DISTRIBUTED AND OPTIMIZED SUB-SLAB VENTING (DOSSV)

Dr. L. Moorman
Radon Home Measurement and Mitigation, Inc.
Fort Collins, CO
October 30, 2023

Gary Hodgden
Midwest Radon
Olath, KS

AARST Symposium
Nashville, TN

Summary of Radon Mitigation Models

- (1) Reddy-Sextro et al. model (EPA, 1992), 2 dim, air movement through soil under foundation walls.

  Dynamics: Pressures and flows in plenum are vastly different close to pipe (turbulent), compared to far away (laminar).

- (2) Hantusch-Jacob model (T. McAlary, 2018), "Leaky aquafer": 2- dim, leaks from above & leaks from below

  Dynamics: Same comment as in (1).

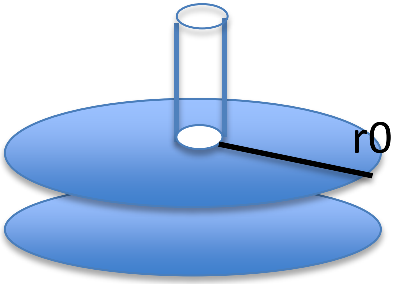
- (3) New, DOSSV proposed for new construction allows solving a much simpler 1- dim problem, Air vacuum and flow through the aggregate bed (plenum) can be calculated for any gravel or sand with known characteristics.

  Dynamics: flow is the same throughout the aggregate. (homogeneous and isotropic). (Viscous (laminar), or Transition regime)

Simplified Model of airflow dynamics in SSD RMS for Residences with Gravel Beds

T.A. Reddy, K.J. Gadsby, H.E. Black, III, D.T. Harrje, and R.G. Sextro,

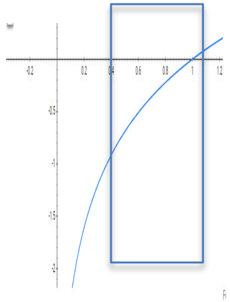
May 1992 EPA-600/R-92-090



Assumptions in the model:

1) Two parallel impermeable discs with radius r0
2) Central extraction (or pressurization) hole
3) Gravel … soil in between discs

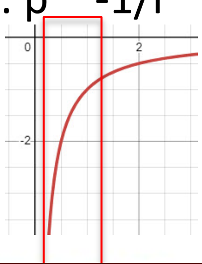
Laminar regime: p ~ ln(r/r0) + C



Re =< 1

Larger values of r, but still
r/r0 < 1
Beyond a critical circle, away from the vent pipe

Turbulent regime: p ~ -1/r



Re => 5 or 10

Smaller values of r, and
r/r0 < 1
Within a critical circle, close to the vent pipe.

From Reddy et al. 1992

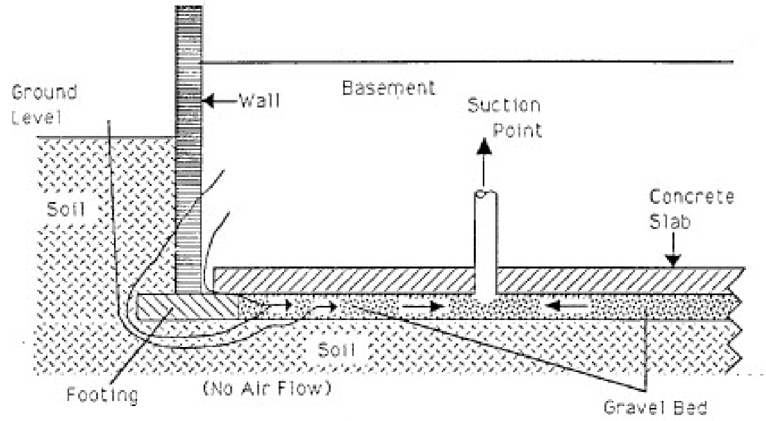


Fig. 1 Schematic of subslab air flows in a house with a gravel bed when the house is being mitigated following the subslab depressurization technique. Note that part of the air flowing through the gravel bed originates from the basement and the rest from the ambient air.

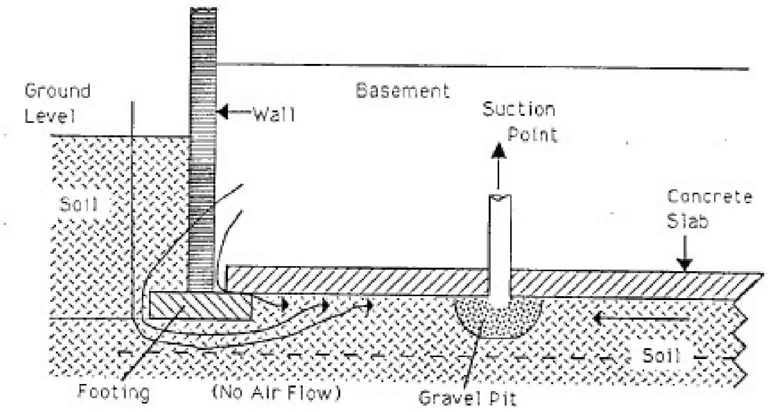
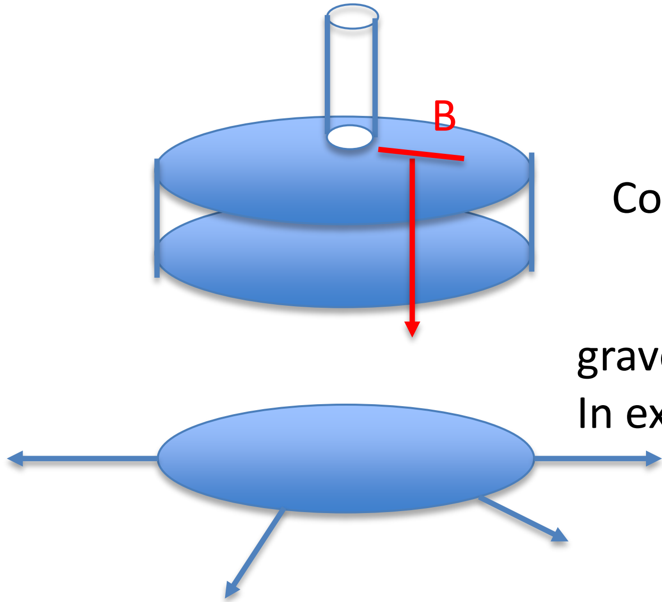


Fig. 2 Schematic of subslab air flow in a house without a gravel bed when the house is being mitigated following the subslab depressurization technique.

Indoor Environments™ 2023 - Radon and Vapor Intrusion Symposium

Summary of Research on Mitigation System design and monitoring
T. McAlary, W. Wertz, D. Mali, 2018, Myrtle Beach
SSD, ASD→SSV



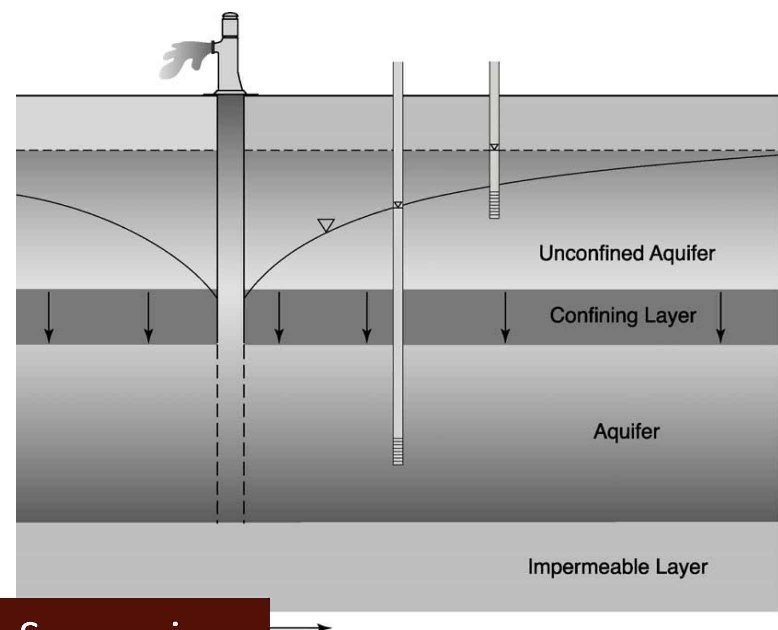
Concrete slab (b′, K′)

gravel…sand (b; K)
In extraction zone

Hantusch-Jacob Model (1955)
Laminar, and gravel, hydrodyn.

Leakance: B [L] 5.5 ft…18 ft

Transmittivity T [t] 54 ft^2/day



P(vacuum)=Qssv/(2 pi T) K_0(r/B)

Velocity= Qssv/(2 pi b n B) K_1(r/B)

Fitting the functions from the model to the experimental data allows to extract unknown parameters (B, T)
(From T. McCalary, et al. 2018)

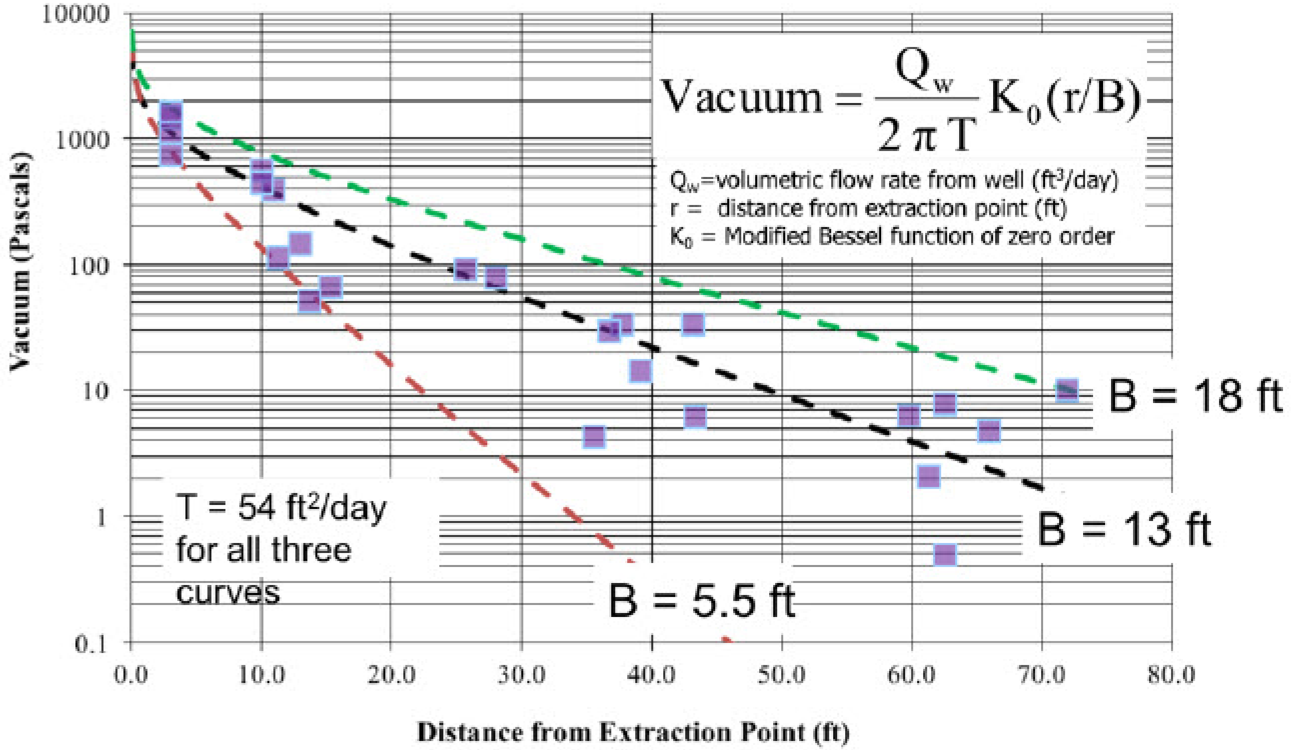
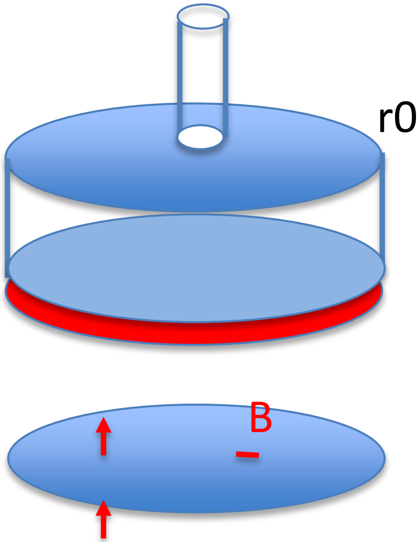


Figure (3): Comparison of vacuum vs distance measurements to profiles calculated using the Hantush-Jacob Model

Best Model For New Construction Plenum



Concrete:
B’= thickness
K’= Bulk pneumatic conductivity
B = Leakance through slab

Aggregate: gravel…sand:
T: Transmissivity in extraction zone

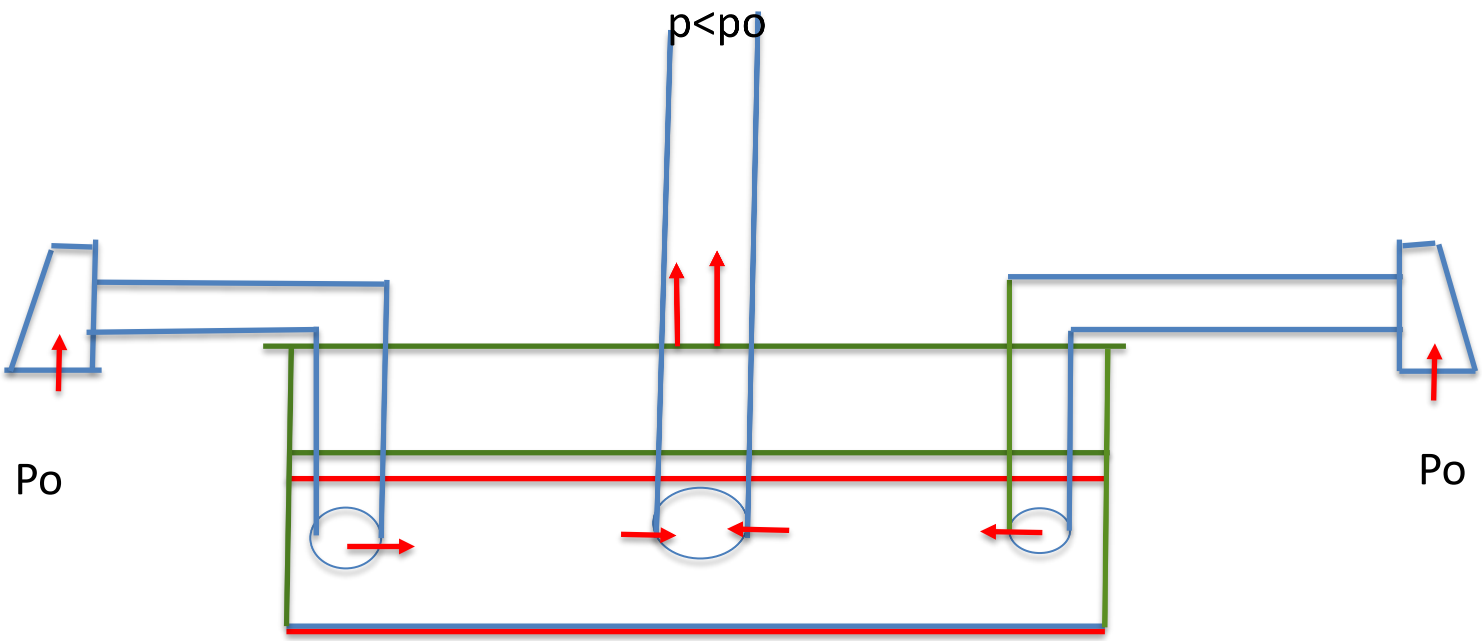
Bottom of Plenum is semipermeable with a leakage (in B)

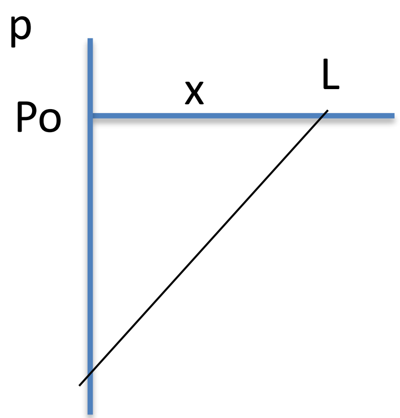
P(vacuum)=Qssv/(2 pi T) K_0(r/B)

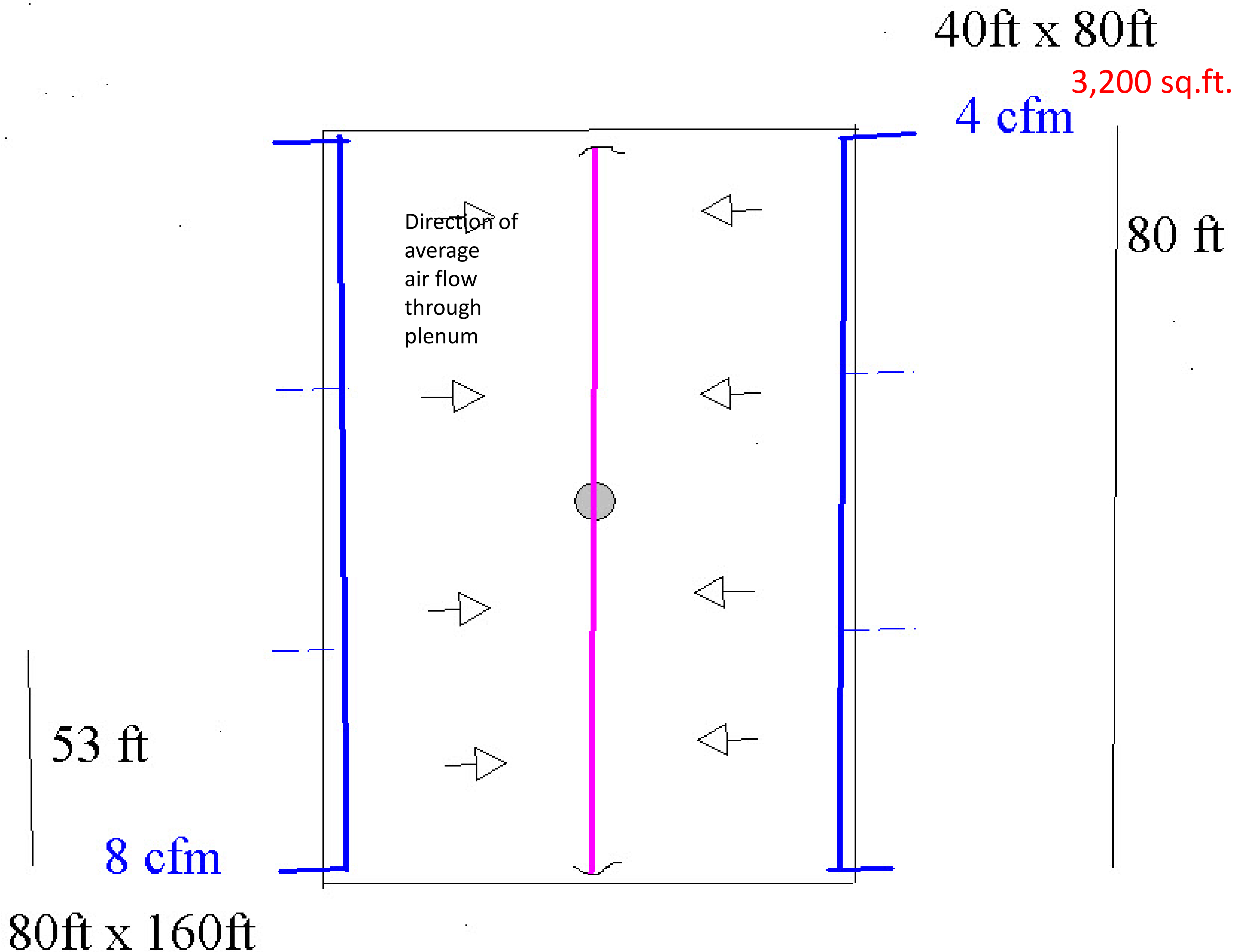
Velocity= Qssv/(2 pi b n B) K_1(r/B)

WHAT IF IN NEW CONSTRUCTION WE COULD SIMPLY MAKE THE PROBLEM 1 DIMENSIONAL?

In Line Fan imposes a vacuum



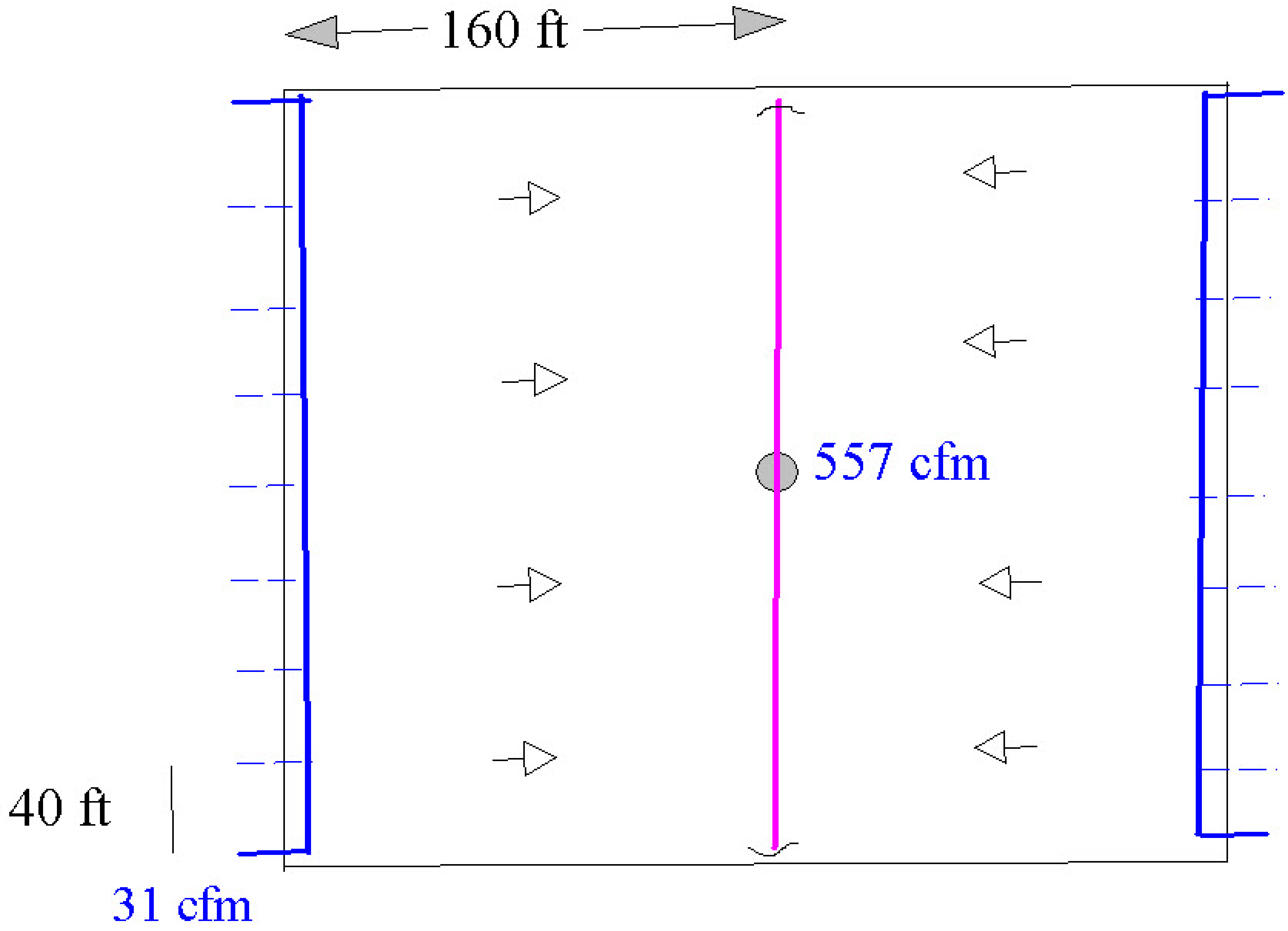




40ft x 80ft
3,200 sq.ft.
4 cfm
80 ft
Direction of average air flow through plenum
53 ft
8 cfm
80ft x 160ft

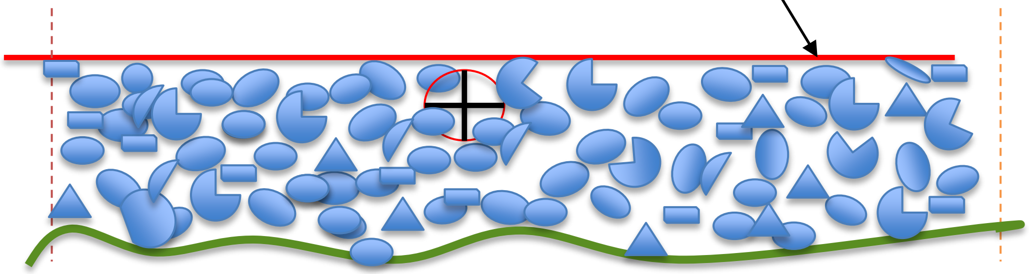
317 ft x 317 ft

>100,000 sq. ft.



Flow model: shown is the cross section perpendicular to the direction of average air flow through the plenum

High density polyethylene sheet acting as an impenetrable barrier for air and radon (very slick plastic) Fully sealed



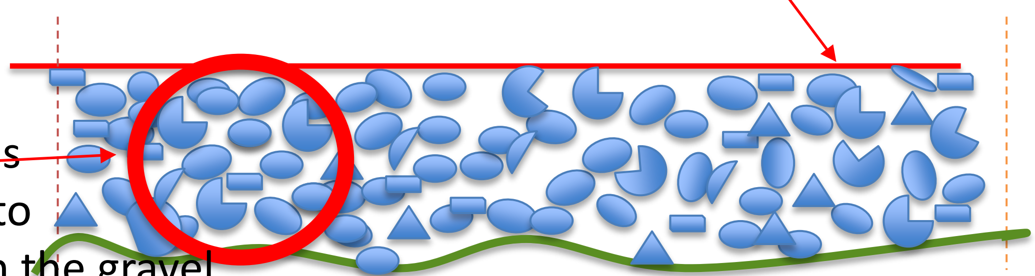
4” or 6” thick layer
The “plenum”.
Reflective Boundary Conditions on the sides, or treat this as one cell of many side by side.

Original soil, or compacted soil, clay, silt has a much smaller permeability for air than any other component, or best is a fully sealed sheet of high density polyethylene.

Flow model cross section perpendicular to the direction of average air flow through the plenum under the concrete slab. (The plenum is the entire gravel bed)

High density polyethylene sheet acting as an impenetrable barrier for air and radon (very slick plastic) Fully sealed

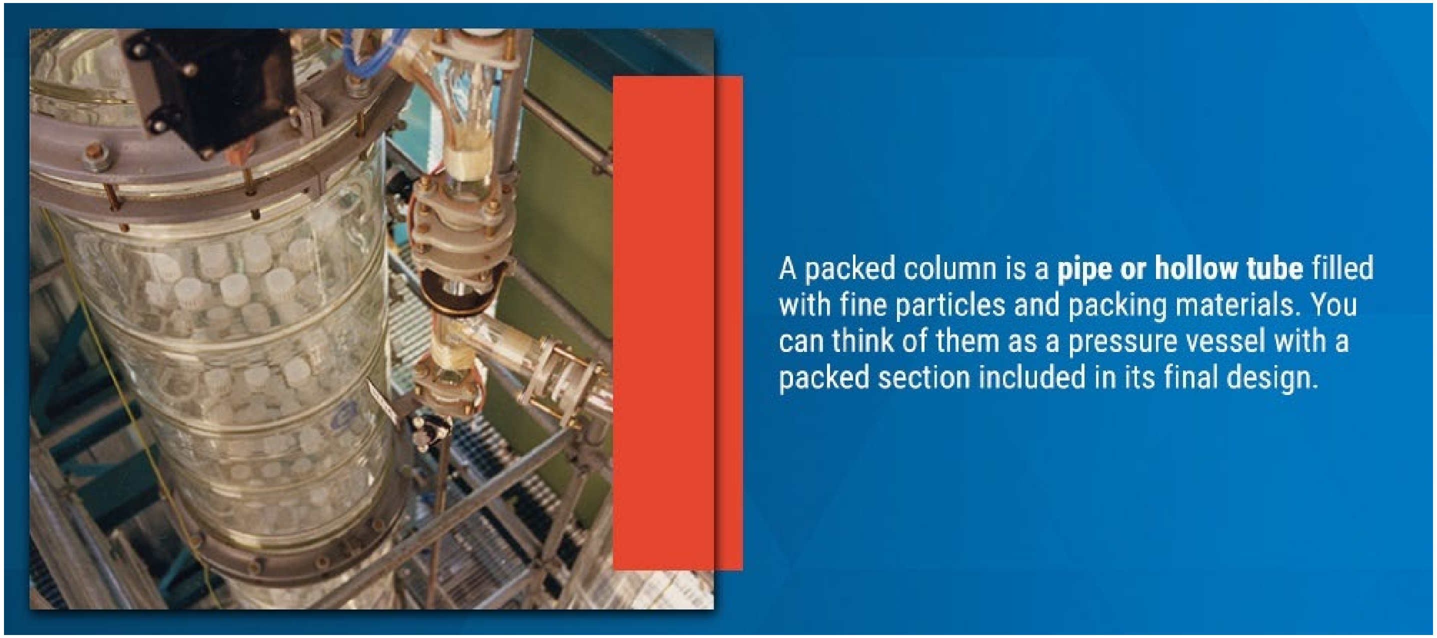
4” layer thick gravel bed = The “plenum”.

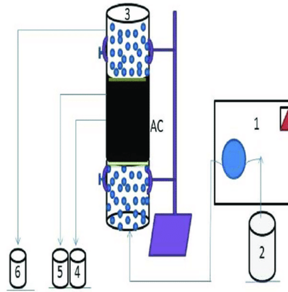


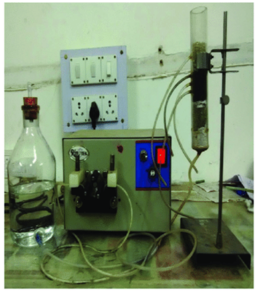
Packed column is here simulated to lie horizontaly in the gravel bed. Its length direction is parallel to the air flow in the gravel bed (plenum), and this is in the width direction of the building.

Length of the pipe inside-wall cross section (= a circle): pi*D=31.9 cm
Length of equivalent cross section for the “walls of the plenum”: 2*D=20.3 cm
Thus, the wall effects are less important in the flow under the slab than in the pipe by 1- (2/pi) = 36%

Packed columns examples







1. Peristaltic pump
2. Wastewater reservoir
3. Packed column (glass beads +cotton +activated carbon +cotton +glass beads)
4./5./6. Sample storing vial (at each 1 cm height of filled activated carbon)

Industry: Petrochemical Dilstillation

Ergun Equation (1952)

Named after Sabri Ergun (Turkish Engineer)
Describes the flow through porous media.
Applicable for packed columns, 1-dimensional problem.
Used in titration, chemical reactors and adsorption columns, and packed towers, as well as the design and optimization of separation and filtration processes.

It describes the non-linear relationship between the decrease in pressure and the "superficial velocity" through the column, in the direction of the flow.

- $$\Delta p = \frac{150\mu}{{D_p}^2}\frac{(1-\varepsilon)^2}{\varepsilon^3}v_s + \frac{1.75\,L\,\rho}{D_p}\frac{(1-\varepsilon)}{\varepsilon^3}v_s|v_s|$$

Ergun equation

4 languages

Article Talk Read Edit View history Tools

From Wikipedia, the free encyclopedia

The **Ergun equation**, derived by the Turkish chemical engineer Sabri Ergun in 1952, expresses the friction factor in a packed column as a function of the modified Reynolds number.

Equation [edit]

$$f_p = \frac{150}{Gr_p} + 1.75$$

where f_p and Gr_p are defined as

$$f_p = \frac{\Delta p}{L} \frac{D_p}{\rho v_s^2} \left(\frac{\epsilon^3}{1-\epsilon} \right)$$

friction factor

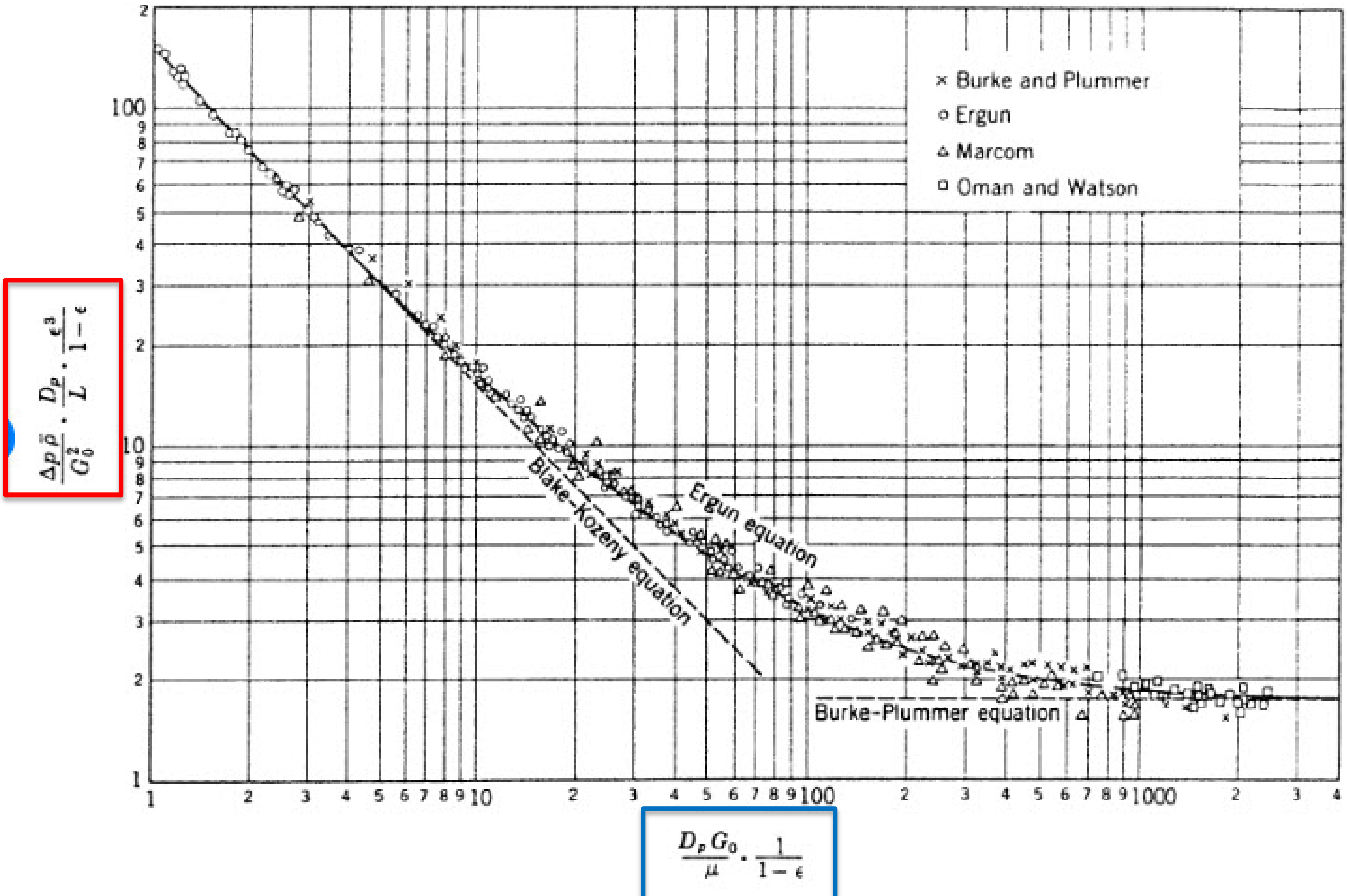
$$y = \frac{150}{x} + 1.75$$

and

$$Gr_p = \frac{\rho v_s D_p}{(1-\epsilon)\mu} = \frac{Re}{(1-\epsilon)};$$

where:

Gr_p is the modified Reynolds number,
f_p is the packed bed friction factor
Δp is the pressure drop across the bed,
L is the length of the bed (not the column),
D_p is the equivalent spherical diameter of the packing,
ρ is the density of fluid,
μ is the dynamic viscosity of the fluid,
v_s is the superficial velocity (i.e. the velocity that the fluid would have through the empty tube at the same volumetric flow rate)
ϵ is the void fraction (porosity) of the bed.
Re is the particle Reynolds Number (based on superficial velocity[1]) .

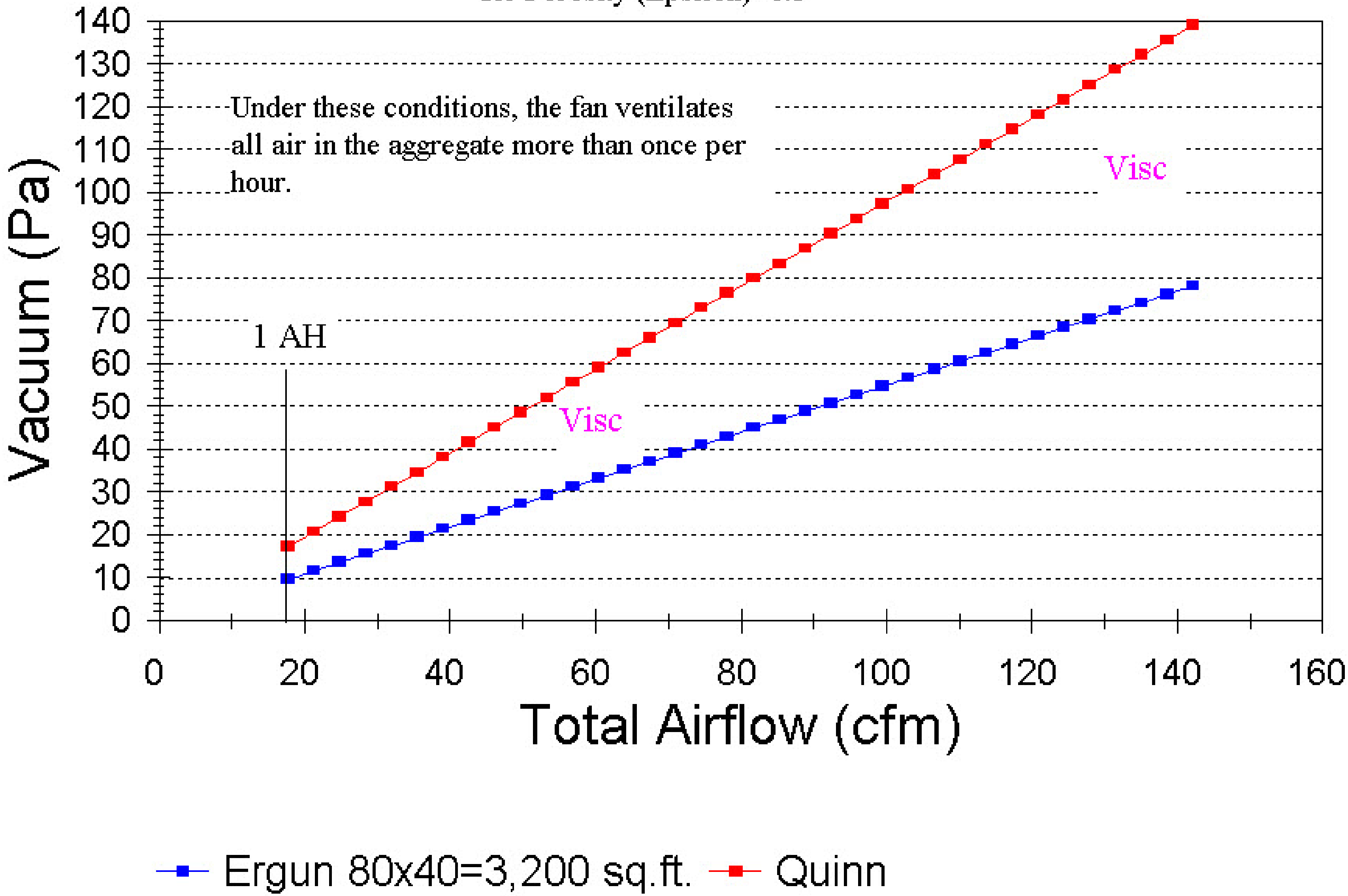


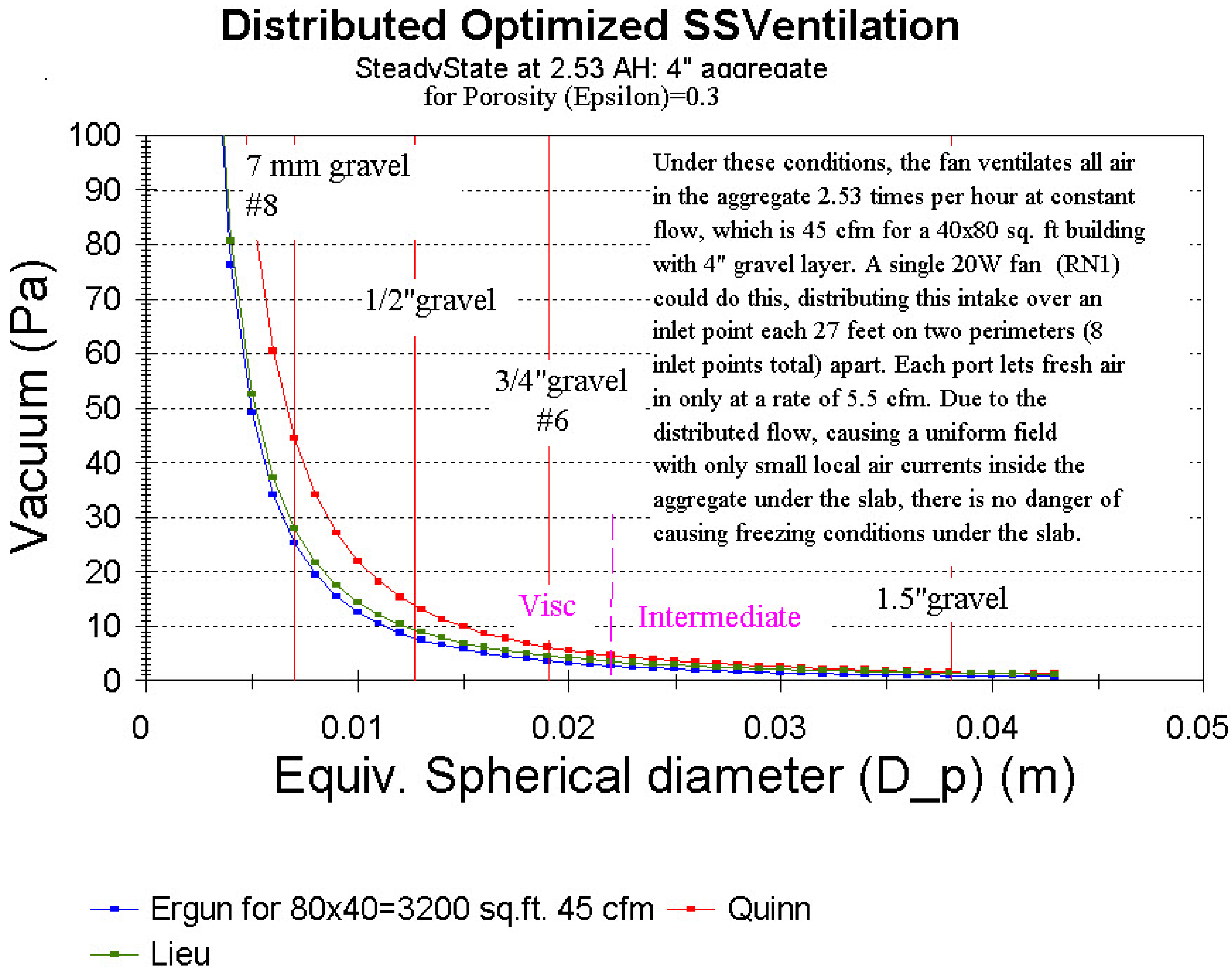
Normalised plot of the Ergun equation (after Ergun, 1952; Bird et al., 1960).

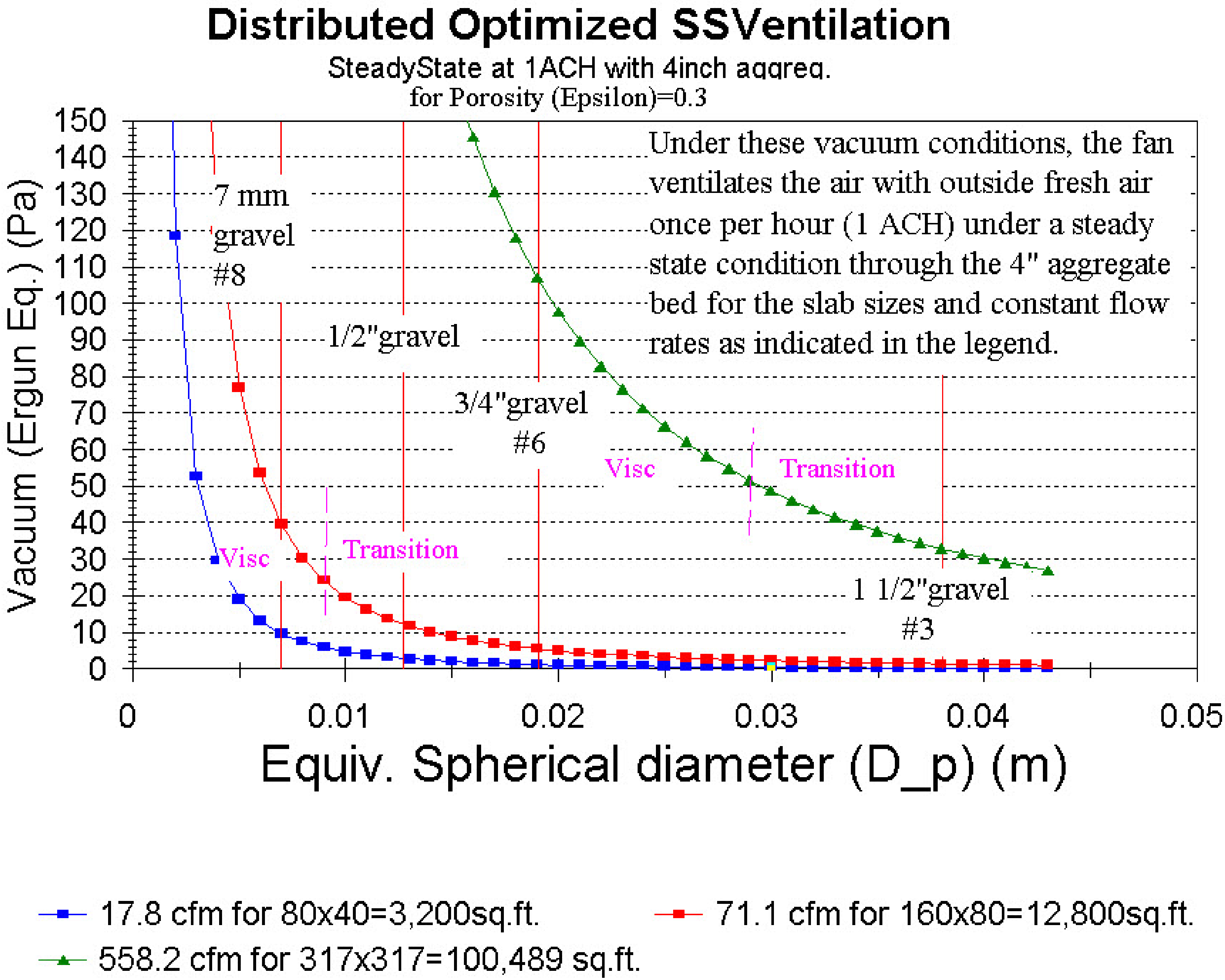
Distributed Optimized SSVentilation

SteadyState for #8 gravel (depth=4in)

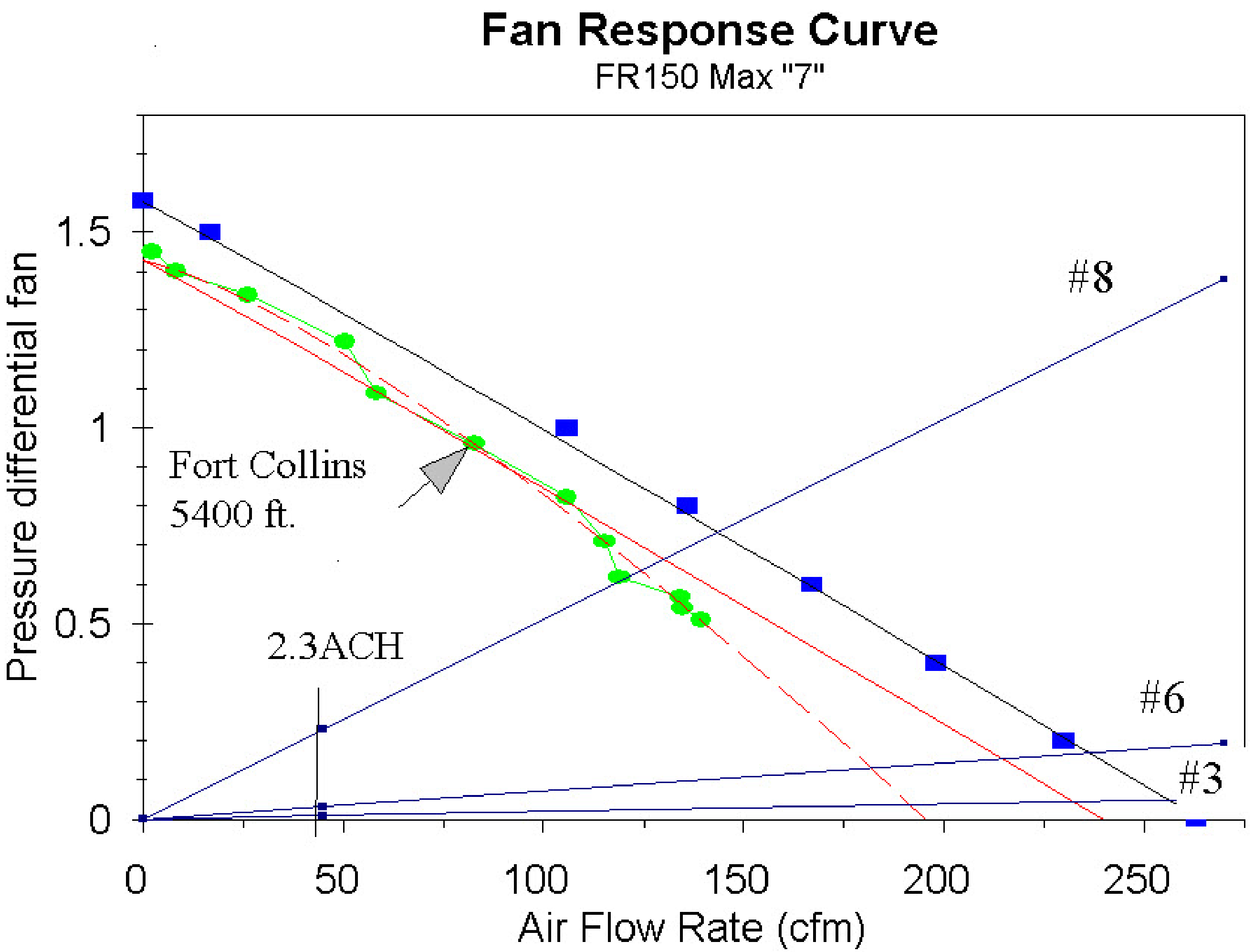
for Porosity (Epsilon)=0.3




Distributed Optimized SSVentilation
SteadyState at 2.53 AH: 4" aggregate
for Porosity (Epsilon)=0.3
Vacuum (Pa)
100
90
80
70
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
0.05
Equiv. Spherical diameter (D_p) (m)
7 mm gravel
#8
1/2"gravel
3/4"gravel
#6
Visc
Intermediate
1.5"gravel
Under these conditions, the fan ventilates all air in the aggregate 2.53 times per hour at constant flow, which is 45 cfm for a 40x80 sq. ft building with 4" gravel layer. A single 20W fan (RN1) could do this, distributing this intake over an inlet point each 27 feet on two perimeters (8 inlet points total) apart. Each port lets fresh air in only at a rate of 5.5 cfm. Due to the distributed flow, causing a uniform field with only small local air currents inside the aggregate under the slab, there is no danger of causing freezing conditions under the slab.
Ergun for 80x40=3200 sq.ft. 45 cfm
Quinn
Lieu

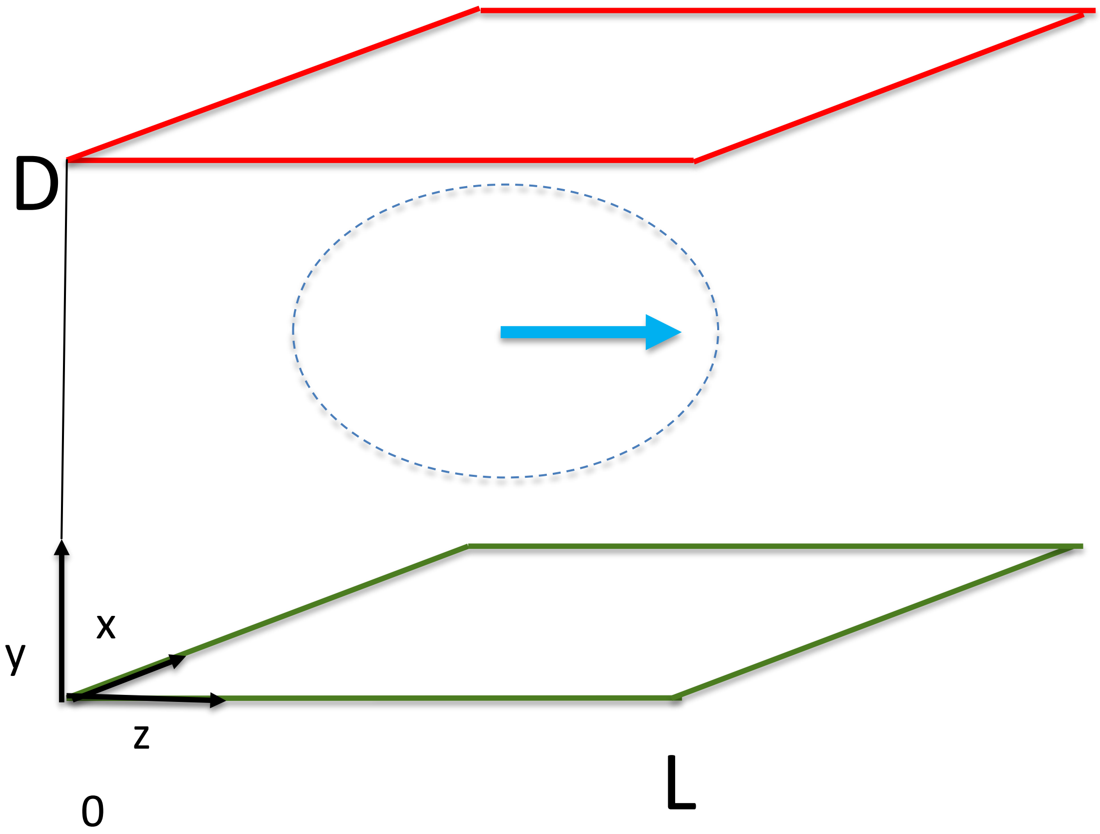


Distributed Optimized SSVentilation
SteadyState at 1ACH with 4inch aggreg.
for Porosity (Epsilon)=0.3
Under these vacuum conditions, the fan ventilates the air with outside fresh air once per hour (1 ACH) under a steady state condition through the 4" aggregate bed for the slab sizes and constant flow rates as indicated in the legend.
7 mm gravel #8
1/2"gravel
3/4"gravel #6
1 1/2"gravel #3
Visc
Transition
Visc
Transition
Vacuum (Ergun Eq.) (Pa)
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
0.05
Equiv. Spherical diameter (D_p) (m)
17.8 cfm for 80x40=3,200sq.ft.
71.1 cfm for 160x80=12,800sq.ft.
558.2 cfm for 317x317=100,489 sq.ft.

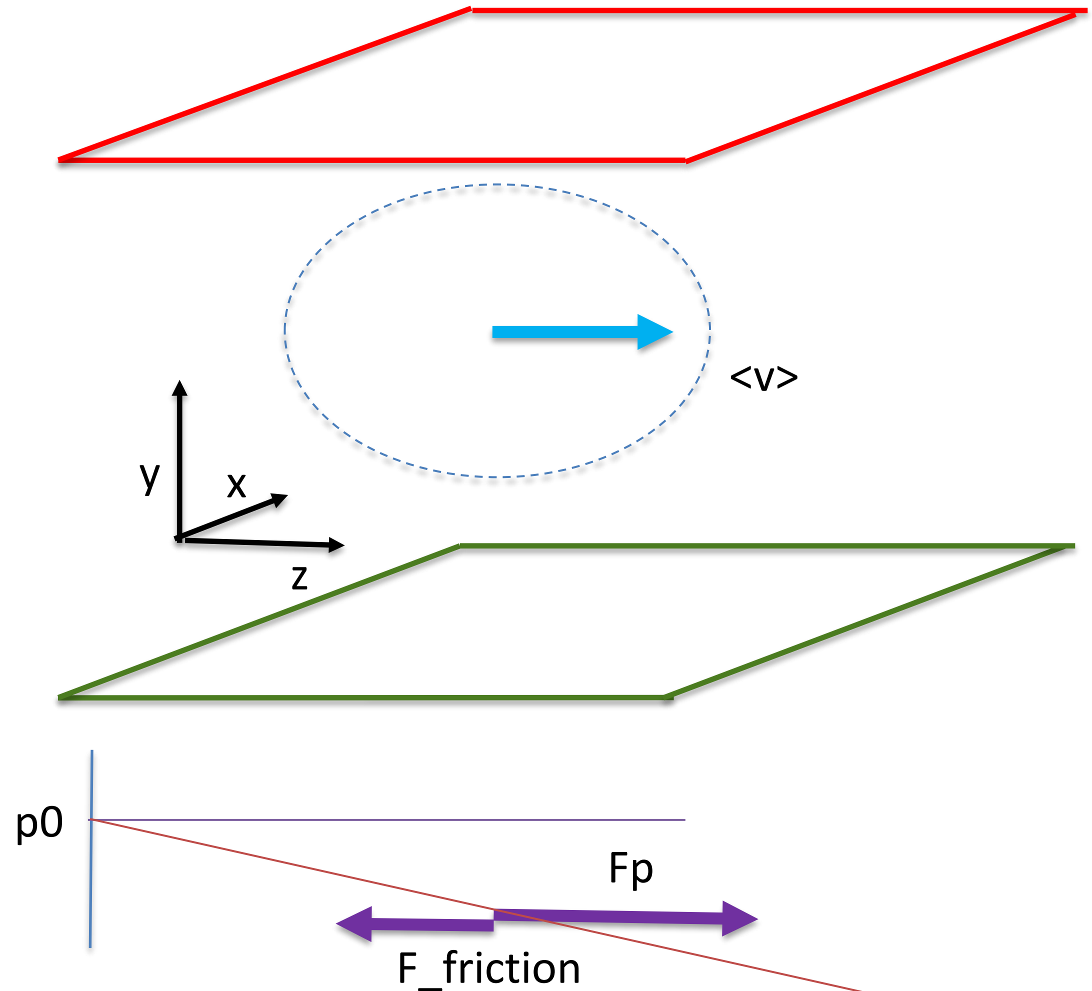


Current medium power fans have much more power than are needed for DOSSV flow rate

The Physical Model



Consider a mesoscopic unit control volume (element) (fluid, or air
and describe parameters averaged per unit of volume
(density, instead of mass).



A net force will accelerate an object: 2nd law of motion (Newton)

F=m dv/dt

If no net force acts on an object, it will maintain its motion: 1st Law of Newton

Second law of Motion (Newton):

$$m\frac{d\vec{u}}{dt} = \vec{F}$$

F(gravity)

Fluid dynamics model (Navier Stokes Eq.):

$$\rho\frac{d\vec{u}}{dt} = -\rho g\vec{k} - \vec{\nabla}p + \mu\Delta\vec{u} + \vec{f}_{ext}$$

f(gravity) f(pressure) f(viscous) + f(friction with aggregate)

Employ symmetries of the problem,

and the Boundary Conditions (BCs)

and Initial Conditions.

Choose the z-axis to point parallel to the equilibrium velocity vector (local average of volume flow on a volume element, Darcy velocity) is given by:

$$\vec{q} = -\frac{k}{\mu}\frac{dp}{dz}\,\vec{e}_z$$

(In opposite direction to the increase of pressure)

RESULTS FROM EXPERIMENTS OF FLUIDS DISSIPATING THROUGH PACKED COLUMNS:

It describes the control volume is

"sliding down the hill towards lower pressures"

This is the result of a balancing act of the pressure force with the friction forces due to the air being forced to go through the many small connected holes and curved pathways (pores), taking into account the fluid's internal viscosity.

k= permeability through the pores, mu= viscosity for the fluid

Use Energy conservation

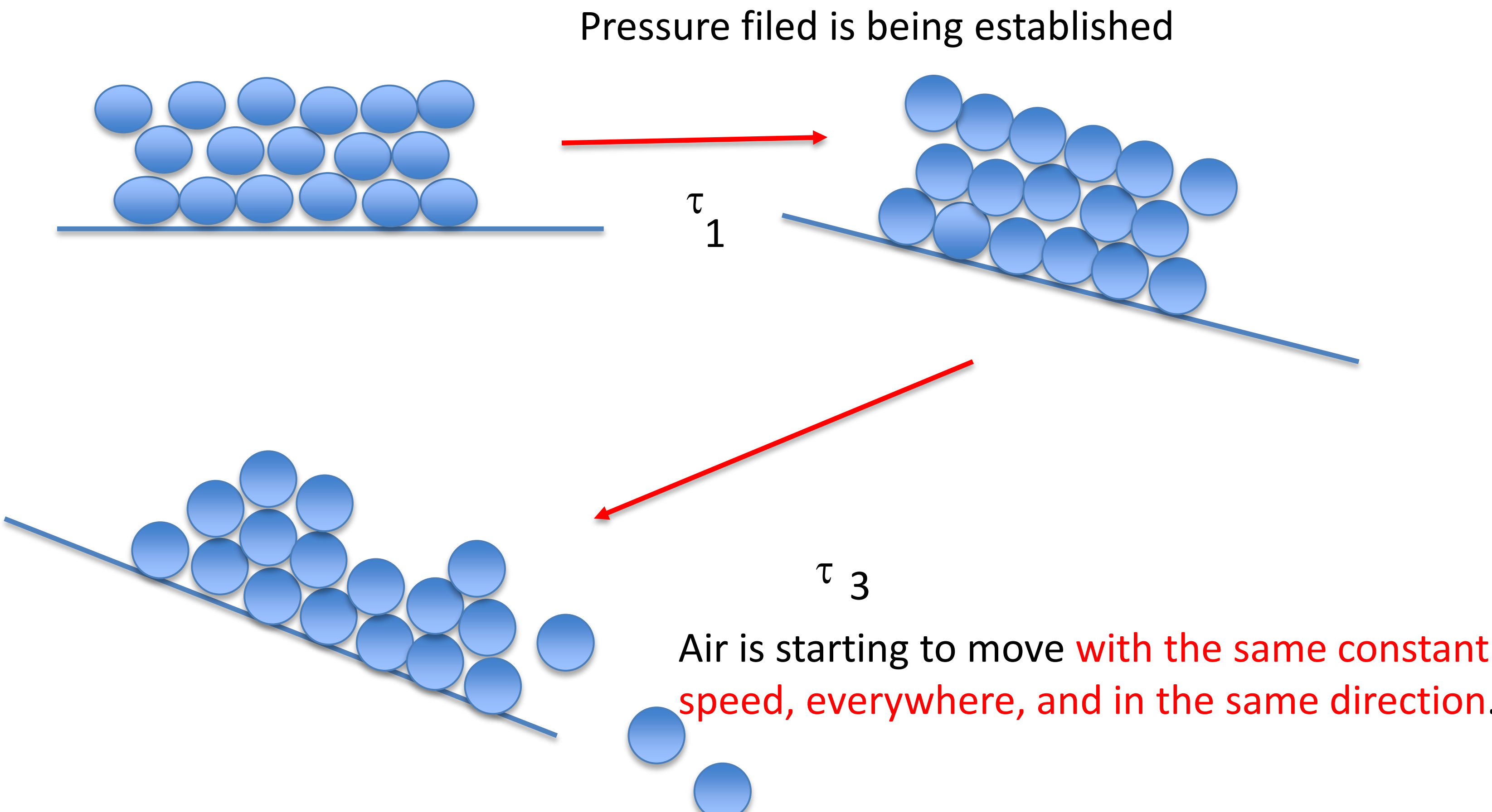
- $p(x, y, z, t) = p_0 \left(\frac{z}{L}\right) + terms\ dying\ off\ quickly$
- How quickly?
- $\tau_{c1} < \frac{\alpha}{\left(\frac{\pi}{D}\right)^2} = \alpha \left(\frac{D}{\pi}\right)^2 = \left(\frac{\theta_a \mu}{k P_0}\right)\left(\frac{D}{\pi}\right)^2 \equiv \tau_{c2}$
- $\vec{f}_z = -\vec{\nabla} p_\infty(z) = -\frac{p_0}{L}\vec{e}_z$
- The pressure force on each volume element everywhere in the aggregate is constant, the same, and in the same direction, (homogeneous and isotropic), as is also the averaged friction forces,
- ....and they will balance each other out

- The resulting equilibrium average speed, averaged over the volume element, is given by the Darcy equation:
- $\vec{q} = -\frac{k}{\mu}\frac{dp}{dz}\vec{e}_z = -\frac{k}{\mu}\ \frac{p_0}{L}\vec{e}_z$

which is constant and isotropic, when averaged over a volume element.

"Dumptruck" Model

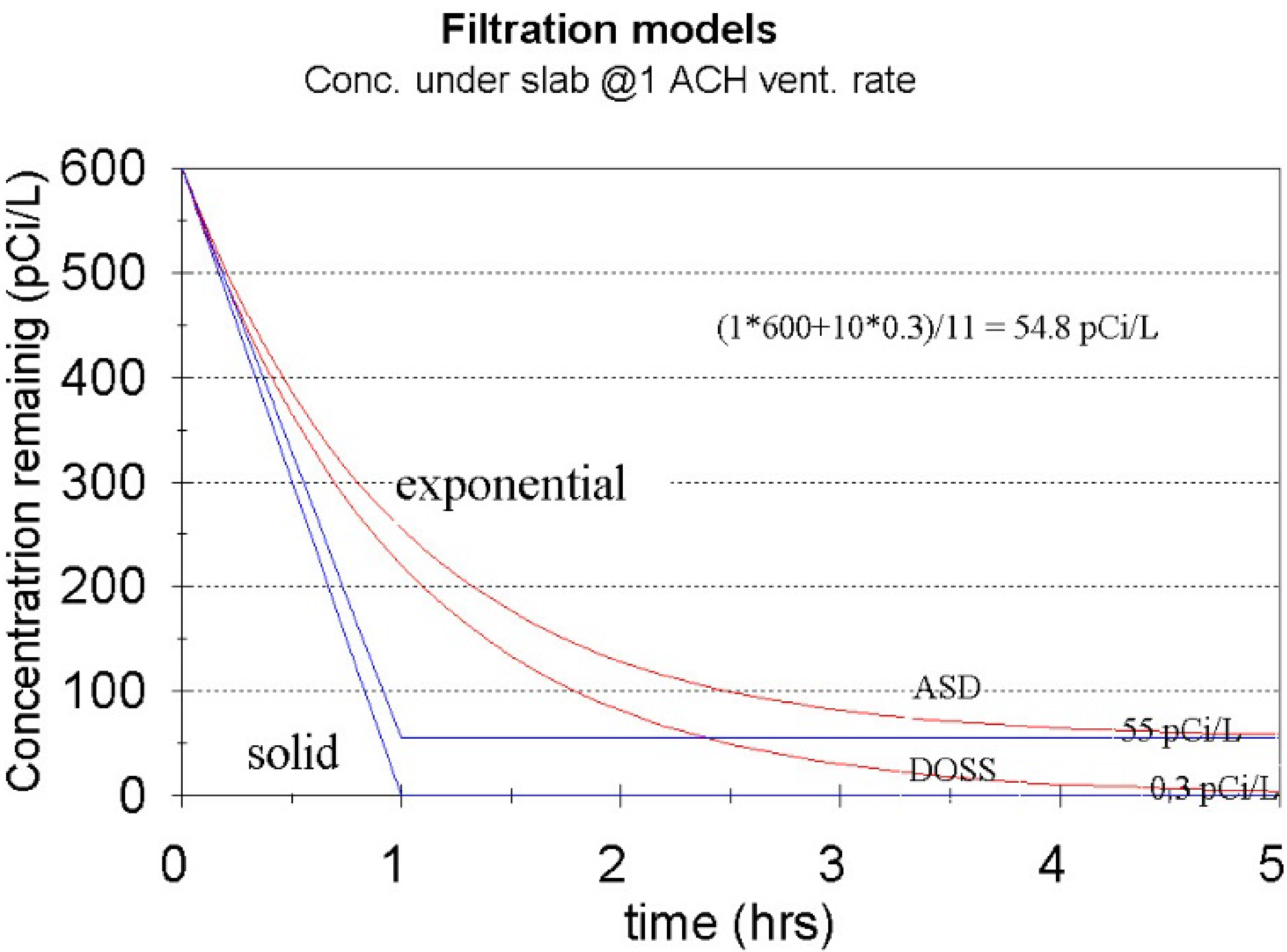
(for DOSSV only, not for ASD)



Characteristic time scales

Characteristic time	Gravel	Clean sand	Silty sand
Typical intrinsic permeability (k)	10^{-9} m^2	10^{-11} m^2	10^{-12} m^2
For vertical (y) pressurization of plenum with D=4”	5.3 10^{-5}s	0.0053 s	0.053 s
For distance from supply to discharge pipes (z) (20 ft)	0.19 s	19.2 s	192 s

Efficiency for radon removal of DOSSV is better than ASD



Summary of Radon Mitigation Models

- (1) Reddy-Sextro et al. model (EPA, 1992), 2 dim, air movement through soil under foundation walls.

  Dynamics: Pressures and flows in plenum are vastly different close to pipe (turbulent), compared to far away (laminar).

- (2) Hantusch-Jacob model (T. McAlary, 2018), "Leaky aquafer": 2- dim, leaks from above & leaks from below

  Dynamics: Same comment as in (1).

- (3) New, DOSSV proposed for new construction allows solving a much simpler 1- dim problem, Air vacuum and flow through the aggregate bed (plenum) can be calculated for any gravel or sand with known characteristics.

  Dynamics: flow is the same throughout the aggregate. (homogeneous and isotropic). (Viscous (laminar), or Transition regime)

Advantages of Using the DOSSV configuration over ASD in New Home Construction:

- Final radon concentrations are expected lower than with ASD because we replace with fresh air. (higher efficiency)
- # of main vent pipes in large footprint buildings, or large open work areas can be reduced, due to the higher radon removal efficiency.
- Lower power radon fans can be as effective as ASD for equivalent sized buildings.
- Design can be optimized during architectural phase, and for a less optimal situation, the resulting pressure and flow can still be calculated based on the info of gravel used, or chosen.
- The same configuration can be used to minimize Vapor Intrusion more effectively into the building.