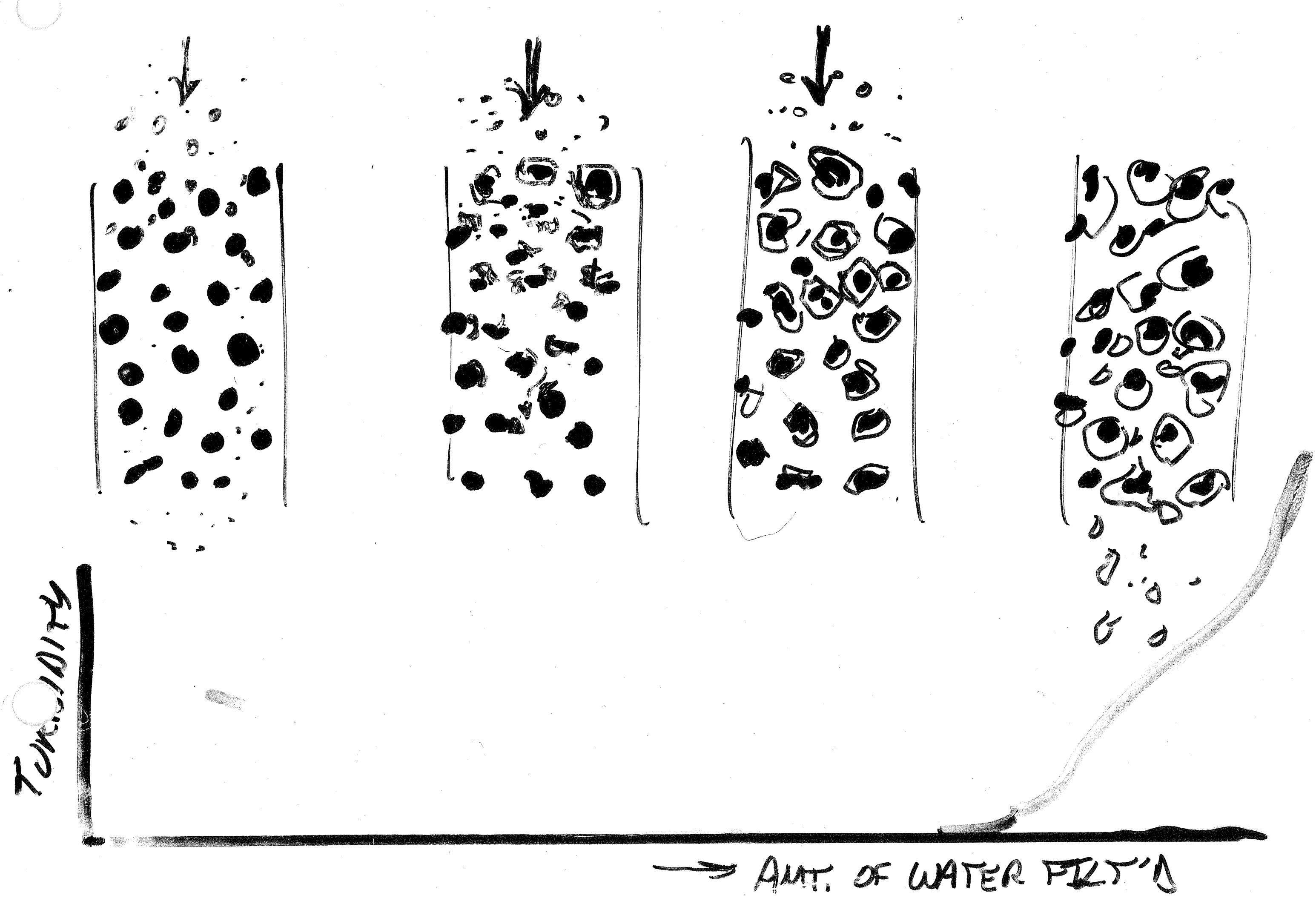
GRAVITY GRANULAR-MEDIA FILTRATION

- STRAINING
- INTERCEPTION
- FLOCCULATION
- SEDIMENTATION



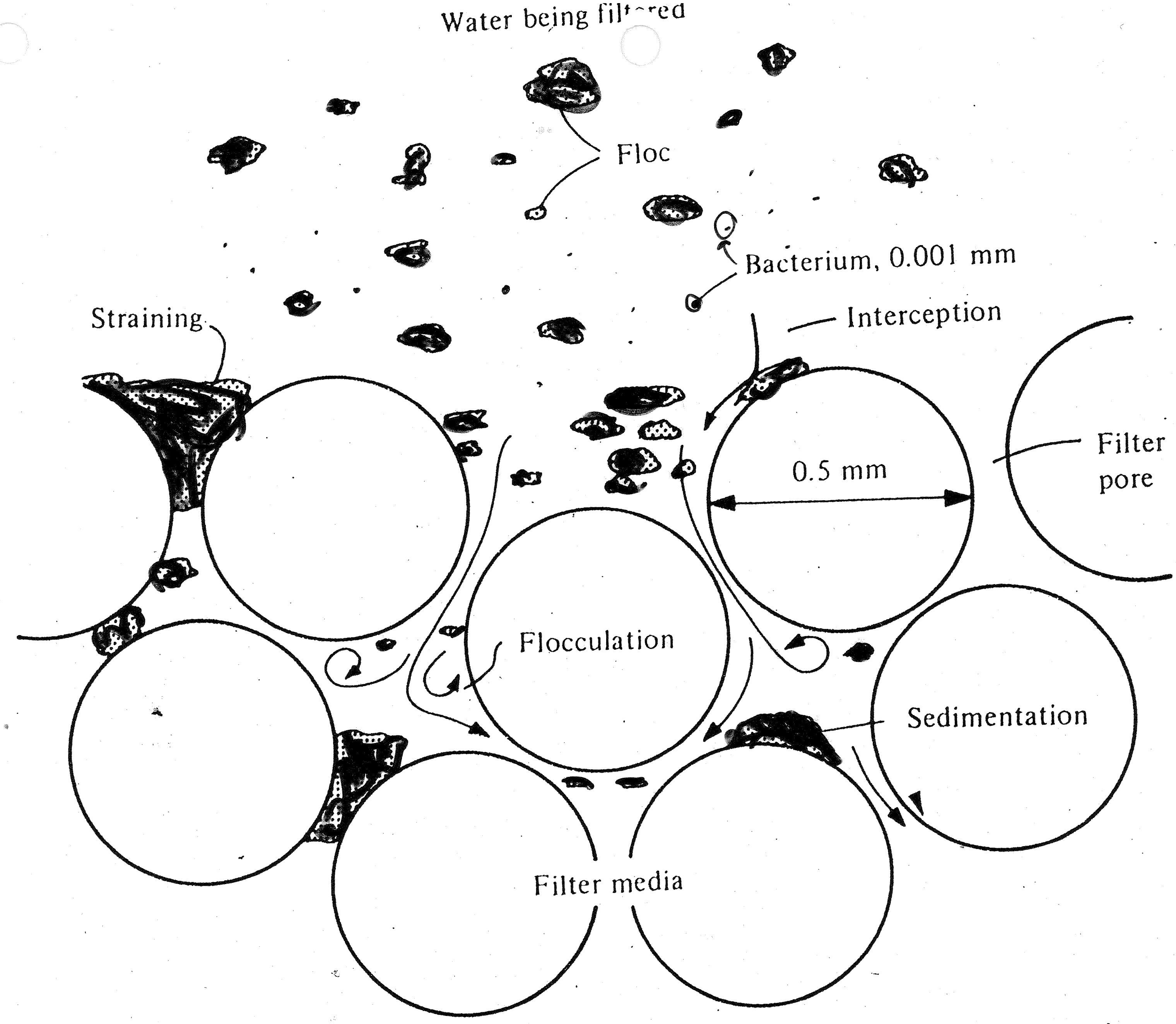
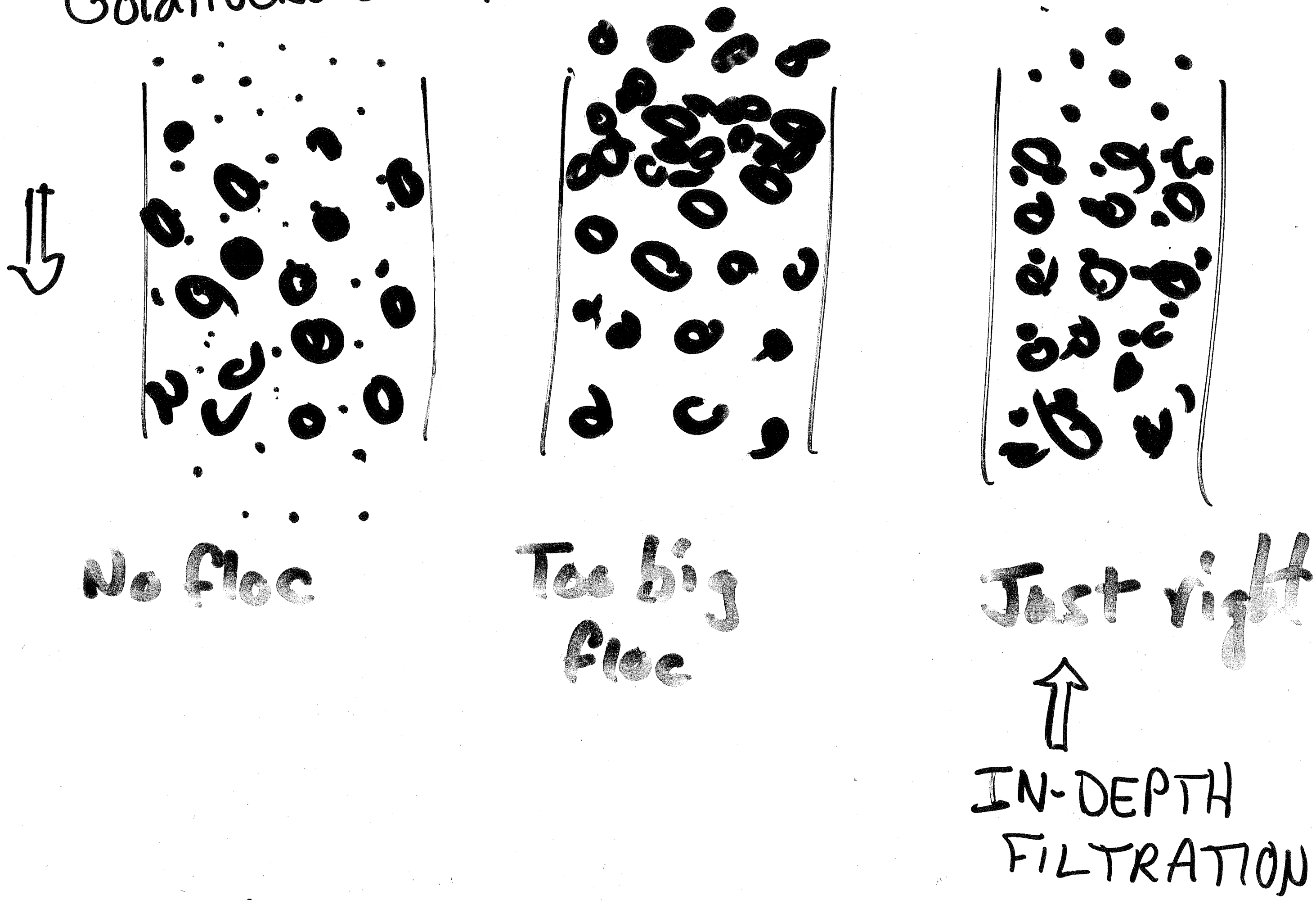


Figure 10.26 Schematic diagram illustrating straining, flocculation, and sedimentation actions in a granular-media filter.

Goldilock's and the Three Clarifiers



Esp. important now
↳ that we need filtration to get rid of Giardia cysts & Cryptosporidium

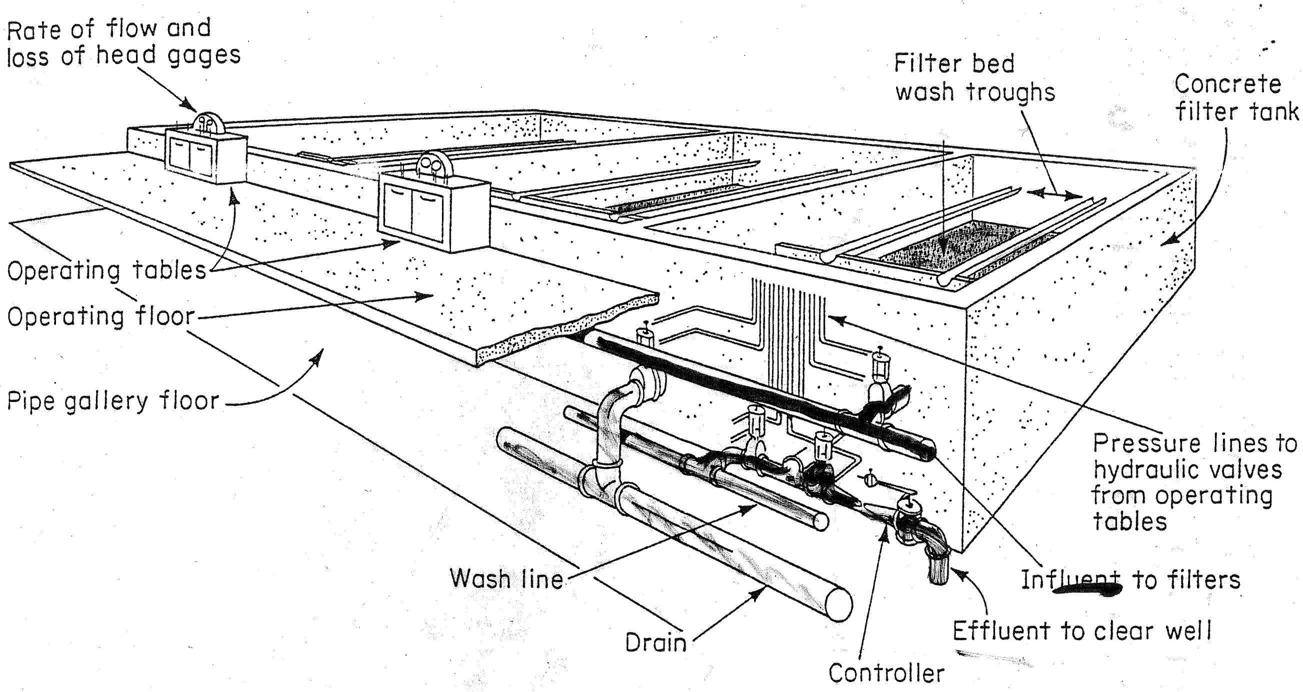


Fig. 1 Battery of three filters.

Pretreatment Effects

The traditional rapid-sand filter, containing sand of 0.5 mm effective size, 24 to 30 in. thick, operating at a 2 gpm/sq ft filtration rate, is not effective in clarifying water that has not received prior treatment. Figure 2, based on data from Chicago and Montreal, shows that rapid-sand filters operated on unflocculated water were unable to produce water meeting the USPHS drinking water standard of five turbidity units (Jackson units—j. u.) when the raw water turbidity exceeded 15. Because of this, flocculation of water prior to filtration is almost always employed. In most cases flocculation has been followed by sedimentation to reduce the quantity of material applied to the filter.

The most important characteristics of the flocculated water applied to filters are: (1) the completeness of the flocculation and (2) the strength of the flocs. If, due to deficiencies in plant facilities or underdosage of coagulant, the fine particles are not all entrapped in the floc, the filters will be unable to remove them. This will be so even with small-diameter media, low filter rates, thick beds, etc. Variations in such parameters have little effect on filter effluent quality when flocculation is insufficient. Because

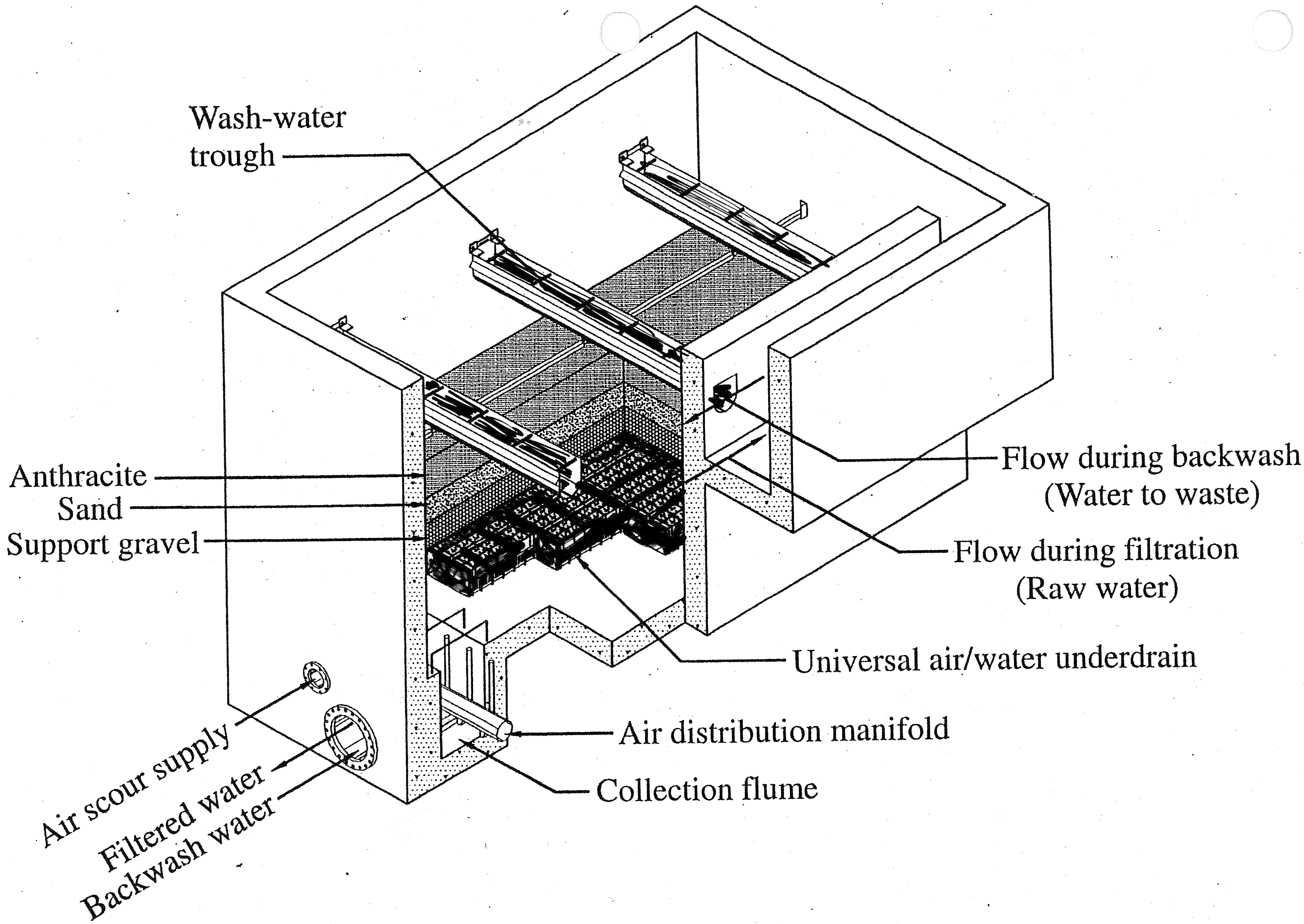


Figure 10.29 Cutaway view of a gravity-filter box with water and air piping, wash-water troughs, and dual-media filter supported on a plastic block underdrain. (Courtesy of the F. B. Leopold Company, Inc.)

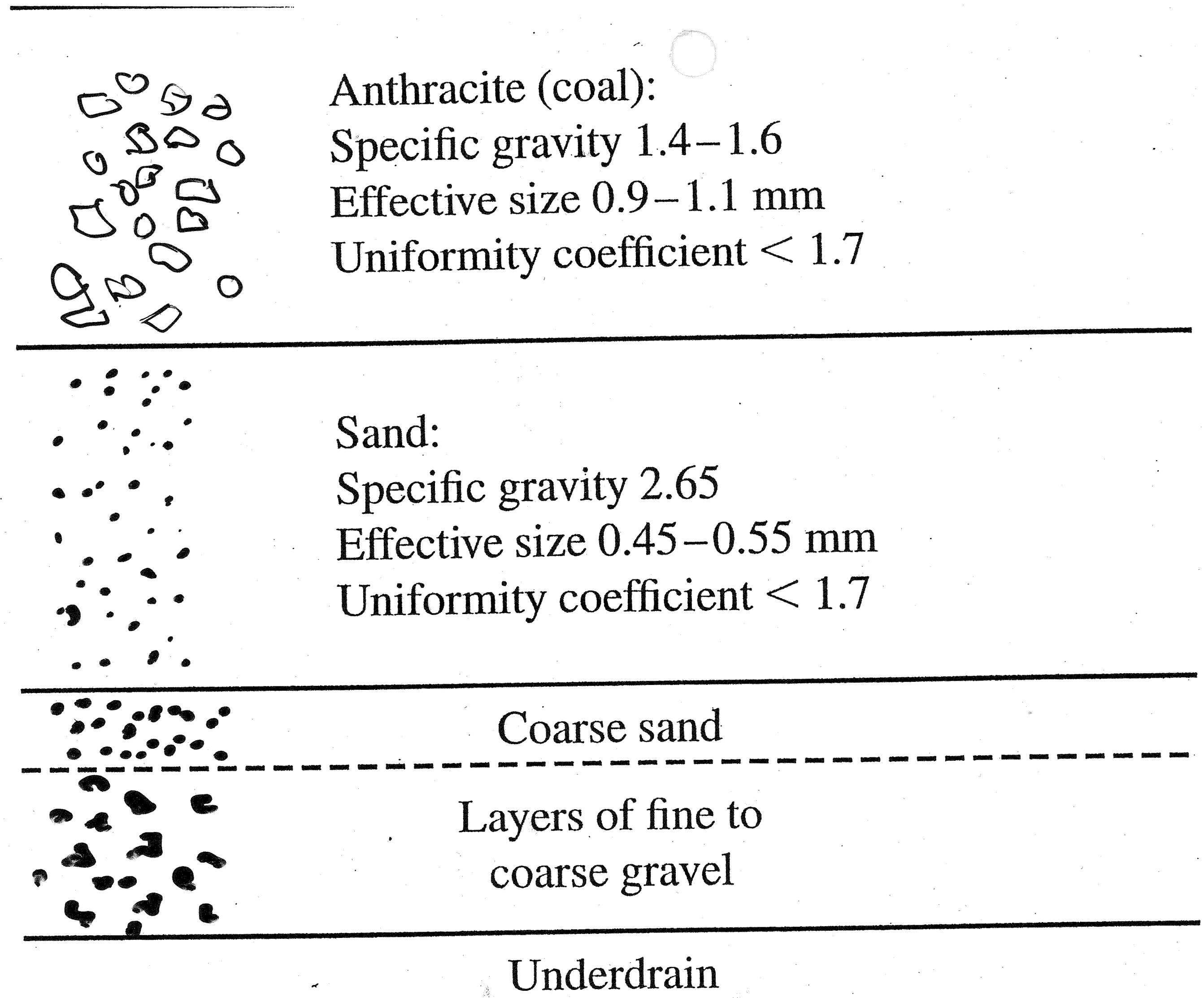
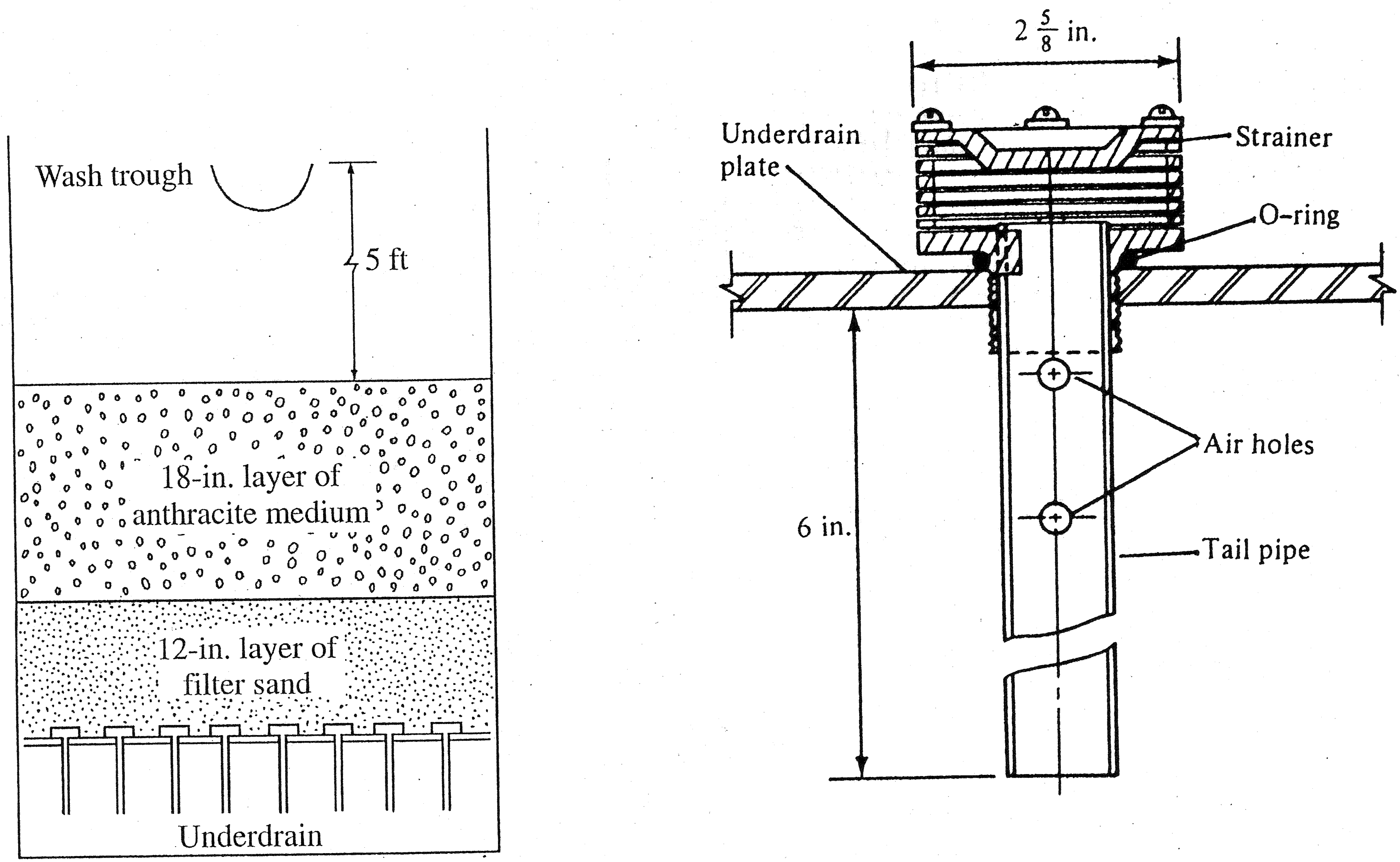


Figure 10.30 Cross section of the media in a coal–sand dual-media filter and supporting gravel layer showing typical grain sizes, specific gravities, effective sizes, and uniformity coefficients.



(a) (b)

Figure 10.32 Underdrain system for air scouring and water backwashing of a granular-media filter. (a) Cross section of the filter. (b) Detail of the air-water nozzle. (Courtesy of General Filter Co., Ames, IA.)

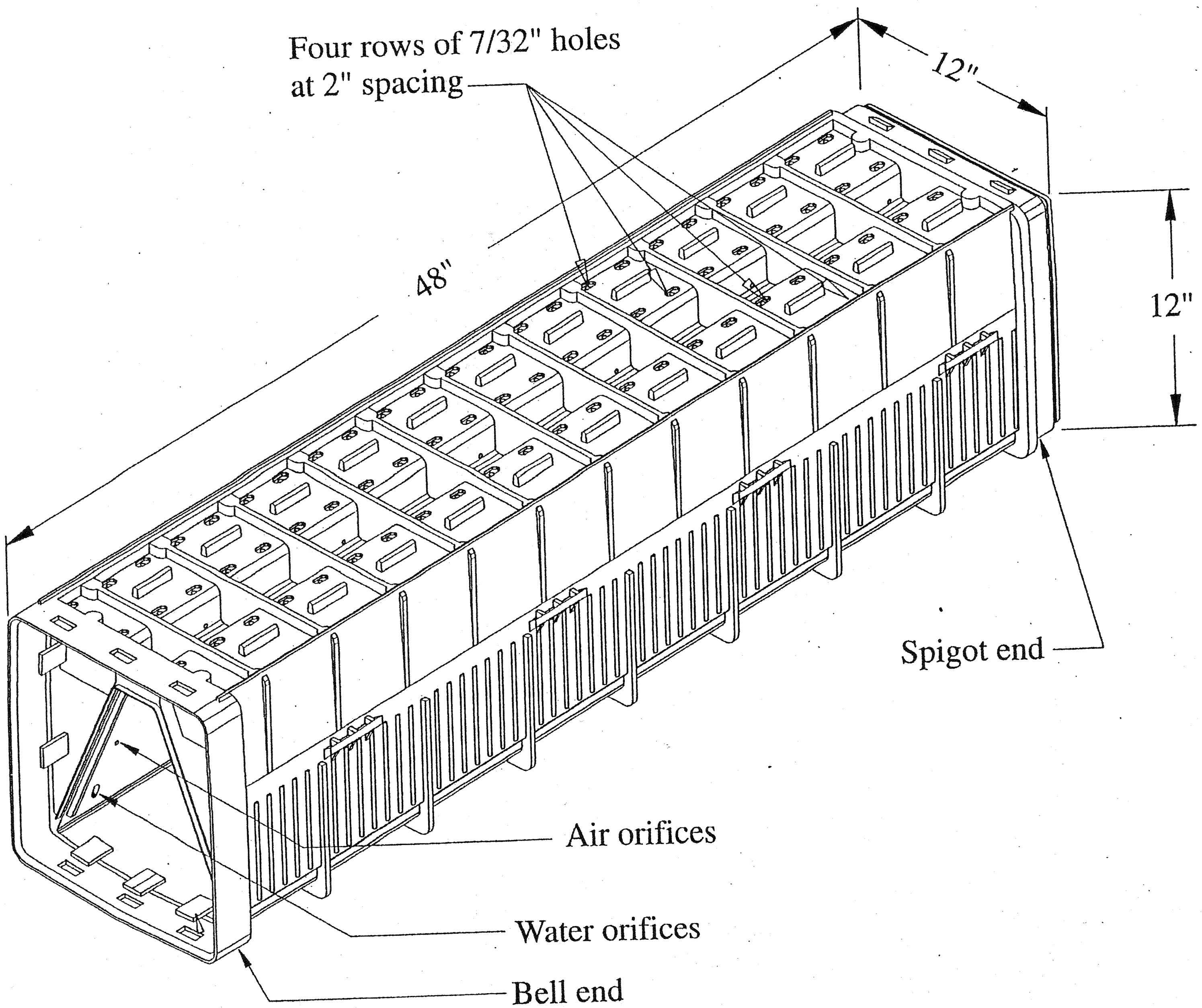


Figure 10.31 High-density polyethylene underdrain block with dual-

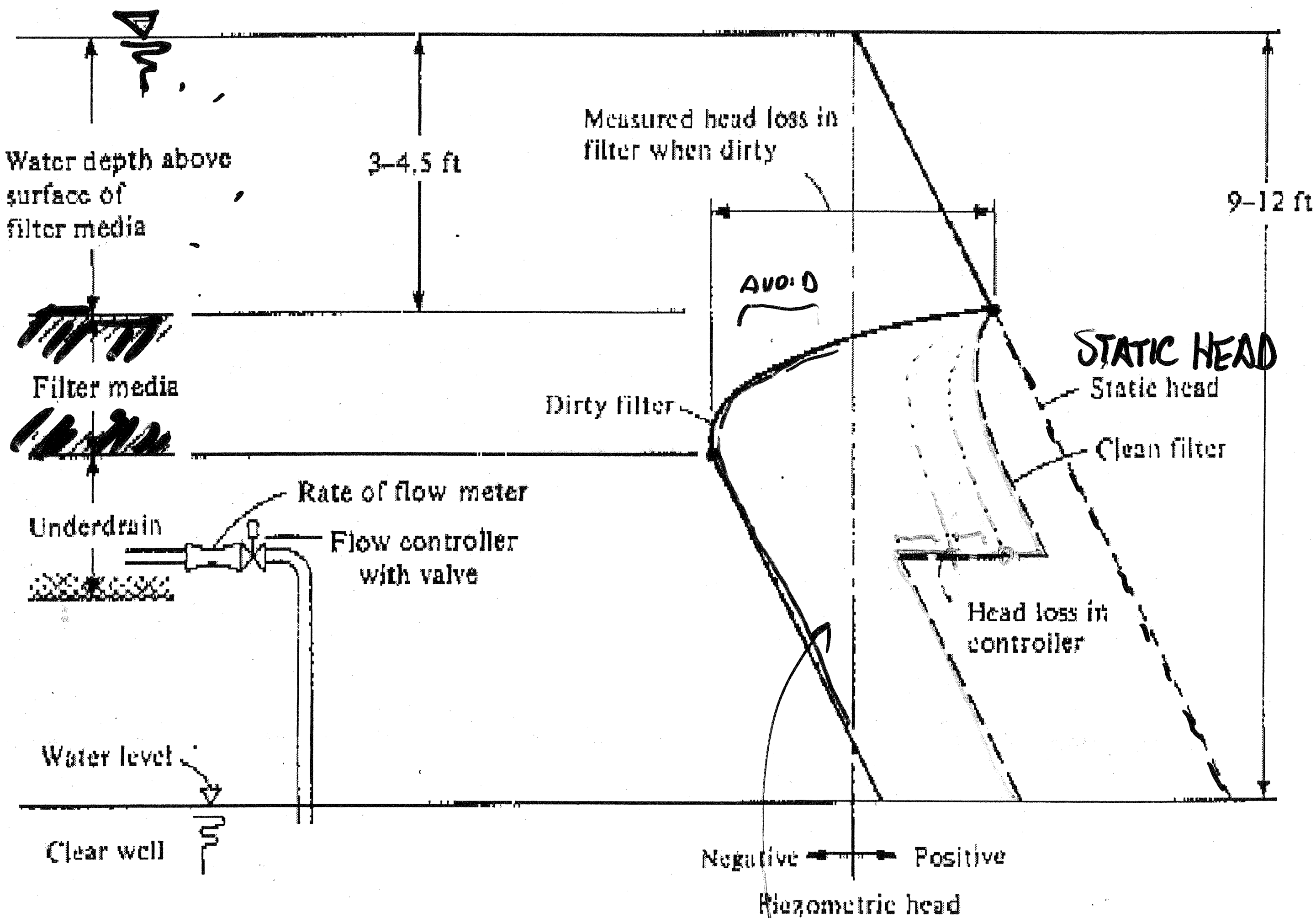
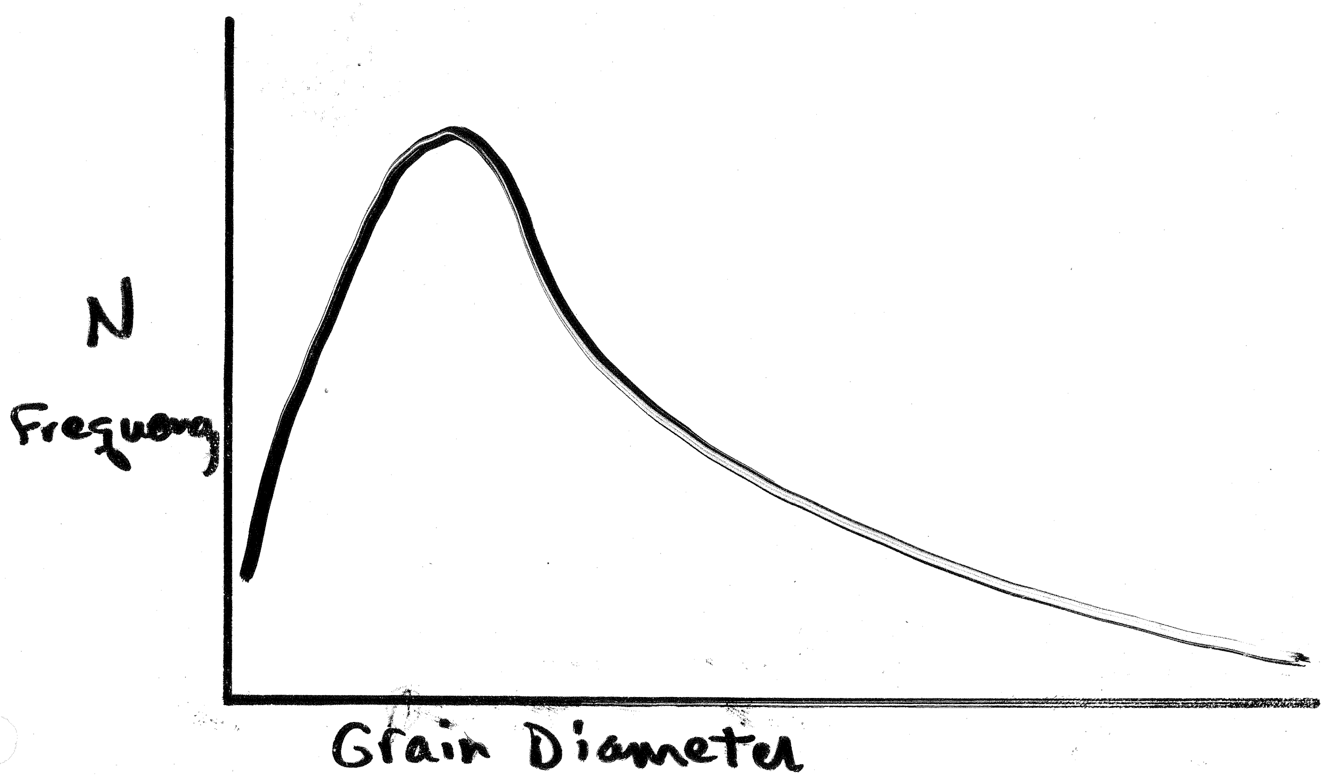
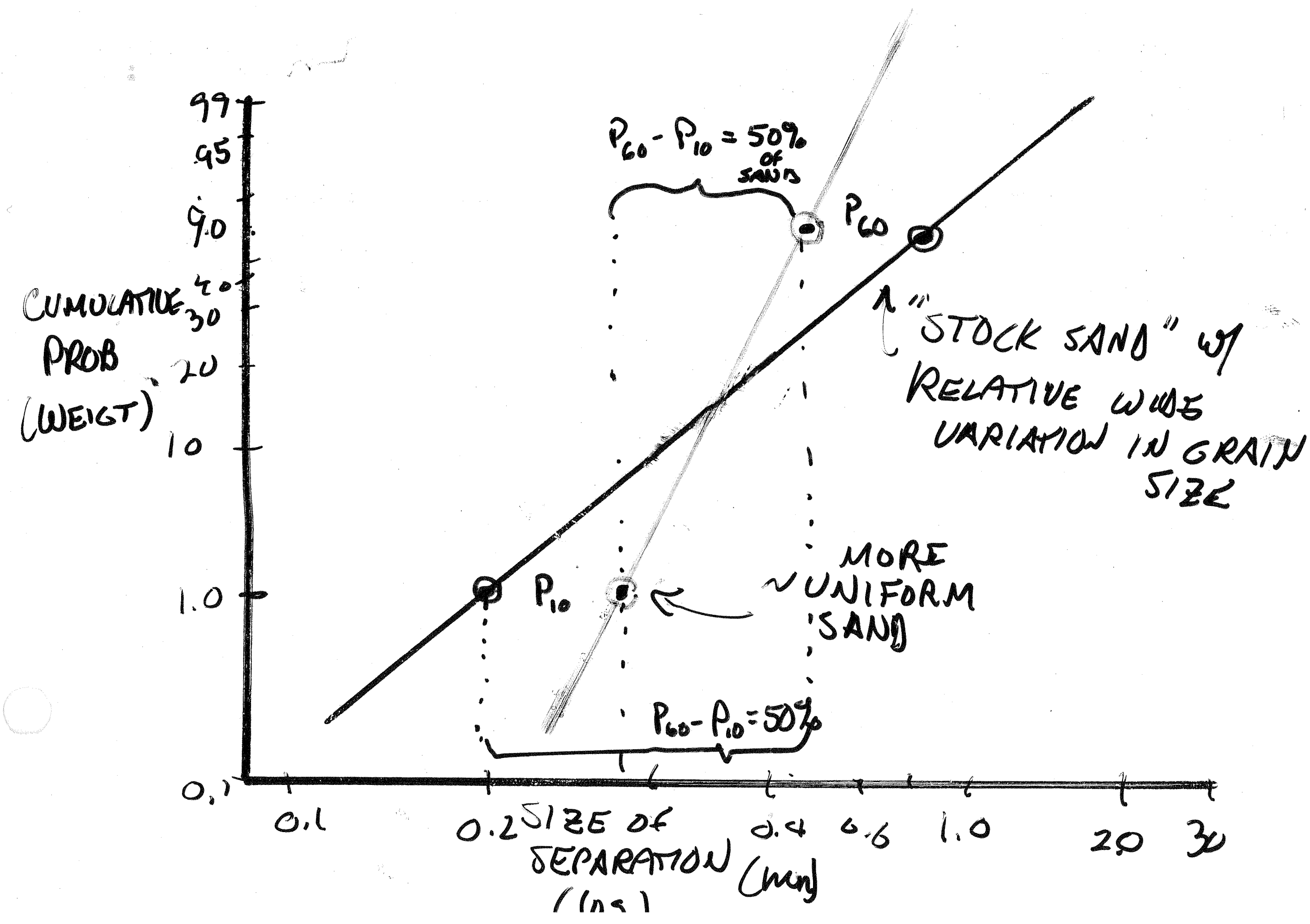


Figure 10.34 Piezometric head diagrams through a gravity filter system operated by control of the rate of flow.

Negative head "suctioning" the water thru the filter bed

SAND SIZE DISTRIBUTION





SAND SIZE

$$\text{Eff. size} = ES \equiv P_{10}$$

size (mm) corresponding
to smallest 10%
(10th percentile)

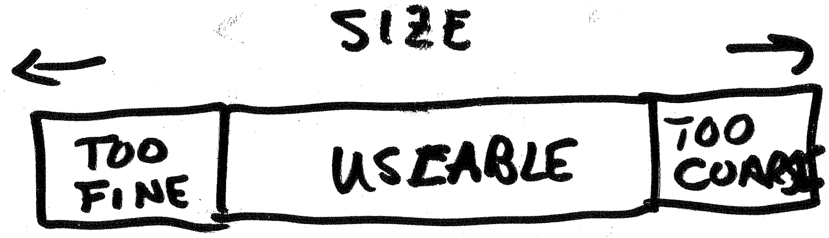
$$\text{Uniformity Coeff} = \mathcal{U} \equiv P_{60}/P_{10}$$

Can use $\mathcal{U}$ to extrapolate to other
size fractions

E.g. $d_{90} = d_{10}\,\mathcal{U}^{1.67}$

Note also: 50% of sand lies between

d_{10} and d_{60}



$$P_{use} + P_f + P_c = 100$$

All sand between P_{10} & P_{60} (specified) is useable (and this is 50% of spec. sand)

FOR STOCK sand can only use the part that corresponds to usable part of spec sand

$$P_{use} = 2(P_{st60} - P_{st10})$$

STOCK SAND WILL HAVE $P_{st10} > P_{10}$ (10%-ile)

BUT CAN ACCEPT 10% of those fines (by definition of P_{10})

$$P_f = P_{st10} - 0.10\, P_{use} = P_{st10} - 0.2(P_{st60} - P_{st10})$$

P_f ↑ TOO FINE

P_{st10} ↑ NOMINAL DESIRED MIN

$0.10\,P_{use}$ ↑ 10% of usable sand we can tolerate below P_{10}

TOO COARSE:

$$P_c = 100 - P_f - P_{use}$$

$$= 100 - \left[P_{st10} + 0.2\left(P_{st60} - P_{st10}\right)\right] - 2\left(P_{st60} - P_{st10}\right)$$

$$\boxed{P_c = 100 - P_{st10} - 1.8\left(P_{st60} - P_{st10}\right)}$$

See Ex. 14.1 in text.

Remove coarse fraction w/ SIEVES

Remove fine fraction "in situ" by backwashing at high rate to drive out fines

(Use stokes law to find backflow velocity) plot. The filter sand specifications are an ES (d_{10}) of 0.050 cm and a unifor coefficient of 1.4.

The d_{60} size is

$$d_{60} = Ud_{10} = 1.4(0.05 \text{ cm}) = 0.70 \text{ cm}$$

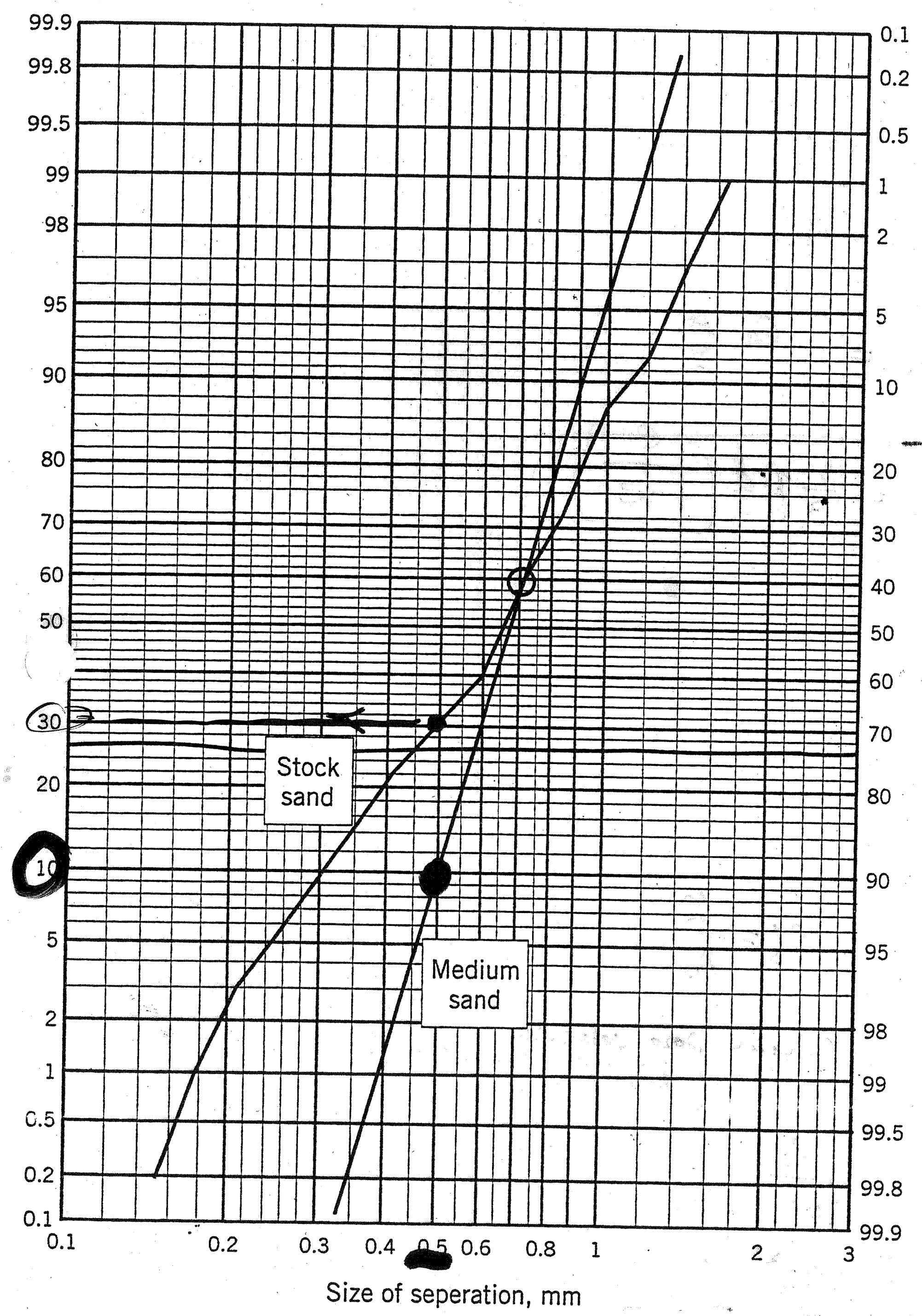


Figure 14.3 Sand grain size distribution for example.

3a) of 6.
the filter
on factor
the
operated
the work
n waste-
account
y weight
fractions
ength, l_i,
tor (Eq.
(.16)

corresponding characteristics for the Ottawa sand are 0.55
The sphericities of the sand and anthracite are 0.95 and C
of 1.5 for anthracite and information in Table 14.3 for
Perform the calculation for a temperature of 10°C and surf
(4 290 gal/ft²/d).

The P_{60} sizes for the media are

anthracite: $d_{60} = Ud_{10} = 1.5(0.85 \text{ mm}) = 1.27 \text{ mm}$

sand: $d_{60} = Ud_{10} = 1.35(0.55 \text{ mm}) = 0.74 \text{ mm}$

The media size distributions are obtained by plotting t
medium on probability paper and drawing a straight line
size distribution data obtained from these plots are tabul

Size Distribution of Media

Percentiles (by weight) of media	d_1 mm	d_2 mm	Geometric Mean size[a] mm = $\sqrt{d_1 \cdot d_2}$
Anthracite			
5–20[b]	0.72	1.00	0.85
20–40	1.00	1.18	1.09
40–60	1.18	1.27	1.22
60–80	1.27	1.53	1.39
80–95[b]	1.53	1.81	1.66
Sand			
5–20[b]	0.51	0.61	0.56
20–40	0.61	0.68	0.64
40–60	0.68	0.74	0.71
60–80	0.74	0.82	0.74
80–95[b]	0.82	0.93	0.87

[a]The mean size is the geometric mean size because a probability plot is used. $d = \sqrt{d_1 d_2}$.
[b]The 5th and 95th percentile sizes were chosen to represent the extreme sizes.

The headloss calculations are performed by calculati
calculating the term after the summation sign in Eq. (14.16
are shown for each layer in the table of media sizes. The
each medium.

HEAD LOSS

Head Loss in a PIPE

$$h_L = \underset{\text{friction factor}}{f} \; \underset{\text{Length \& Diam}}{\frac{L}{D}} \; \underset{\text{velocity}}{\frac{v^2}{2g}}$$

Eq. 14.9

CUT TO THE CHASE...

CARMAN-KOZENY EQN

$$\frac{h_L}{L} = f\,\frac{3(1-e)v_s^2}{4g\psi d e^3} = \underbrace{f_f\left(\frac{1-e}{e^3}\right)\frac{v_s^2}{\psi d g}}$$

Eq. 14.12

e = porosity = $\frac{\text{void vol}}{\text{filter vol}}$

$1-e$ = $\frac{\text{vol. of particles}}{\text{filter vol}}$

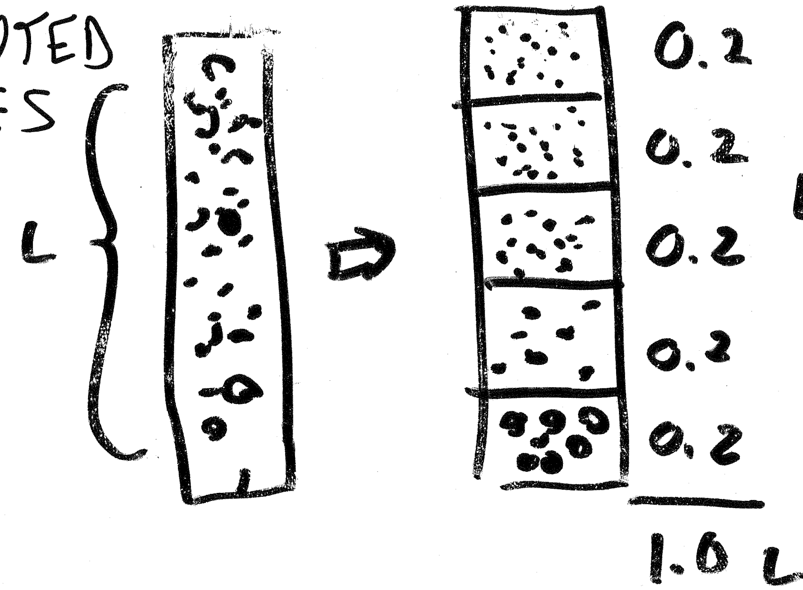
$v_s = \frac{Q}{A_s}$ SURFACE LOADING RATE

ψ = sphericity $\left(\frac{A_s/V \text{ spher}}{A_p/V_{par}}\right)$

d = particle diameter

HEADLOSS CALCULATIONS

FOR DISTRIBUTED GRAIN SIZES



$$h_L^{TOT} = \sum h_{L_i} = \left[\left(\frac{1-e}{e^3}\right)\frac{v_s^2}{\psi g} L\right] \cdot \sum f_{f_i}\frac{x_i}{d_i}$$

FRICTION FACTOR: $f_{f_i} = 150\,\frac{1-e}{Re} + 1.75$

So, for given: bed depth: L

sphericity: ψ

surf. loading rate: $V_s = \frac{Q}{A_s}$

Find the summation of the friction and size factors

~~FINDING k EXPERIMENTALLY~~

HEAD LOSS THRU A FILTER

Eqns 10.26 & 10.27

↑ UNIFORM (10.26)   ↑ GRADED (10.27)

~~10.27~~ 14.15
$$\frac{h}{l} = \frac{36 k \nu (1-\varepsilon)^2 V}{g \varepsilon^3 \psi^2} \sum_{i=1}^{n} \frac{P_i}{d_i^2}$$

$k = 5.0$

ν = kin. viscosity

ε = porosity

V = approach velocity $\left(\frac{Q}{A}\right)$

ψ = sphericity

P_i = fraction of grains in any layer

d_i = geometric mean

$= \sqrt{d_{max} \cdot d_{min}}$

ψ = sphericity (known/given)
$v_s = \frac{Q}{A_s}$ = surf. loading rate
e = porosity (given)

ρ = density (T)
μ = viscosity (T)

$$\boxed{R_e = \frac{\rho v_s \psi d}{\mu}}$$

$$\boxed{f_f = 150\frac{1-e}{Re} + 1.75 \quad (k)}$$

Headloss Calculations

FROM PRIOR TABLE Percentiles (by weight) of media	Mean size mm	Re[a]	f_{fi}	x_i/d_i[b] mm^{-1}	$f_{\mathrm{fi}}\frac{x_i}{d_i}$ mm^{-1}
Anthracite					
5–20	0.85	1.02	67.6	0.236	15.9
20–40	1.09	1.31	53.2	0.184	9.8
40–60	1.22	1.48	47.4	0.163	7.7
60–80	1.39	1.68	41.8	0.143	6.0
80–95	1.66	2.01	35.3	0.120	4.2
				Total	43.7
Sand					
5–20	0.56	0.82	111.5	0.359	40.0
20–40	0.64	0.95	96.8	0.311	30.0
40–60	0.71	1.04	88.0	0.282	24.8
60–80	0.74	1.15	80.3	0.257	20.6
80–95	0.87	1.28	71.8	0.229	16.4
				Total	131.9

[a]The porosities of anthracite and sand are 0.55 and 0.40, respectively, from Table 14.3.
[b]The fractions, x_i, were taken to be 0.20 for each mean size.

$$h_L = h_{La} + h_{Ls} = \left(\frac{1-e_a}{e_a^3}\right)\frac{v_s^2}{\psi_a g}L_a\sum\left(f_{fai}\frac{x_{ai}}{d_{ai}}\right) + \left(\frac{1-e_s}{e_s^3}\right)\frac{v_s^2}{\psi_s g}L_s\sum\left(f_{fsi}\frac{x}{d}\right.$$

$$h_L = \frac{(1-0.55)\left[175\,\frac{\text{m}}{\text{d}}\left(\frac{1\text{ d}}{86\,400\text{ s}}\right)\right]^2(0.45\text{ m})}{(0.55)^3(0.72)(9.81\text{ m/s}^2)}(43.7\times10^3\text{ m}^{-1})$$

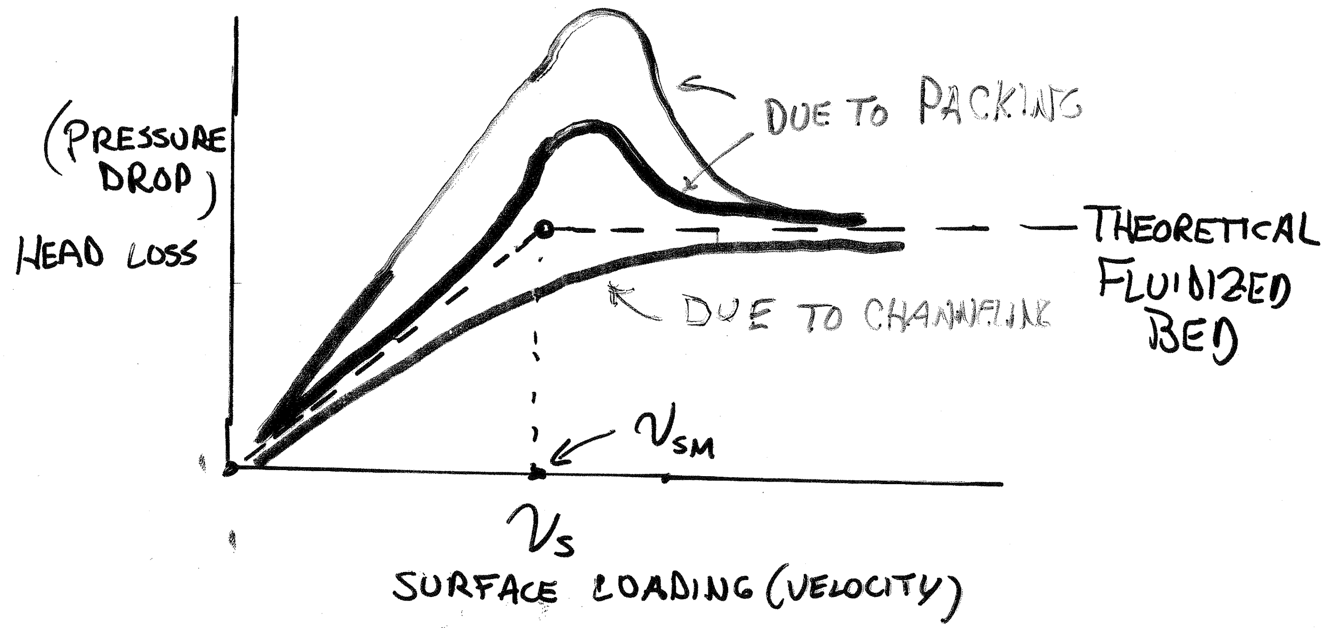
$$+\frac{(1-0.40)\left[175\,\frac{\text{m}}{\text{d}}\left(\frac{1\text{ d}}{86\,400\text{ s}}\right)\right]^2(0.30\text{ m})}{(0.40)^3(0.95)(9.81\text{ m/s}^2)}(131.9\times10^3\text{ m}^{-1})$$

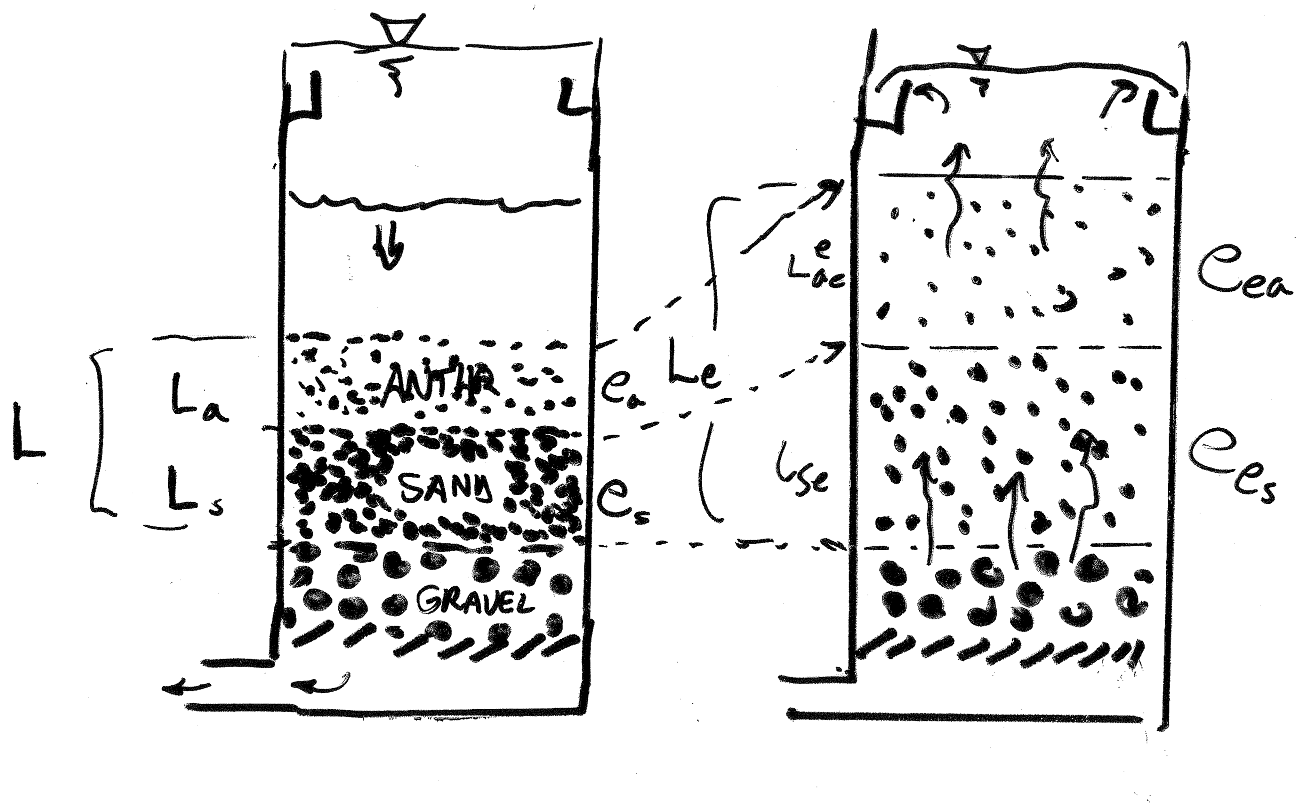
$$= 0.032\text{ m} + 0.163\text{ m} = 0.195\text{ m}$$

In U.S. units:

$$\left[\ \ldots\ \frac{\text{gal}}{}\left(\frac{1\text{ ft}^3}{}\right)\left(\frac{1\text{ d}}{}\right)\right]^2(1.5\text{ ft})$$

FILTER BACKWASHING





Uses ~ 1-5% of product water

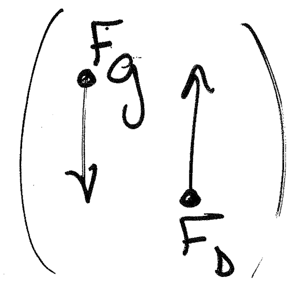
∴ → want to MINIMIZE

HEADLOSS DURING BACKWASH

$$\frac{\text{Eff. weight of medim}}{\text{Vol. of medium}} = \underbrace{(\rho_s-\rho)}_{\text{"Reduced" density}} g[1-e_e]$$

Porosity of fluidized bed

$$(\rho_s-\rho)g(1-e_e) = \frac{F_{DRAG}}{A_s L_e}$$



$F_D \propto$ HEADLOSS THRU MEDIUM
(i.e. frictional drag on water)

$$\frac{F_D}{A_s} = (\rho g)\, h_{Le}$$

$$\underbrace{(\rho_s-\rho)(1-e_e)g}_{\text{Eff. wt expanded}}\, L_e = \rho g \cdot h_{Le} = \underbrace{(\rho_s-\rho)g(1-e)}_{\text{Eff. wt. at REST}}\, L$$

* $$h_{Le} = \frac{(\rho_s-\rho)}{\rho}(1-e_e)L_e = \frac{(\rho_s-\rho)}{\rho}(1-e)L \quad \text{(Eq. 14.20)}$$

And ∴ $$\frac{L_e}{L} = \frac{1-e}{1-e_e} \quad \leftarrow (e_e = ?) \quad \text{(Eq. 14.21)}$$

CALCULATING MINIMUM BACKWASH VELOCITY

For grain diameter d

DEFINE TWO GOVERNING DIMENSIONLESS PARAMETERS

$$Re_{mf} = \frac{vL}{\nu} = \frac{\rho v_{mf} d}{\mu} = \left[\frac{\rho d}{\mu}\right] v_{mf}$$

Reynolds No. for Min. Fluidization

SOLVE FOR THIS

$$Ga = \frac{L^3 \rho (\rho_s - \rho_s) g}{\mu^2} = \frac{d^3 (\rho_s - \rho) \rho g}{\mu^2}$$

Galileo No. for particles

SemiEmpirical Expression:

$$Re_{mf} = \left[\frac{\rho d}{\mu}\right] v_{mf} = \left[(33.7)^2 + 0.0408\, Ga\right]^{1/2} - 33.7$$

FIND THIS

SOLVE FOR v_{mf}

FIND Ga

$$\boxed{\text{P.S.: USE } d = d_{90}}$$

BED EXPANSION:
What is e_e?

$$\left(\frac{L_e}{L} = \frac{1-e}{1-e_e}\right)$$

Two relationships were developed

① (a) $$Re_{filt} = \frac{\rho v_b \psi d}{6\mu(1-\underline{e_e})}$$

← FOR GIVEN v_b
get some expn'n to e_e
But ~~bat~~ not independent

(b) $$\Theta = f_f Re_f^2$$

$$\Theta = \underbrace{\left[\frac{\rho(\rho_s-\rho)g(\psi d)^3}{36\mu^2}\right]}_{\text{CONSTANT}} \cdot \frac{e_e^3}{(1-e_e)^2} \qquad \text{Eq. } 14.31$$

② REGRESSION ANALYSIS Θ vs Re_f

$$\log\left(\frac{\Theta}{6}\right) = 0.565 + 1.09 \log Re_f + 0.179 (\log Re_f)^2 - 0.004 (\log R_f)^4 - 1.5 (\log \psi)^{12}$$

eq. 14.32b

PROCEDURE:
- PICK BACKWASH VELOCITY v_b
- $\Theta = K \cdot \frac{e_e^3}{(1-e_e)^2}$ [14.31]
- $\log\left(\frac{\Theta}{6}\right) = f_{Reg}(\log Re_f) = f_{Reg}\left[\log\left[\frac{\rho v_b \psi d}{6\mu}\right] \cdot \frac{1}{(1-e_e)}\right]$