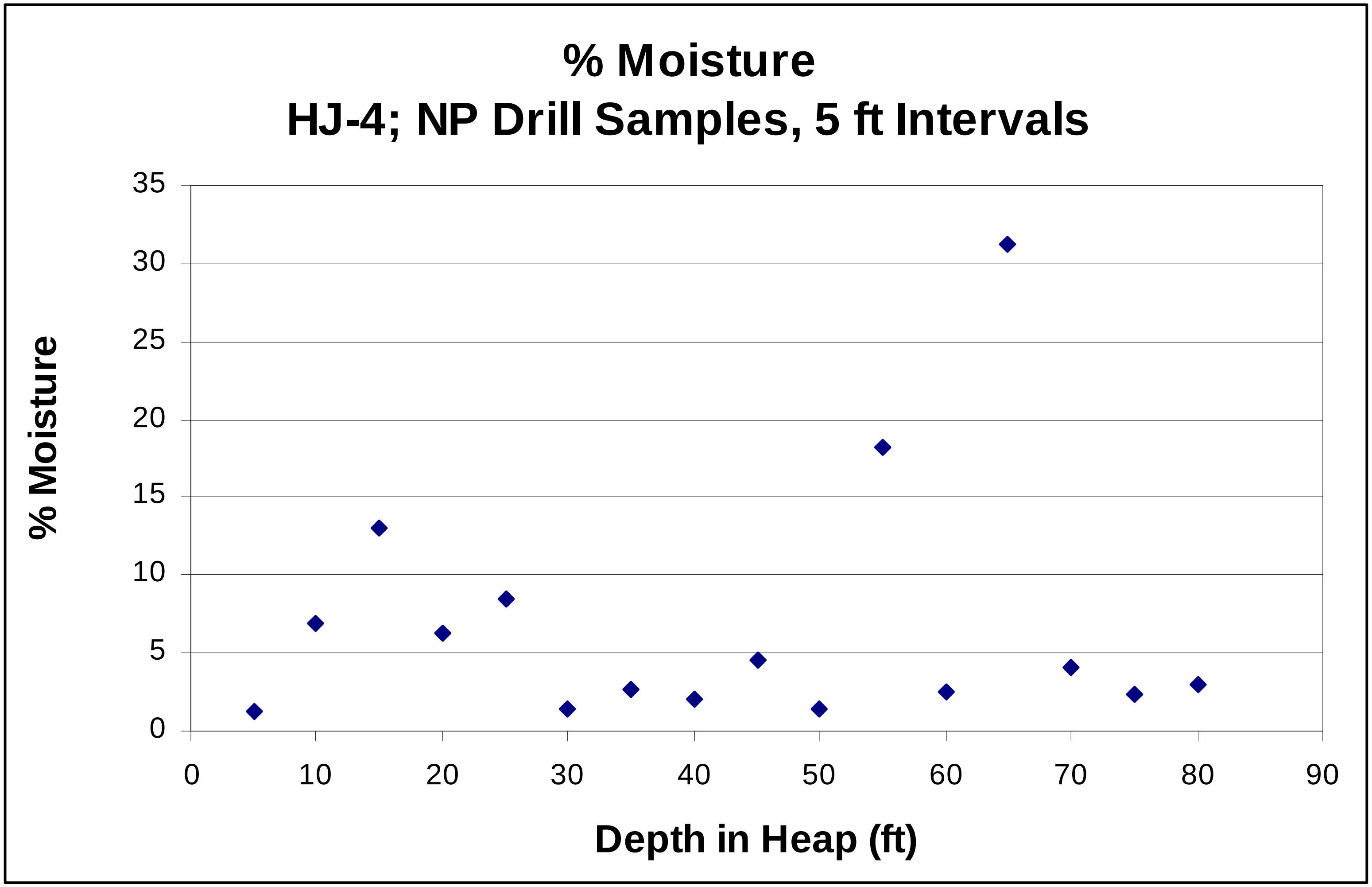
Heap Drain Down Data



Elko Roundtable-14 Drain Down from Mine Piles
Thom Seal, Ph.D., P.E.

Heap Drain Down Moisture

Average 6.75% Moisture



Pan Evaporation – Elko NV

Month	Average Monthly Precipitation		Average Monthly Pan Evaporation	
	(in)	(mm)	(in)	(mm)
January	1.18	29.97	0.92	23.37
February	0.95	24.13	1.38	35.05
March	0.92	23.37	2.68	68.07
April	0.79	20.07	4.15	105.41
May	0.97	24.64	6.26	159.00
June	0.80	20.32	8.00	203.20
July	0.35	8.89	10.49	266.45
August	0.41	10.41	8.93	226.82
September	0.45	11.43	6.16	156.46
October	0.67	17.02	3.90	99.06
November	0.92	23.37	1.80	45.72
December	1.05	26.67	0.99	25.15
Annual	**9.46**	**240.3**	**55.66**	**1413.8**

Table 1 - Average Annual Climate Conditions at Elko Airport (1890-1998)

Drain Down Chemistry

Table 1. TM Barren Pond (mg/L, except for pH) (NDEP files, 1998)

Date	As	Cr	Hg	Wad CN	pH
1st Q92	0.845	--	1.72	60.9	10.9
1st Q93	0.97	0.32	0.29	7.55	10.6
3rd Q93	0.93	0.28	0.084	2.78	10.8
1st Q94	0.91	0.31	0.046	2.65	10.7
3rd Q94	1.00	0.36	0.27	1.04	10.7
1st Q95	1.20	0.23	0.009	0.48	10.1
3rd Q95	1.1	0.31	0.006	0.44	8.7
4th Q95	1.05	0.28	0.010	0.11	8.5

Table 2 contains data that were also obtained from NDEP files and provide examples of drainage water quality. These data demonstrate the substantial differences that can exist between heaps. Water from the CB and LH heaps were recirculated sufficiently to bring the pH below 9, while the GA Barren water has an elevated pH.

Drain Down Chemistry

Table 2. Heap Drainage Chemistry Profiles (NDEP files, 1998)
(all mg/L except for pH)

	CB Effluent	GA Barren	LH Effluent
	6/23/98	8/20/96	4Q 95
pH	7.79	10.04	8.17
TDS	3032		11200
nitrate	54	19.8	171
sodium	340	180	3880
chloride	160		1130
WAD CN	3	4.1	0.11
sulfate	1600	175	6130
antimony	0.023	<0.05	--
arsenic	0.08	1.09	0.543
copper	0.007	0.17	0.028
manganese	0.051	<0.1	0.035
mercury	0.022	0.032	0.004
nickel	0.034	<0.04	--
selenium	0.18	0.01	5.84
cobalt	0.58	0.04	--
molybdenum	0.31	0.13	--
vanadium	<0.002	0.08	--

US Drinking Water Standards

http://www.epa.gov/ 2006

Inorganic Chemicals	CASRN Number	Standards MCLG (mg/L)	Standards MCL (mg/L)
Ammonia	7664-41-7	—	—
Antimony	7440-36-0	0.006	0.006
Arsenic	7440-38-2	zero	0.01
Barium	7440-39-3	2	2
Beryllium	7440-41-7	0.004	0.004
Boron	7440-42-8	—	—
Bromate	7789-38-0	zero	0.01
Cadmium	7440-43-9	0.005	0.005
Chromium (total)	7440-47-3	0.1	0.1
Copper (at tap)	7440-50-8	1.3	TT[6]
Cyanide	143-33-9	0.2	0.2
Lead (at tap)	7439-92-1	zero	TT6
Manganese	7439-96-5	—	—
Mercury (inorganic)	7487-94-7	0.002	0.002
Molybdenum	7439-98-7	—	—
Nickel	7440-02-0	—	—
Nitrate (as N)	14797-55-8	10	10
Nitrite (as N)	14797-65-0	1	1
Nitrate + Nitrite (both as N)		10	10
Selenium	7782-49-2	0.05	0.05
Silver	7440-22-4	—	-
Strontium	7440-24-6	—	-
Thallium	7440-28-0	0.0005	0.002
Zinc	7440-66-6	—	-

US Drinking Water Standards

List of EPA National Secondary Drinking Water Regulations	
Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Air Penetration into Piles

B. Gaseous Diffusion of Oxygen in Ore Heaps

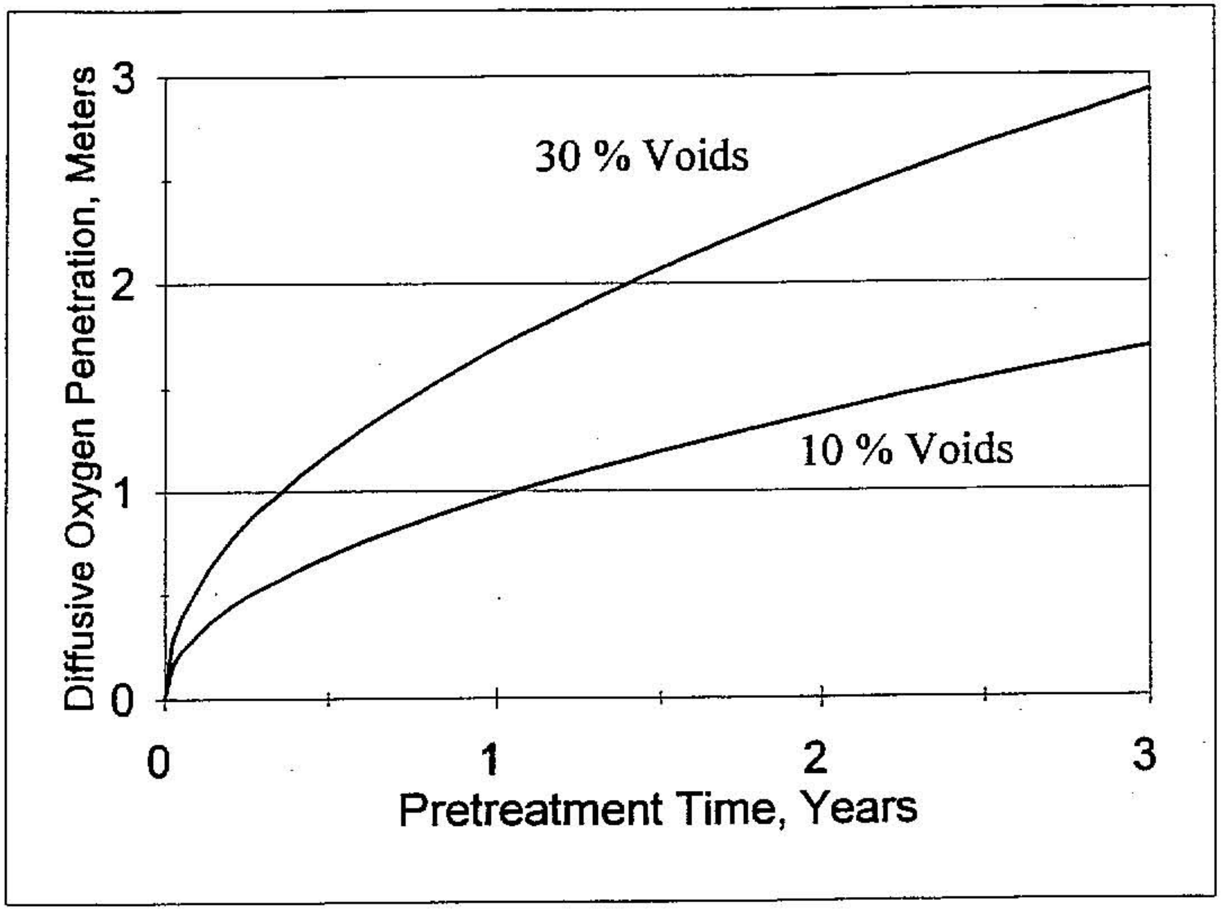


Figure 8.2. Diffusive oxygen penetration into an ore heap as a function of air-filled void space, ν_g, and biooxidation pretreatment time, Pyrite = 1.0 wt pct (Bartlett and Prisbrey, 1995).

Air Penetration into Piles

B. Gaseous Diffusion of Oxygen in Ore Heaps

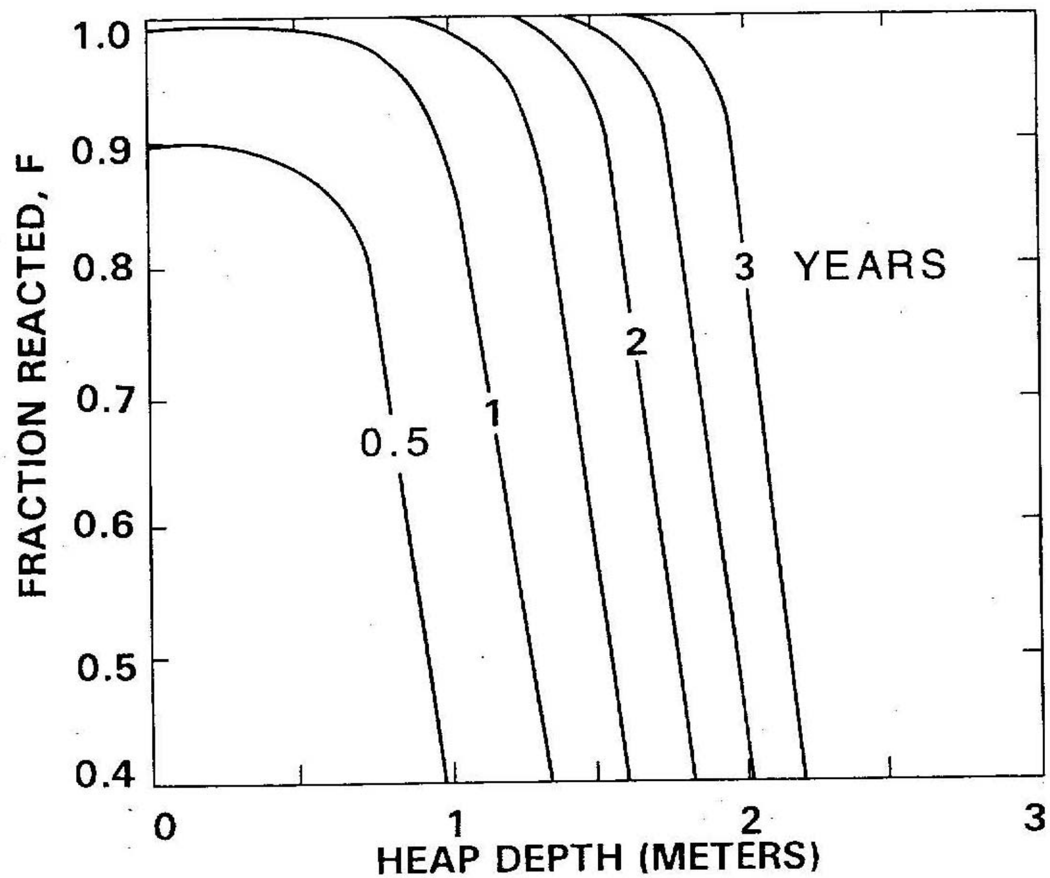
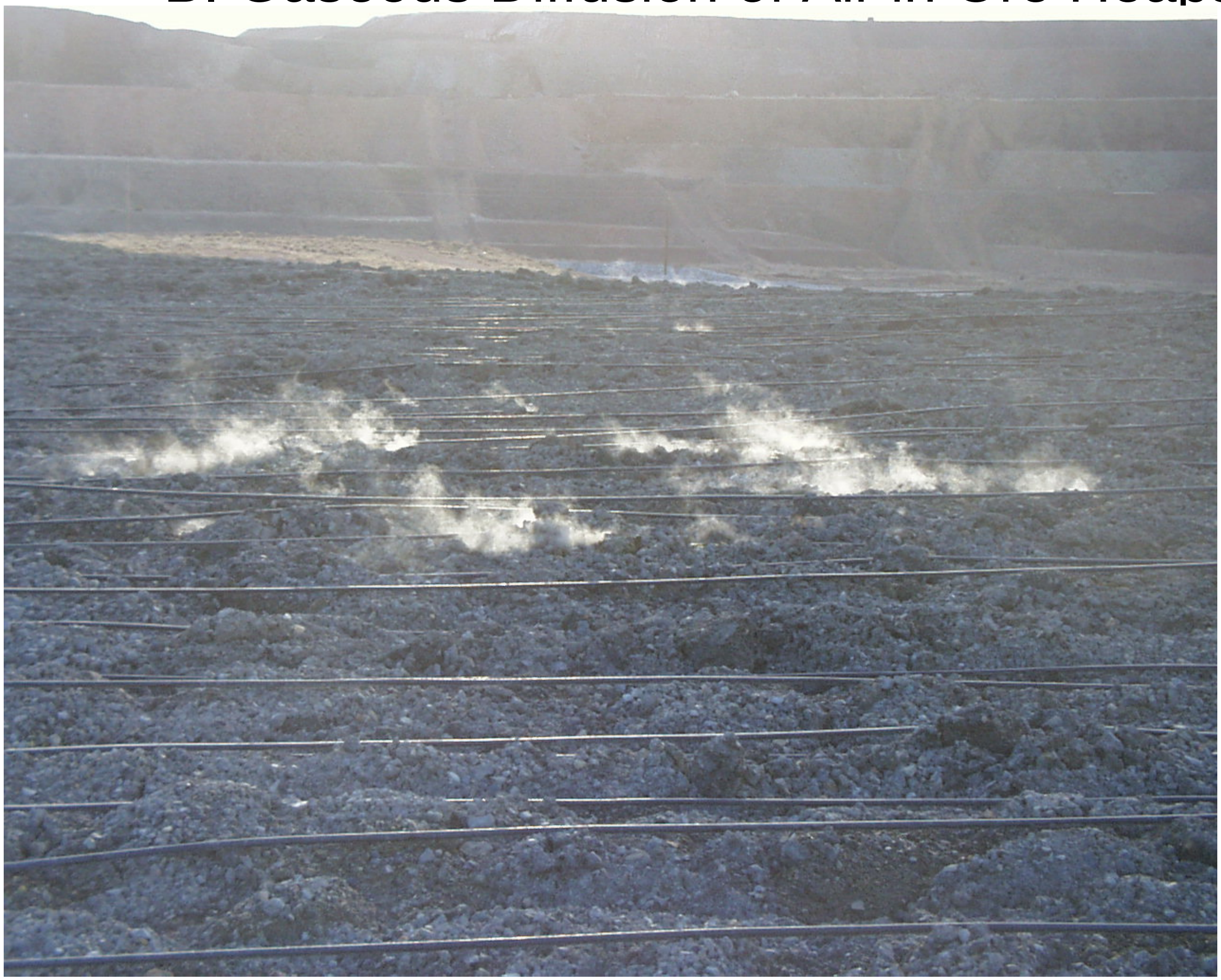


Figure 8.3. Series of fraction reacted, *F*, profiles computed by mixed kinetics/diffusion at six-month intervals for heap biooxidation of an ore with 2.0 wt pct pyrite and 20 μm pyrite grains, $v_g = 0.30$ (Bartlett and Prisbrey, 1996).

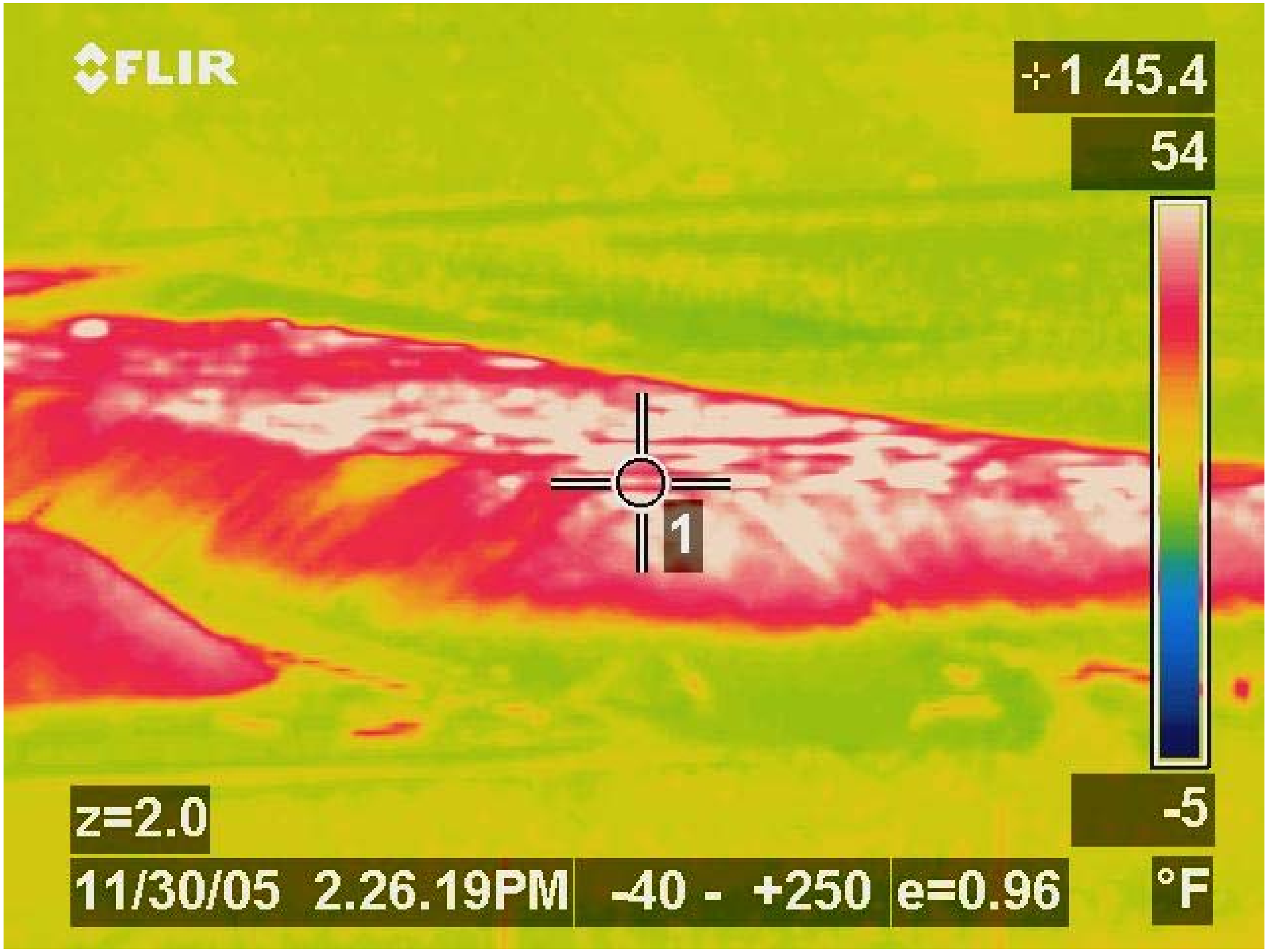
Air Flow Example: Biooxidation

B. Gaseous Diffusion of Air in Ore Heaps



Air Flow Examples: Biooxidation

F. Bioheap Energy Balance and Temperature Control

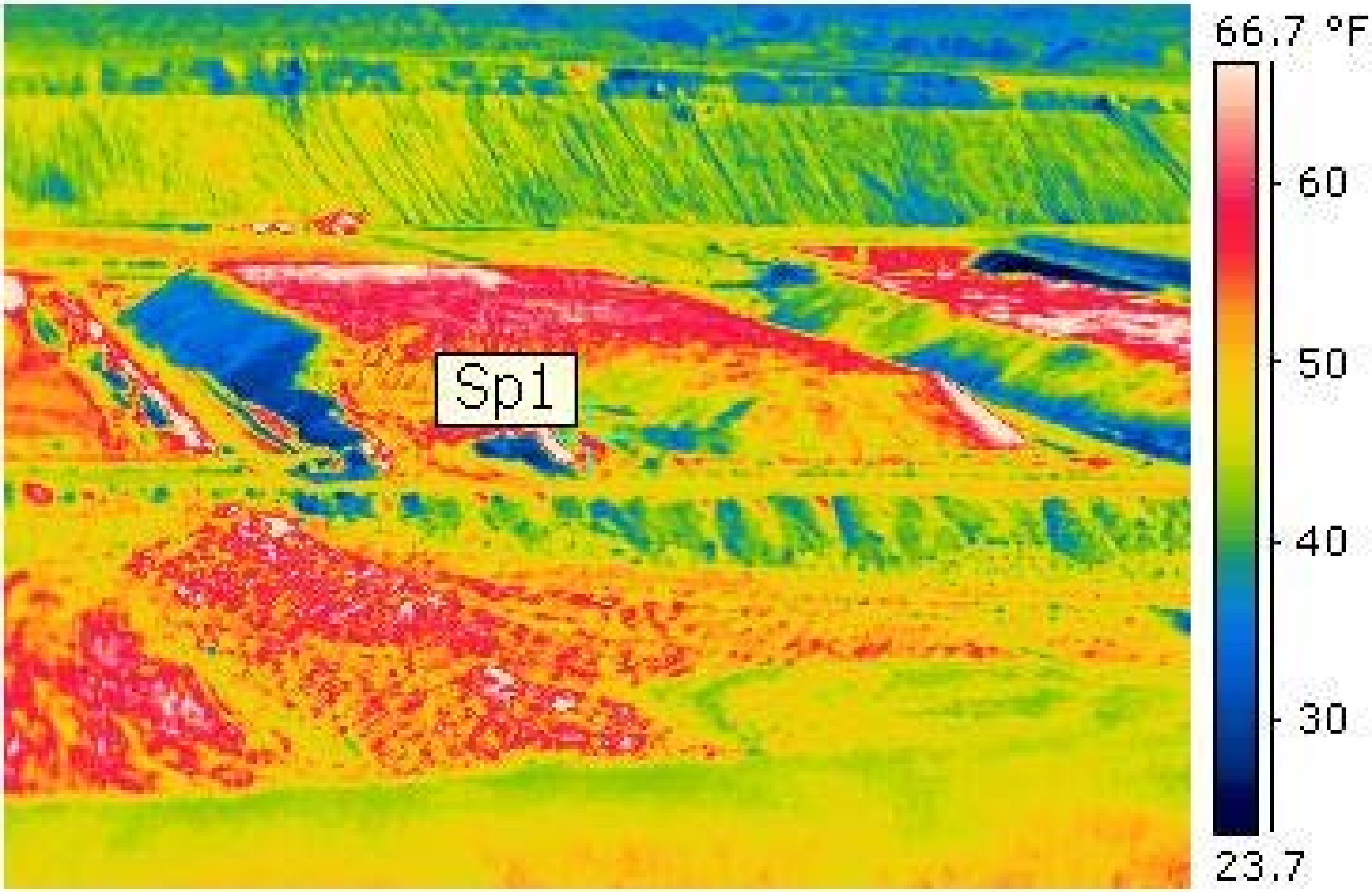


Air Flow Example: Biooxidation

B. Gaseous Diffusion of Oxygen in Ore Heaps

Air Flow Example: Biooxidation

G. Forced A ir Ventilation of Ore Heaps



Air Flow in Piles

C. Vertical Air Flow by Natural Air Advection

- Air velocity through a heap is limited by ore permeability and pressure gradient simplified by Darcy's Equation

$$u_g = \frac{k_i}{\mu_g}\left(\frac{dp}{dx}\right) = \frac{k_i}{\mu_g}\left(\frac{\Delta p_H}{H}\right), \quad (8.2)$$

where Δp_H is the pressure change from bottom to top of a dump or heap of height H, and μ_g is the gas (air) viscosity. This equation is also useful in

- Small pressure gradient, so air flow is laminar
- Flow due to change in buoyancy due to the decrease in density (PV = nRT)

Air Properties

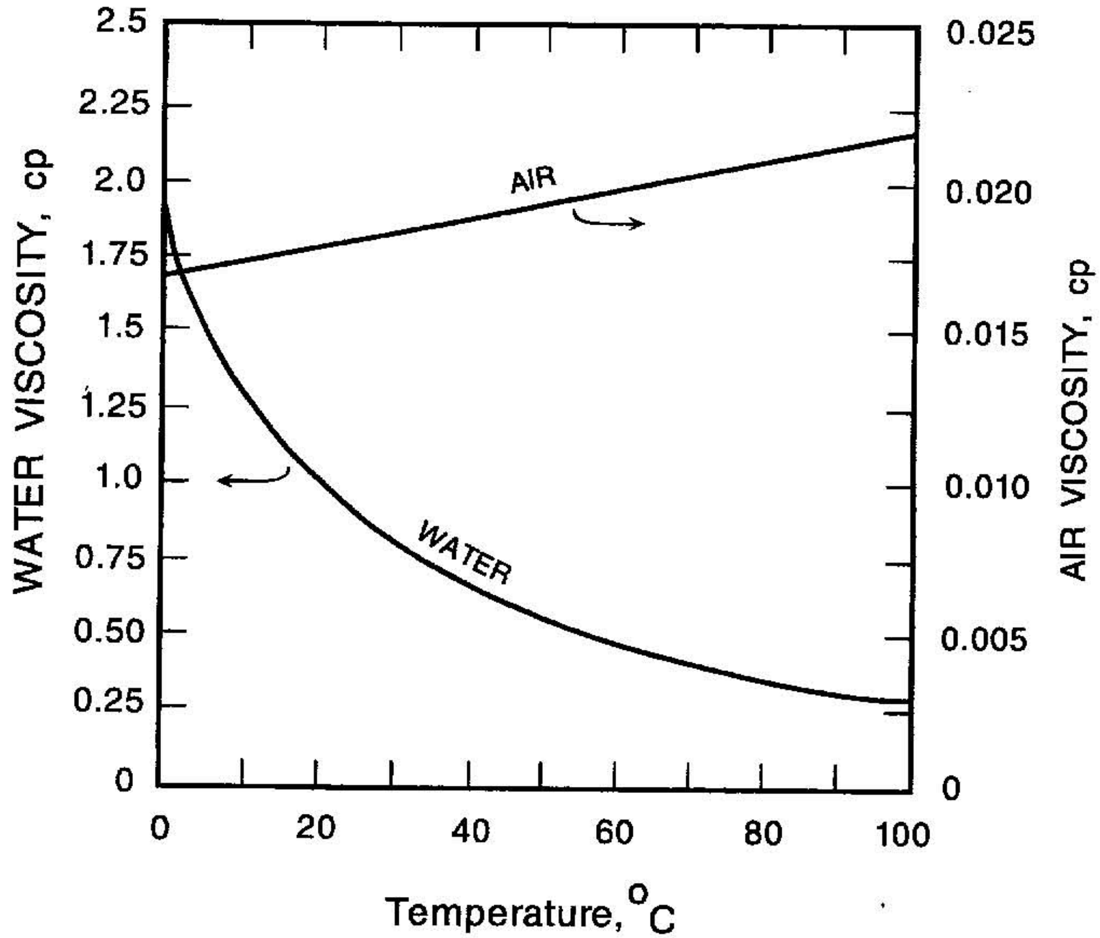


Figure 7.4. Temperature dependence of dynamic viscosities of water and air at 1 atm pressure (Bird et al., 1960).

Air Flow in Piles

C. Vertical Air Flow by Natural Air Advection

- Air velocity is a function of the change in air density
  - Air becomes saturated with water vapor from the contact with the wet heap
  - Air heated from the thermal mass of exothermic sulfide oxidation or change in temperature
  - Air loses oxygen due to chemical and biological processes

Air Flow in Piles

C. Vertical Air Flow by Natural Air Advection

- Air velocity depends on the change in air density
- Average pressure gradient in the heap:

$\Delta p_H/H$, is

$$\frac{\Delta p_H}{H} = g(\rho_0 - \rho_H), \tag{8.3}$$

where g is the gravitation constant and ρ_0 and ρ_H are the gas densities at the bottom and top of the heap respectively. Substituting values for the gas densities using the perfect gas law yields

$$\frac{\Delta p_H}{H} = \frac{g p_t}{R}\left[\frac{\mathrm{MWG}_0}{T_0} - \frac{\mathrm{MWG}_H}{T_H}\right], \tag{8.4}$$

where p_t is the total ambient gas pressure, R is the gas constant, MWG_0 is the molecular weight (g/mole) of the ambient air (STP) and T is the absolute temperature. MWG_H is the molecular weight of the air leaving the heap at STP. MWG_H differs from MWG_0 because of an increase in

Air Flow in Piles

Vertical Air Flow by Natural Air Advection

- Diffusion kinetics controlled by
  - Water vapor saturation
  - Solution in void space
  - Channeling parallel to dump angle of repose 37º
  - Compaction and impermeable zones
  - Salts and evaporates fill in voids and micropores
  - Ponding on the surface & perched water table
  - Heating from exothermic reactions & Loss of dissolved oxygen by chemical/biological reactions if present.

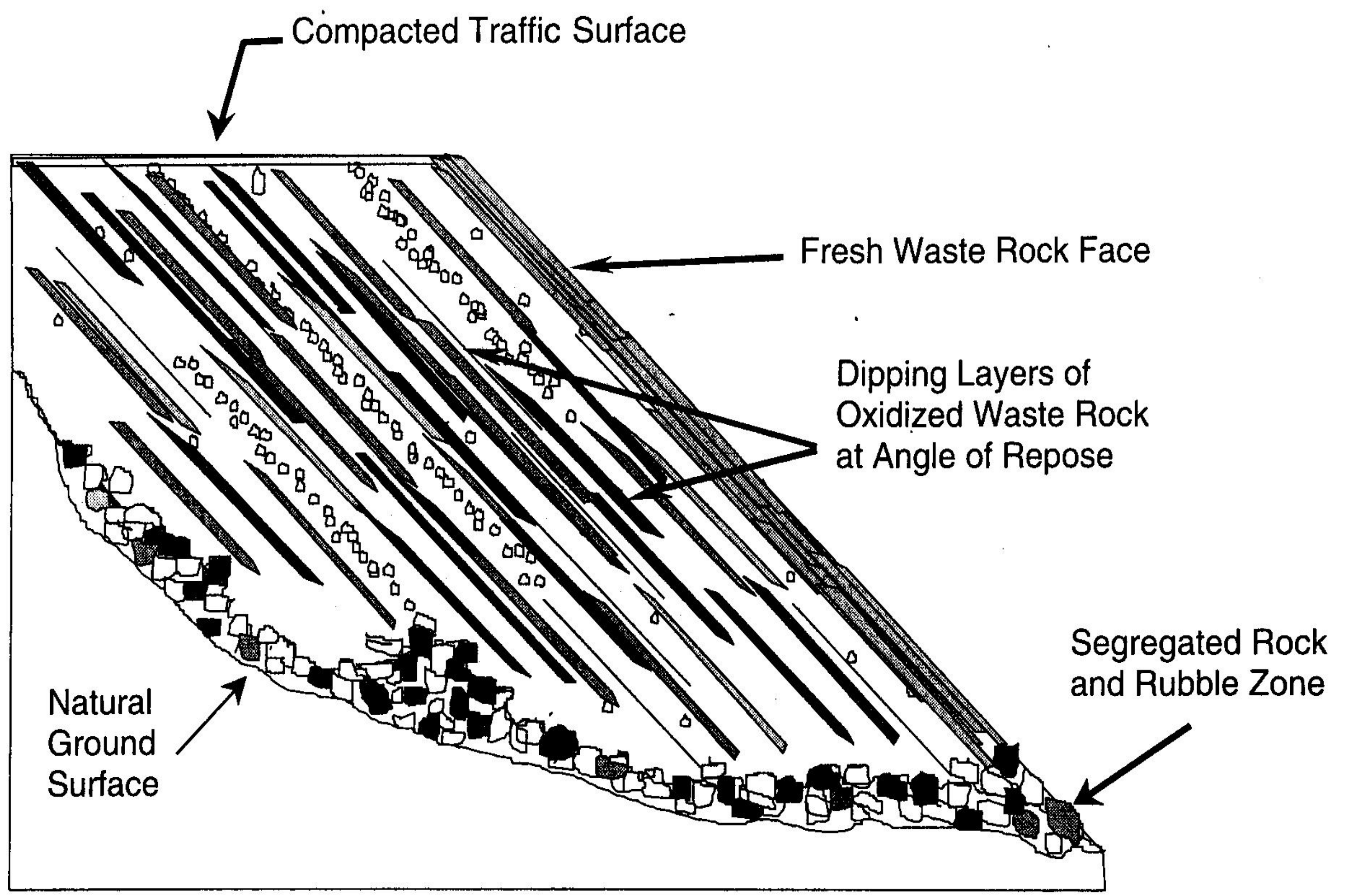
Air Flow in Piles

D. Air Flow by Natural Advection from the Sloping Sides of Ore Heaps

- Air flow into toe of heap and channels upward
  - Segregation of dumped ore
  - Few fines
- Modeling air flow
- Bottom of heap has higher permeability due to segregation of boulders and few fines allows air to travel farther under the dump prior to turning up

Air Flow in Piles

C. Vertical Air Flow by Natural Air Advection



Permeability

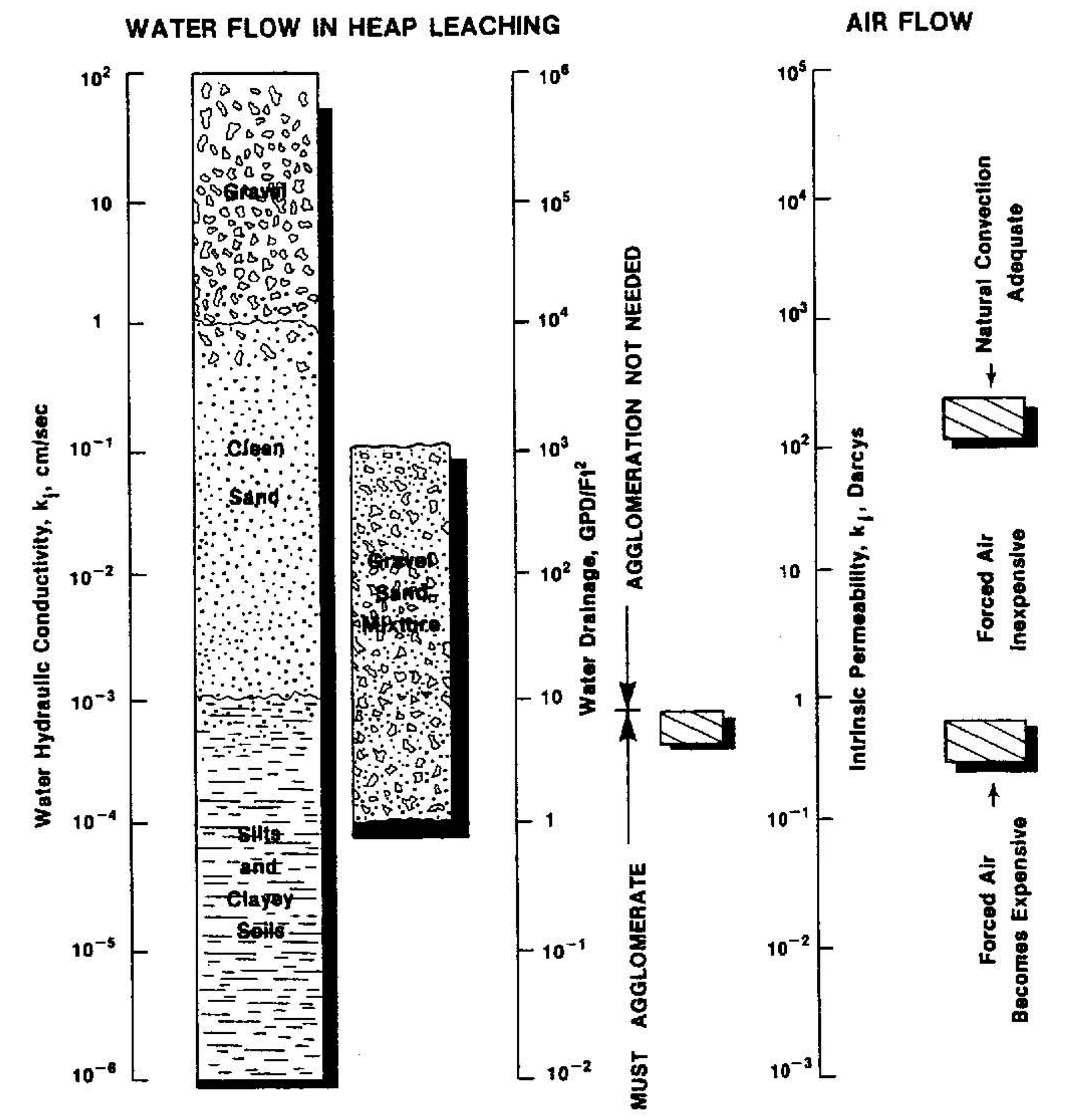


Figure 7.9. Fragmented rock matrix mixtures and permeability.

Air Flow in Piles

D. Air Flow by Natural Advection from the Sloping Sides of Ore Heaps

- Good permeability required (100,000 Darcy) at 45^{o}C for 1 year biooxidation (found in wet coarse gravel) and several years for permeability of 10,000 Darcy
- Normal heaps 10 to1,000 Darcy
- Permeability is the media (void spaces) not the solution
- Clay and fines reduce permeability even more and reduce air flow

Air Flow in Piles

C. Vertical Air Flow by Natural Air Advection

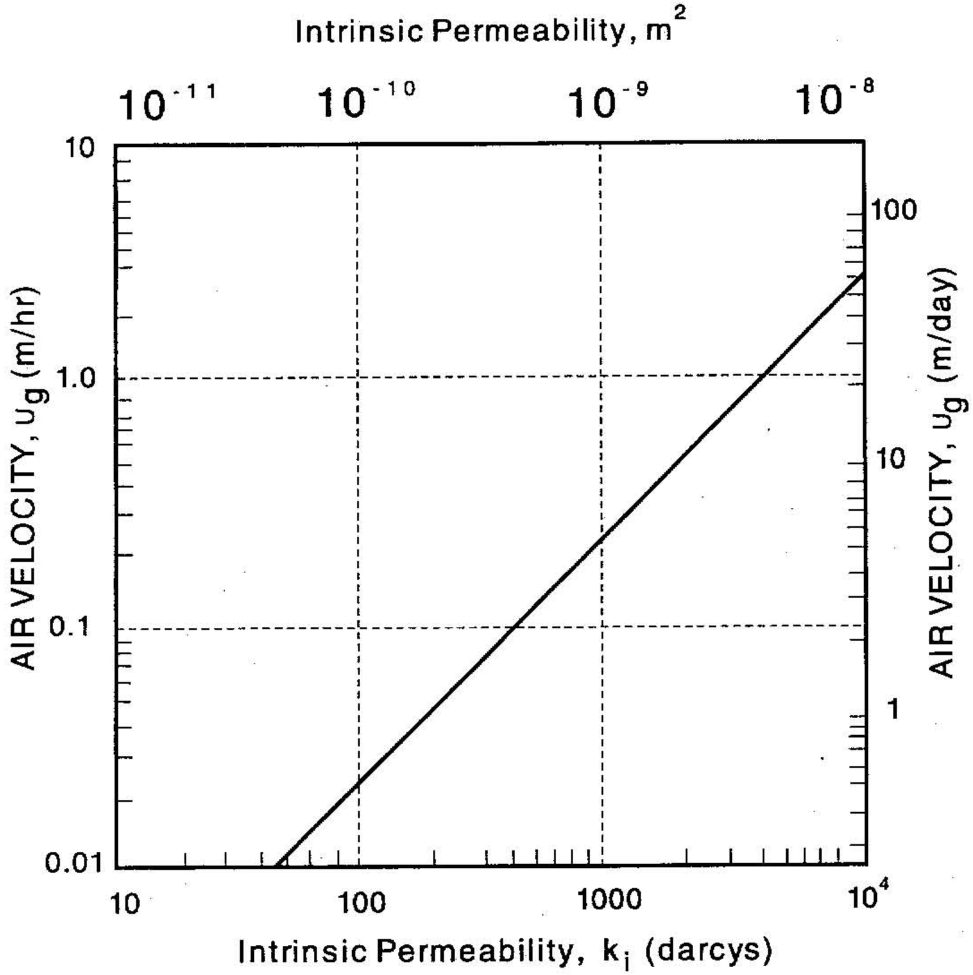
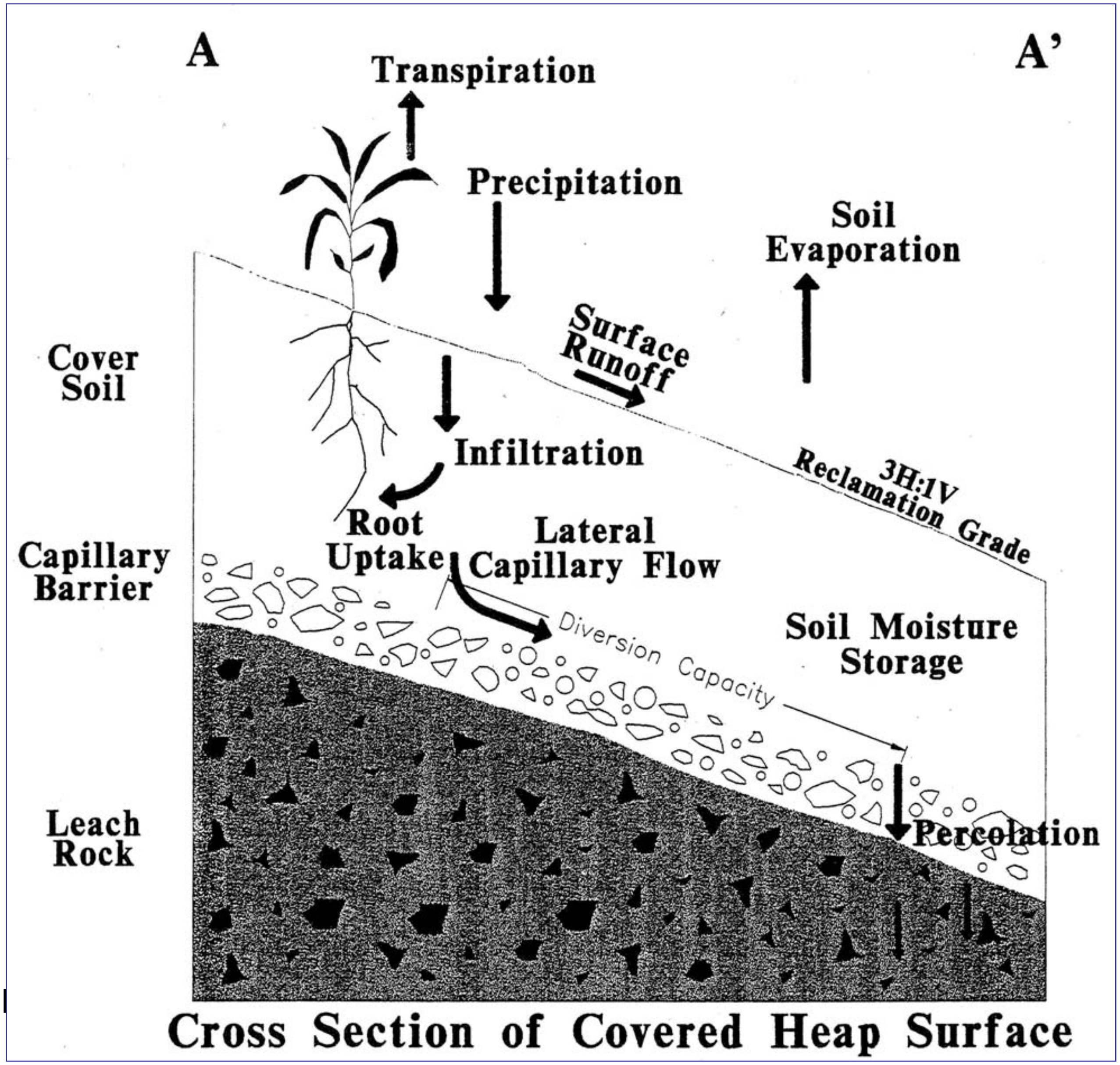


Figure 8.4. Natural advection limiting vertical air velocities and intrinsic permeability for: $T_H - T_0 = 20°C$ and 3% residual O_2 in the exhausted air.

Soil Covers



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Sponge Theory

Sponge Theory

- In areas of Negative Pan Evaporation
- Allow the sponge (pile) to dry out in the summer
- Allow the sponge (pile) to absorb the meteoric water during events

Hypothesis:

- If the pile can be dried out during the summer then the pile will absorb the meteoric water with no discharge.

Meteoric Water Flow

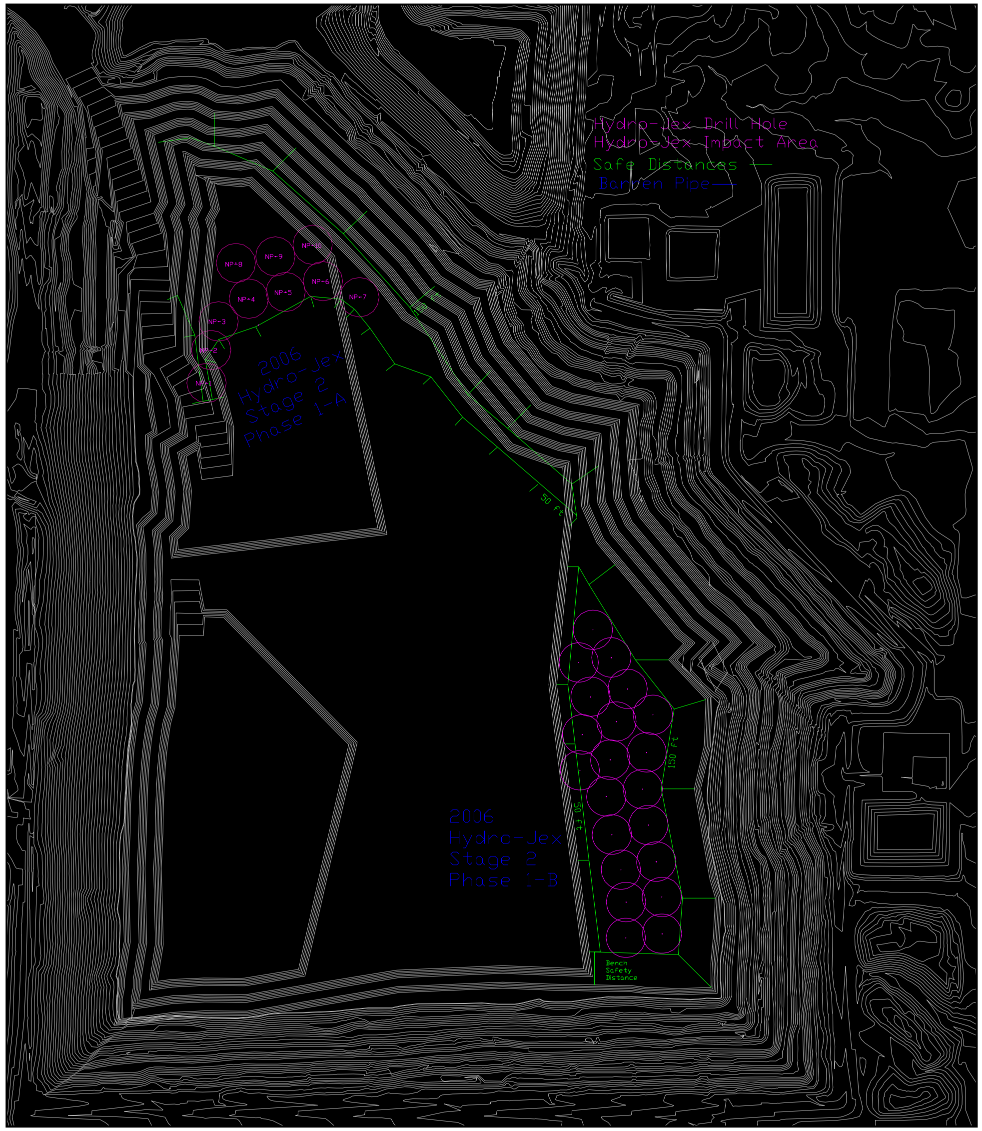
- Fill capillaries – no flow
- Percolation – flow less than local hydraulic conductivity
- Solution Flooding flow more than local hydraulic conductivity
  - Flooding always proceeds upward from a bottleneck
  - Local flooding channels excess solution laterally to find a path of high hydraulic conductivity

Hydro-Jex Operational Data

- Inject over 200,000+ gal/zone (7,500 m^3) of solution, plus.
- Improve the permeability to 100 ft+ radius.
- Long after injection, the uncovered well has observed high humidity and a wet well casing.

Hydro-Jex Operational Data

HJ Pattern.



Dry-Jex

- InJection and **Ex**haust
- US Patent underway
- Designed to dry out piles
- Uses Green Technology
- Disclose May 19, 2014 @

Innovations of Heap Leach, Tails and Waste Rock Management, UNR

References

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- http://water.epa.gov/drink/contaminants/#Inorganic

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