DISTRIBUTED AND OPTIMIZED SUB-SLAB VENTING (DOSSV)

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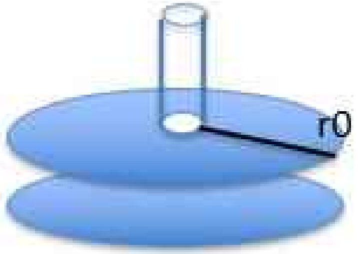
Simplified Model of airflow dynamics in SSD RMS for Residences with Gravel Beds

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

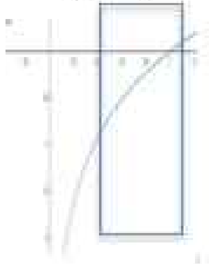
May 1992 EPA-600/R-92-090



Assumptions in the model:

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

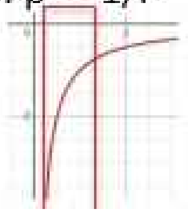
Laminar regime: p ~ ln(r/r0) + C



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.

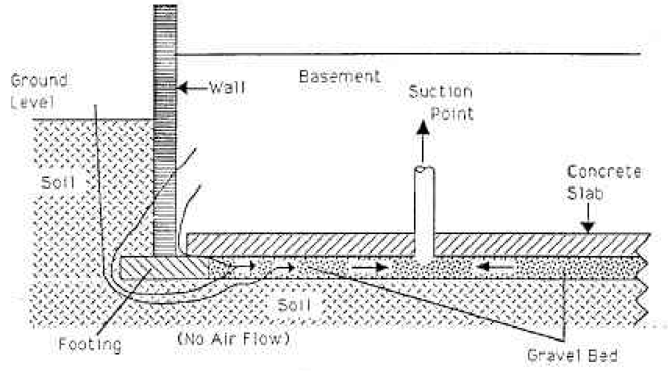


Fig. 1 Schematic of subslab air flows in a house with a gravel bed when the house is being mitigated following the subslab depressurization technique. Note that part of the air flowing through the gravel bed originates from the basement and the rest from the ambient air.

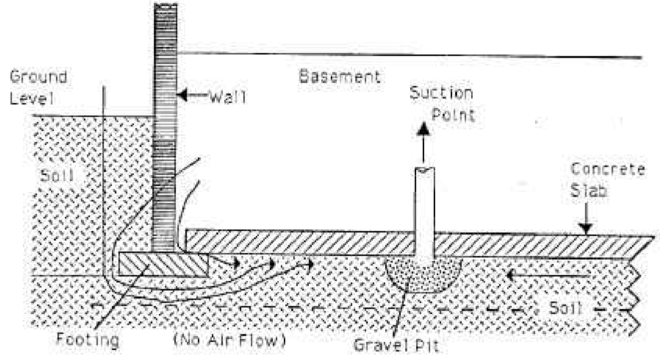
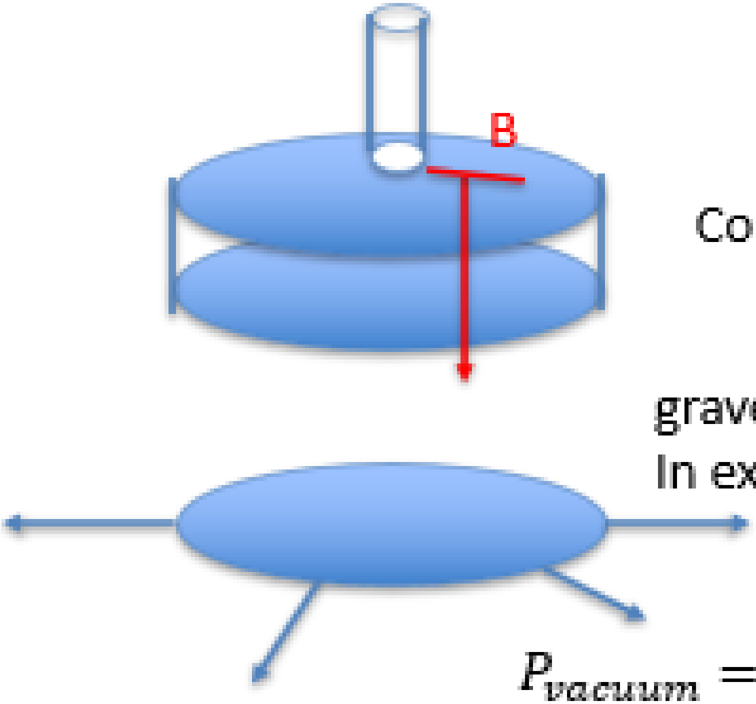


Fig. 2 Schematic of subslab air flow in a house without a gravel bed when the house is being mitigated following the subslab depressurization technique.

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′)

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

gravel…sand (b; K)
In extraction zone

$$P_{vacuum} = \frac{Q_{ssv}}{2\pi T} K_0 \left(\frac{r}{B}\right)$$

Leakance: B [L]   5.5 ft…18 ft

Transmittivity T [t]   54 ft^2/day

$$v = \frac{Q_{ssv}}{2\pi b n B} K_1 \left(\frac{r}{B}\right)$$

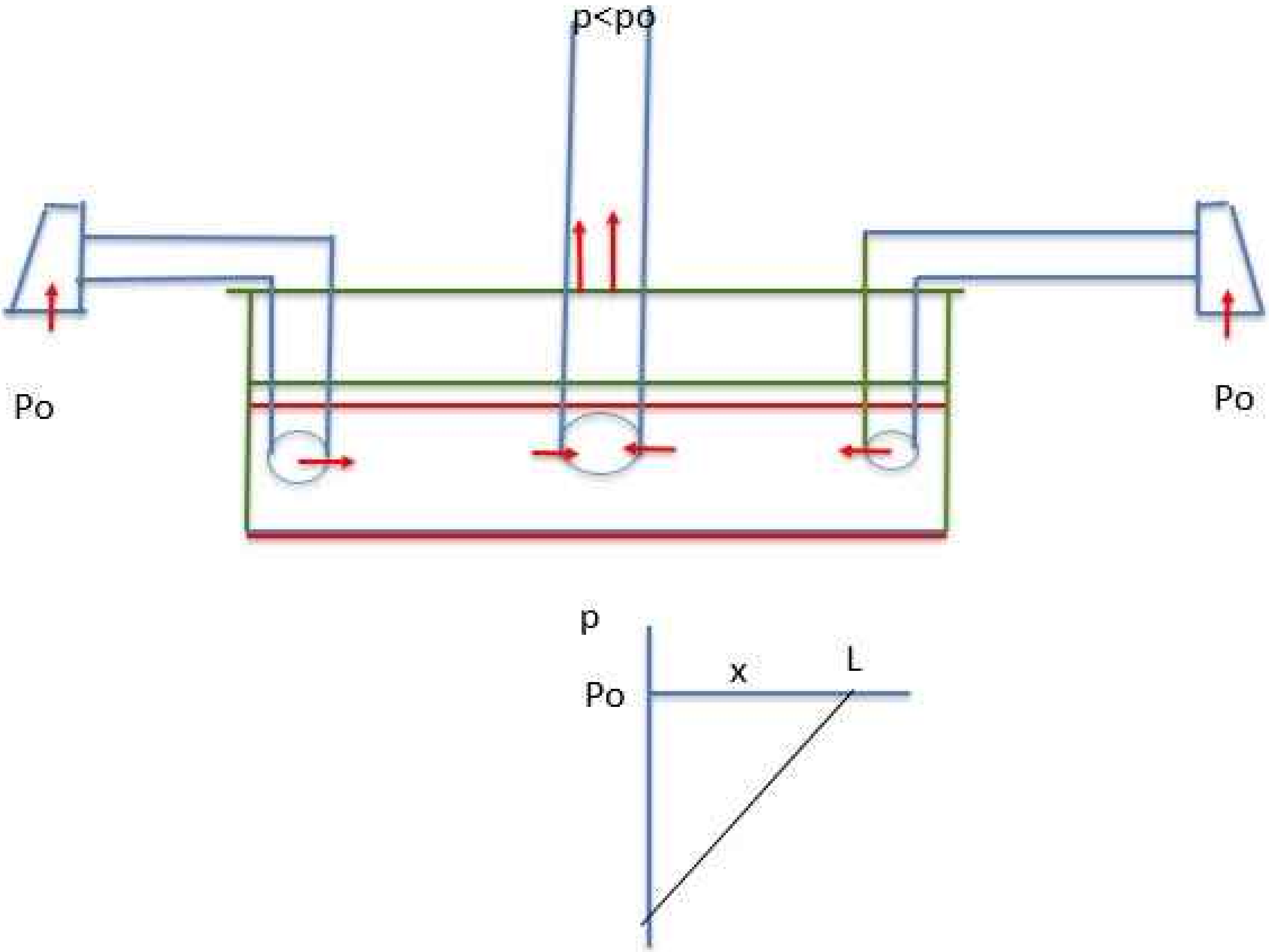
Models for New Construction Plenum (New plenums are sealed from the top)

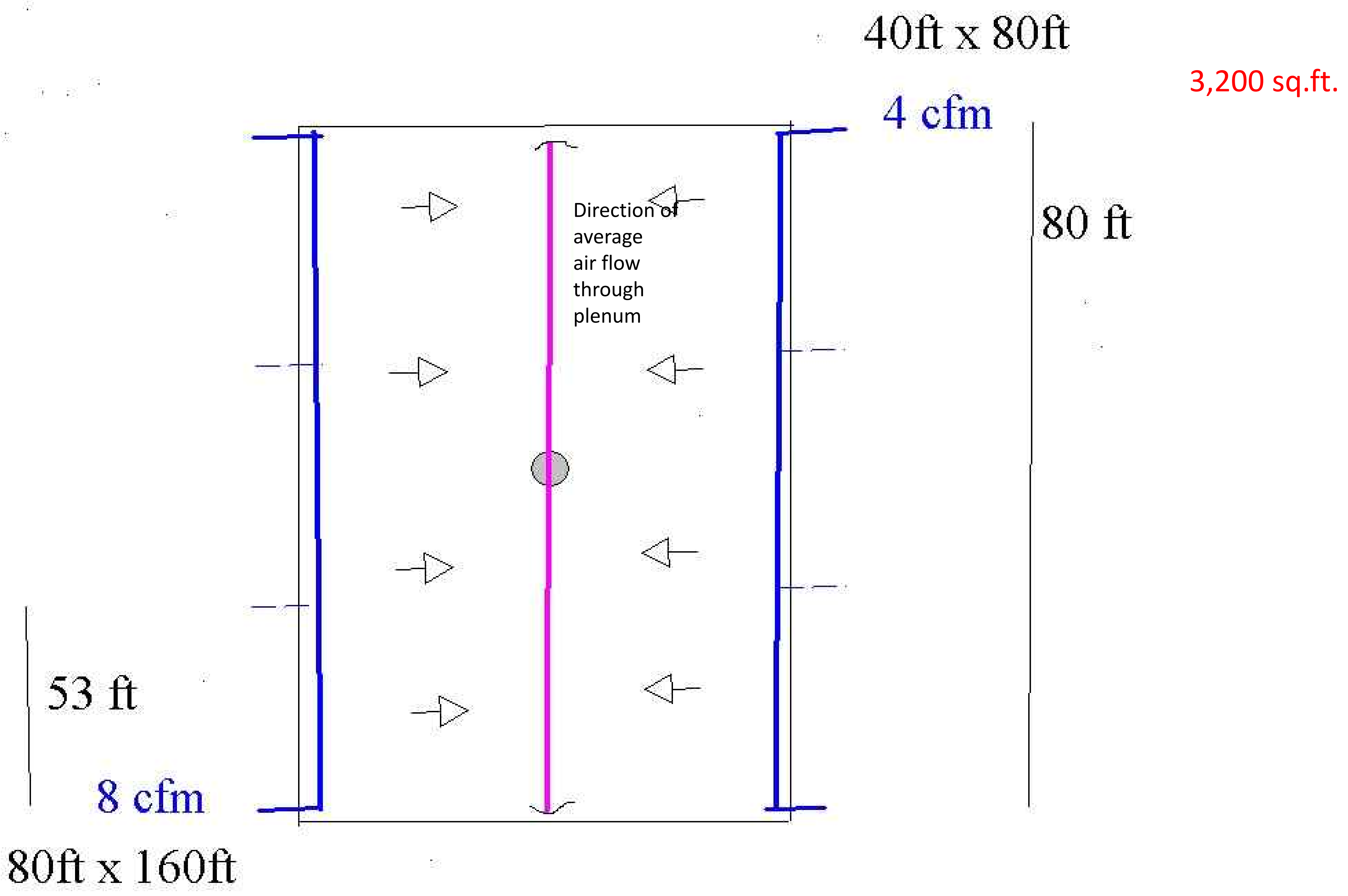
- 2 dim,
- r→infinity, Hantusch model, and
- B describes only the remaining leakage from below the plenum

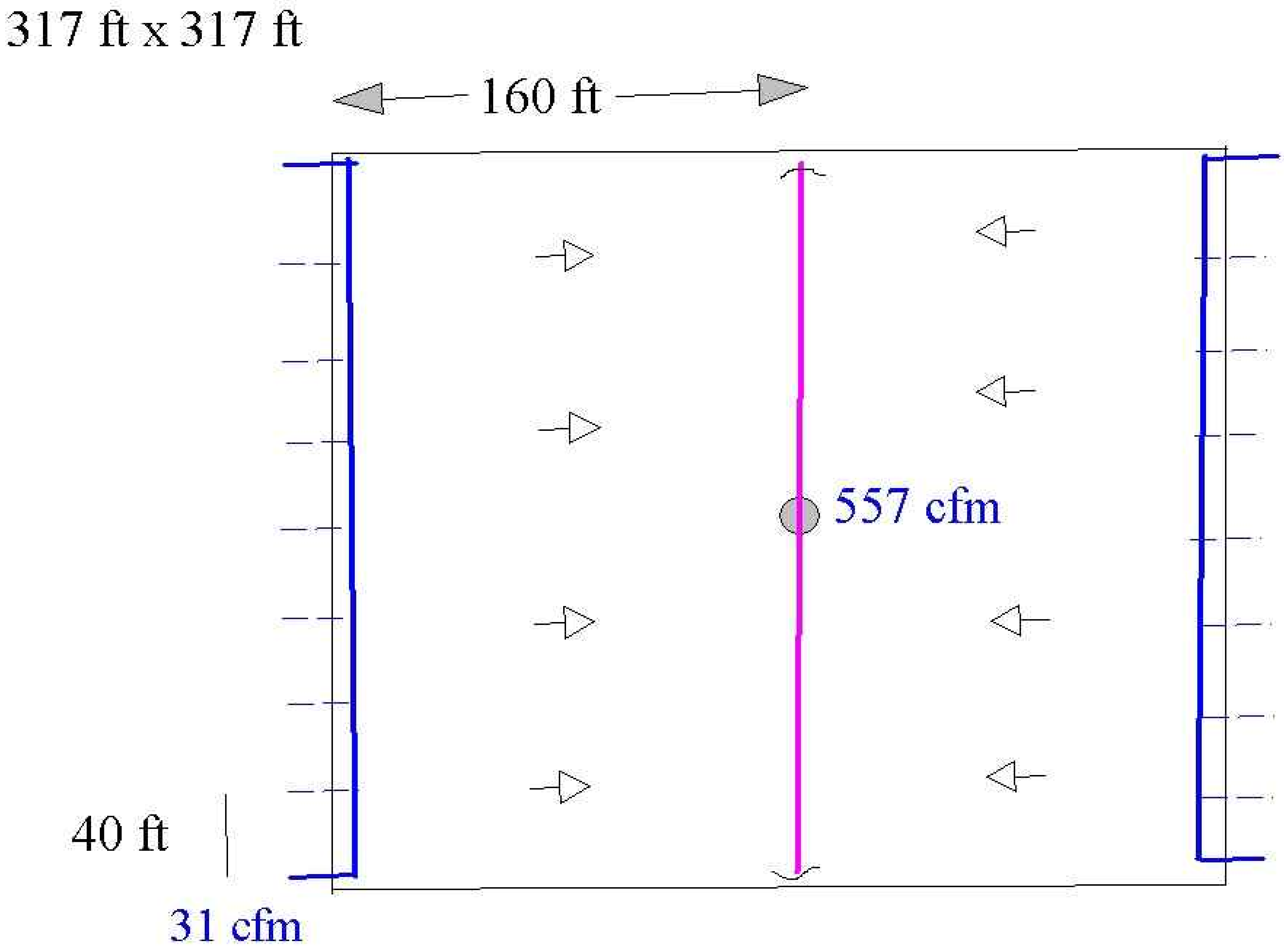
Could we build a simpler configuration in New Construction, so the calculation becomes easier?

Could we make the problem 1 dimensional?

In Line Fan imposes a vacuum

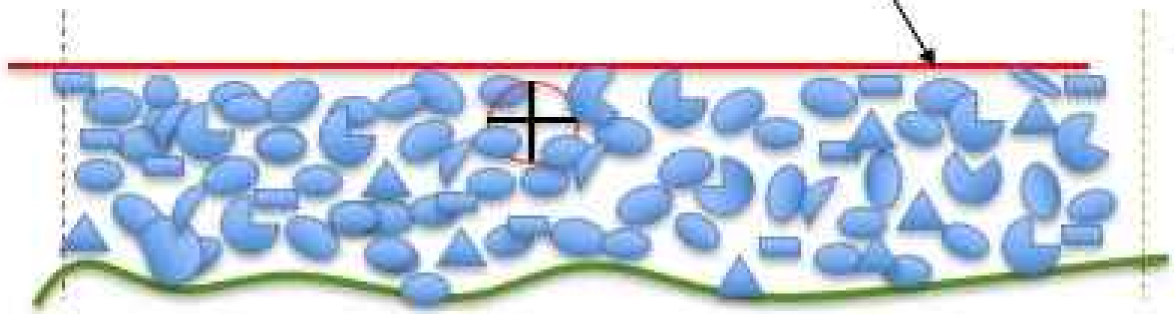



40ft x 80ft
3,200 sq.ft.
4 cfm
Direction of
average
air flow
through
plenum
80 ft
53 ft
8 cfm
80ft x 160ft


317 ft x 317 ft
160 ft
557 cfm
40 ft
31 cfm

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



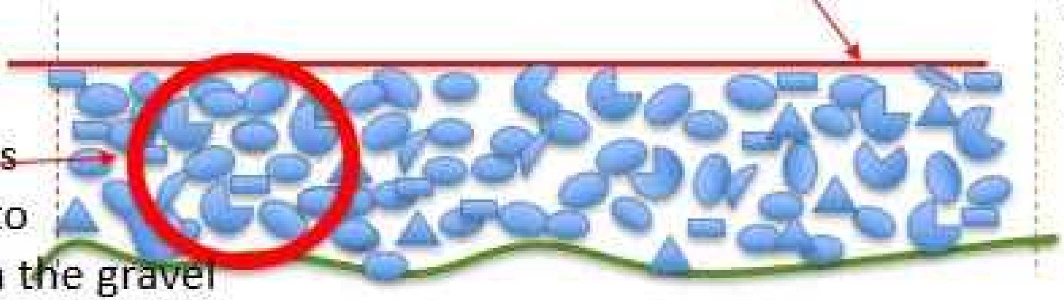
4" or 6" thick layer
The "plenum".
Reflective Boundary Conditions on the sides, or treat this as one cell of many side by side.

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 Column equivalence

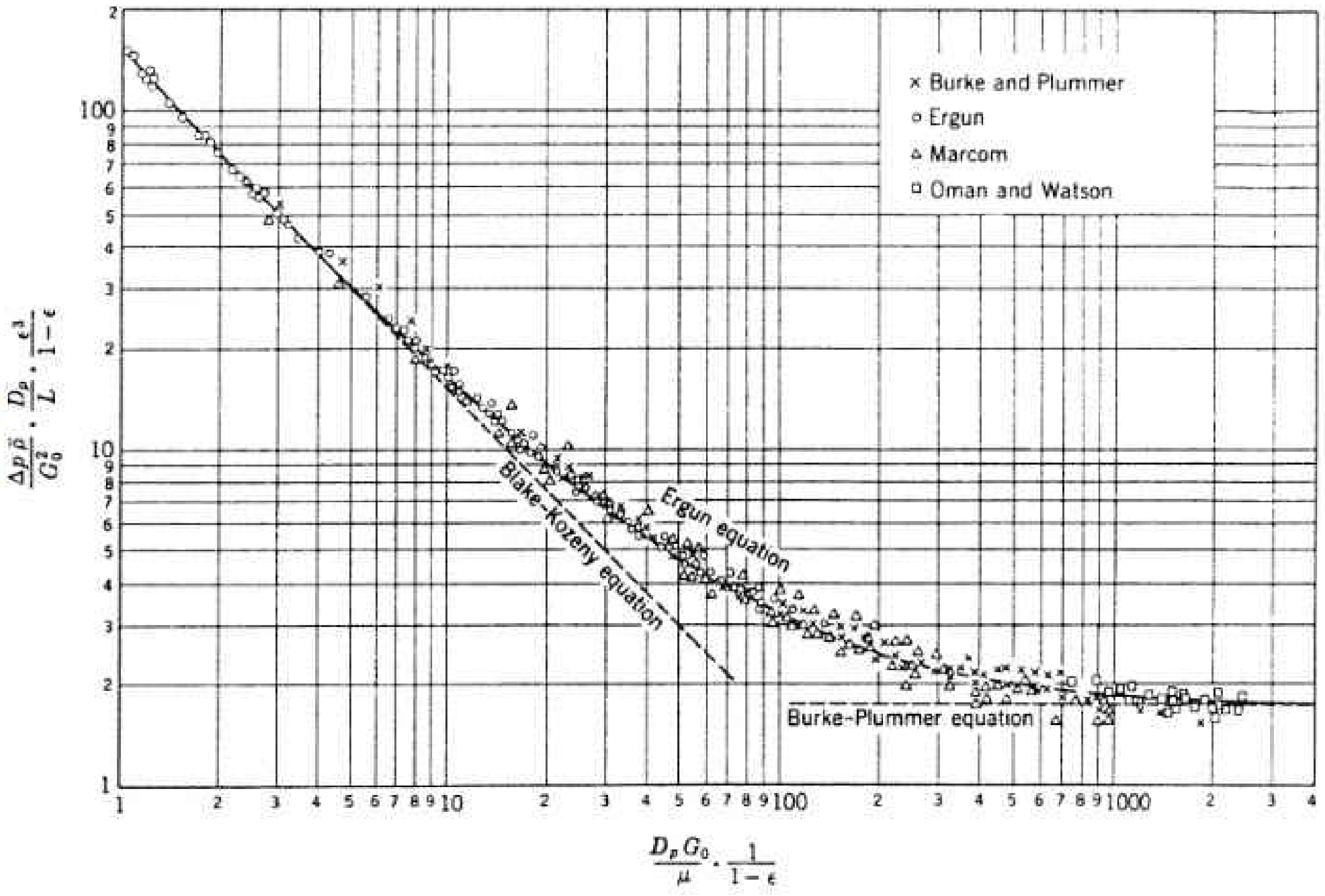
Describes the flow through porous media.
Applicable for packed columns, 1-dimensional problem.

Used in titration, chemical reactors and adsorption columns, and packed towers, as well as the design and optimization of separation and filtration processes.

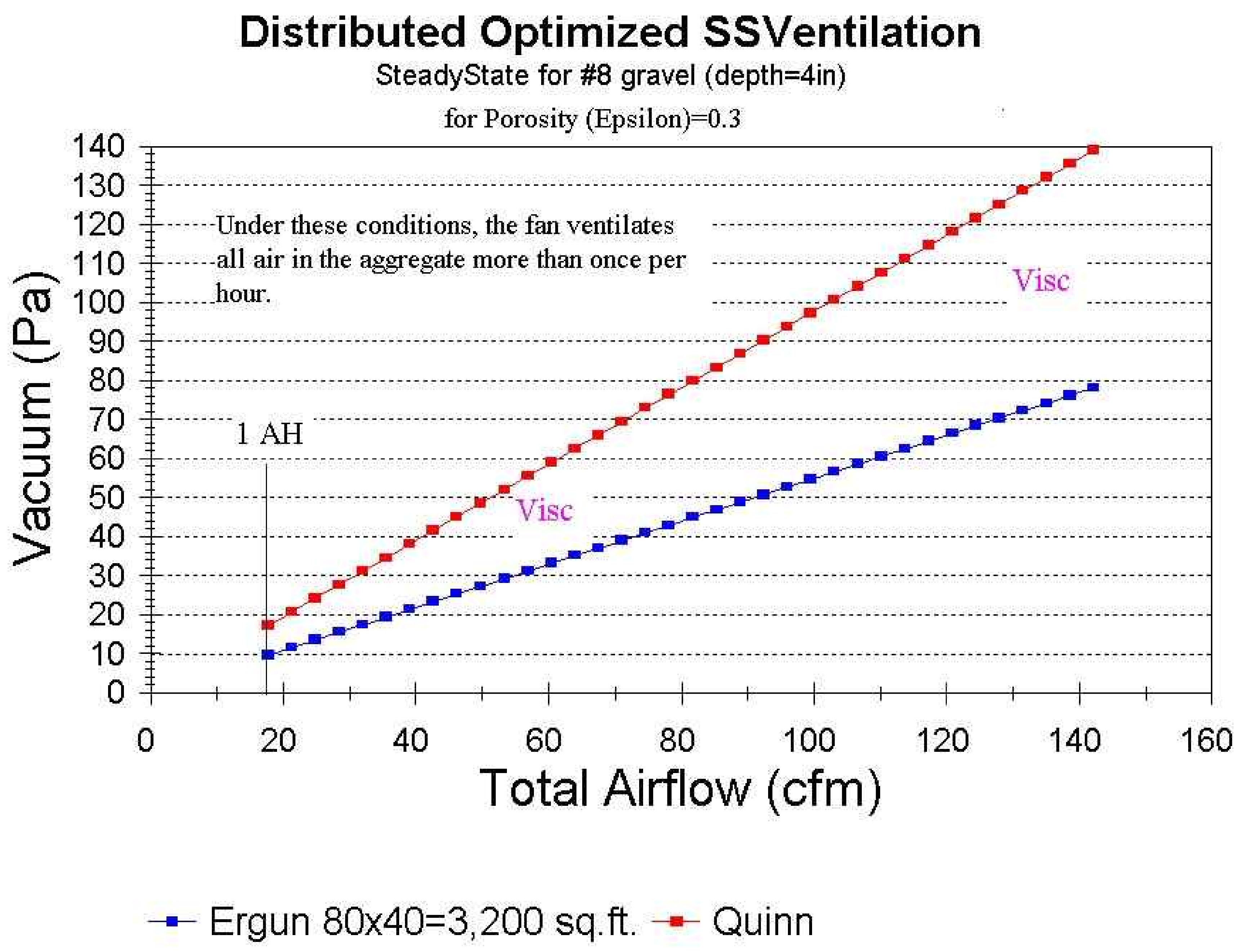
It describes the non-linear relationship between the decrease in pressure and the "superficial velocity" through the column, in the direction of the flow.

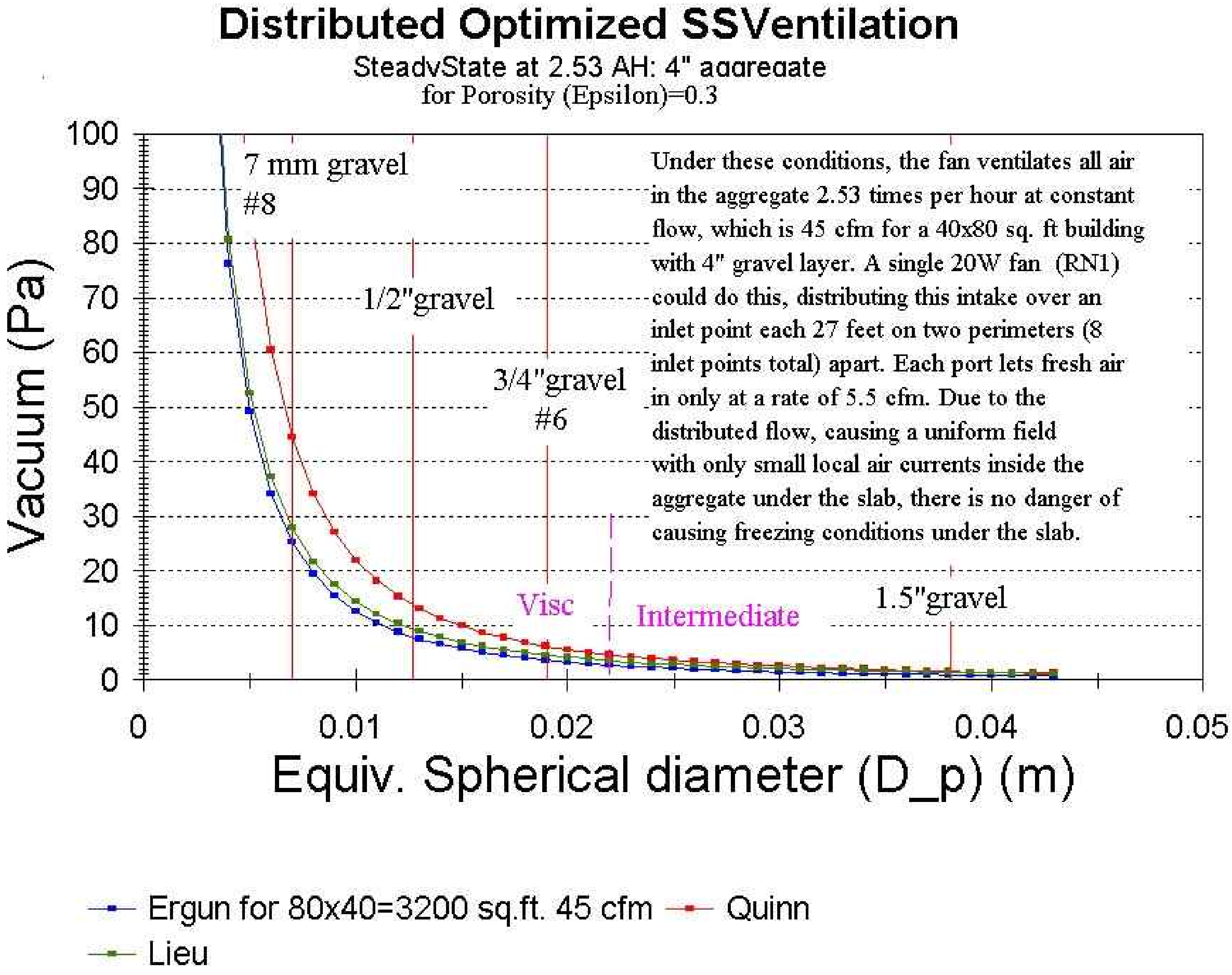
- $\Delta p = \frac{150 \mu L}{{D_p}^2} \frac{(1-\varepsilon)^2}{\varepsilon^3} v_s + \frac{1.75\, L\, \rho}{D_p} \frac{(1-\varepsilon)}{\varepsilon^3} v_s |v_s|$

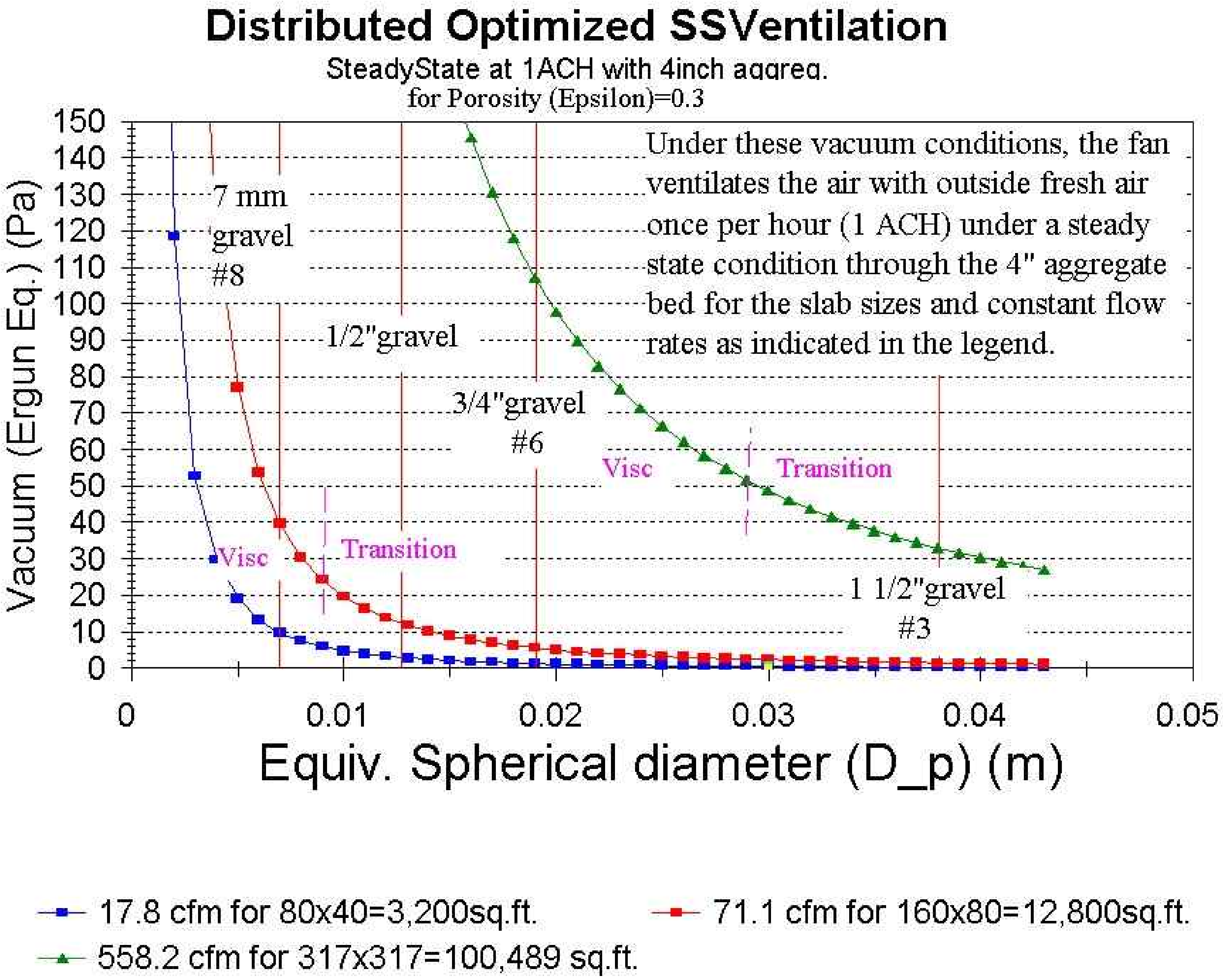
Friction factor $y = \frac{150}{x} + 1.75$ Modified Reynolds number

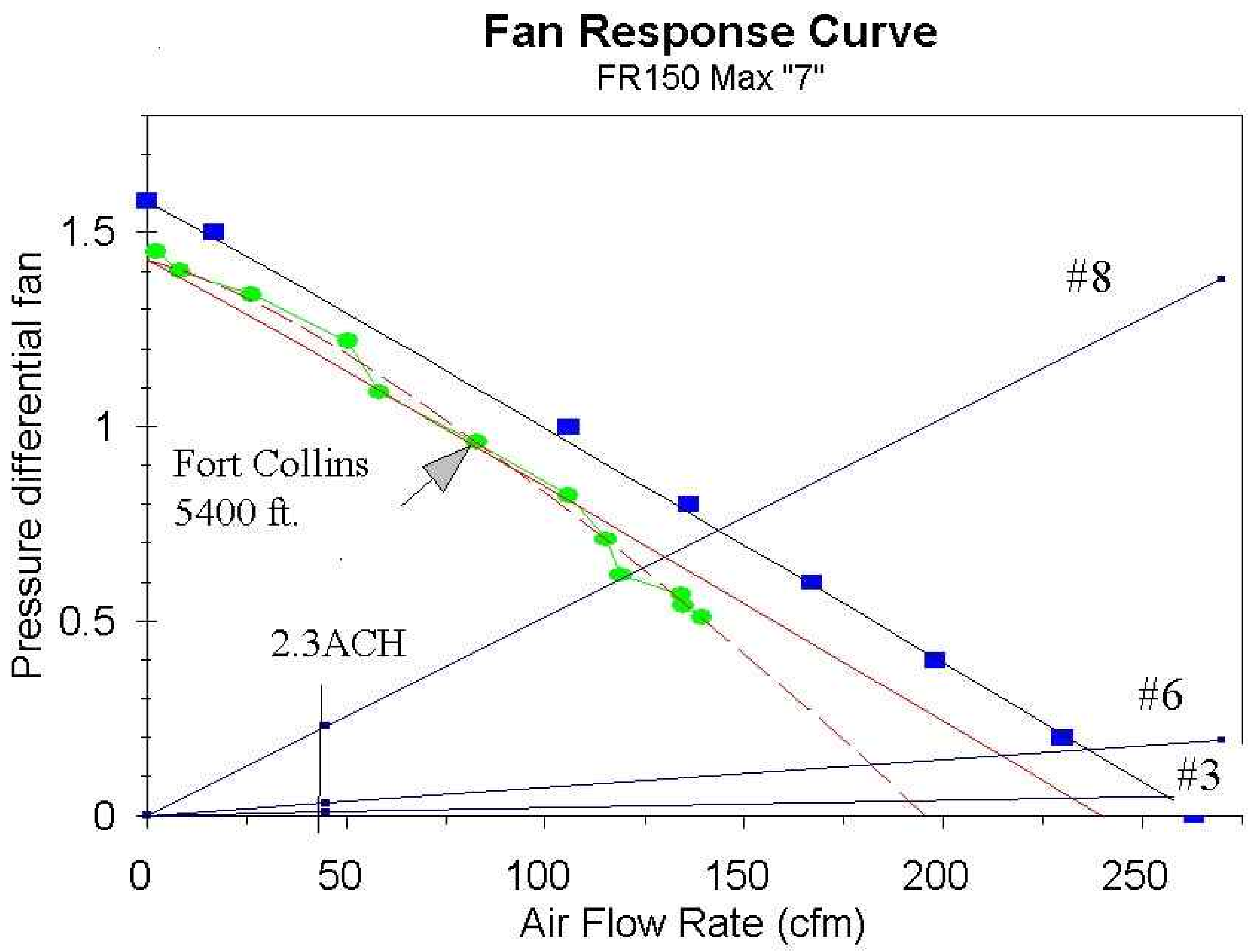


Normalised plot of the Ergun equation (after Ergun, 1952; Bird et al., 1960).


Distributed Optimized SSVentilation
SteadyState for #8 gravel (depth=4in)
for Porosity (Epsilon)=0.3
Under these conditions, the fan ventilates all air in the aggregate more than once per hour.
Visc
Visc
1 AH
Vacuum (Pa)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
0
20
40
60
80
100
120
140
160
Total Airflow (cfm)
Ergun 80x40=3,200 sq.ft.
Quinn


Distributed Optimized SSVentilation
SteadyState at 2.53 AH: 4" aggregate
for Porosity (Epsilon)=0.3
Vacuum (Pa)
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.
Equiv. Spherical diameter (D_p) (m)
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)
Equiv. Spherical diameter (D_p) (m)
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
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

In packed columns the 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 (1 Dimensional)

In DOSSV: <u>"Air element is sliding down the hill towards lower pressures"</u>

This is the result of a balancing act of the <u>pressure force</u> with the <u>friction forces</u> 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.

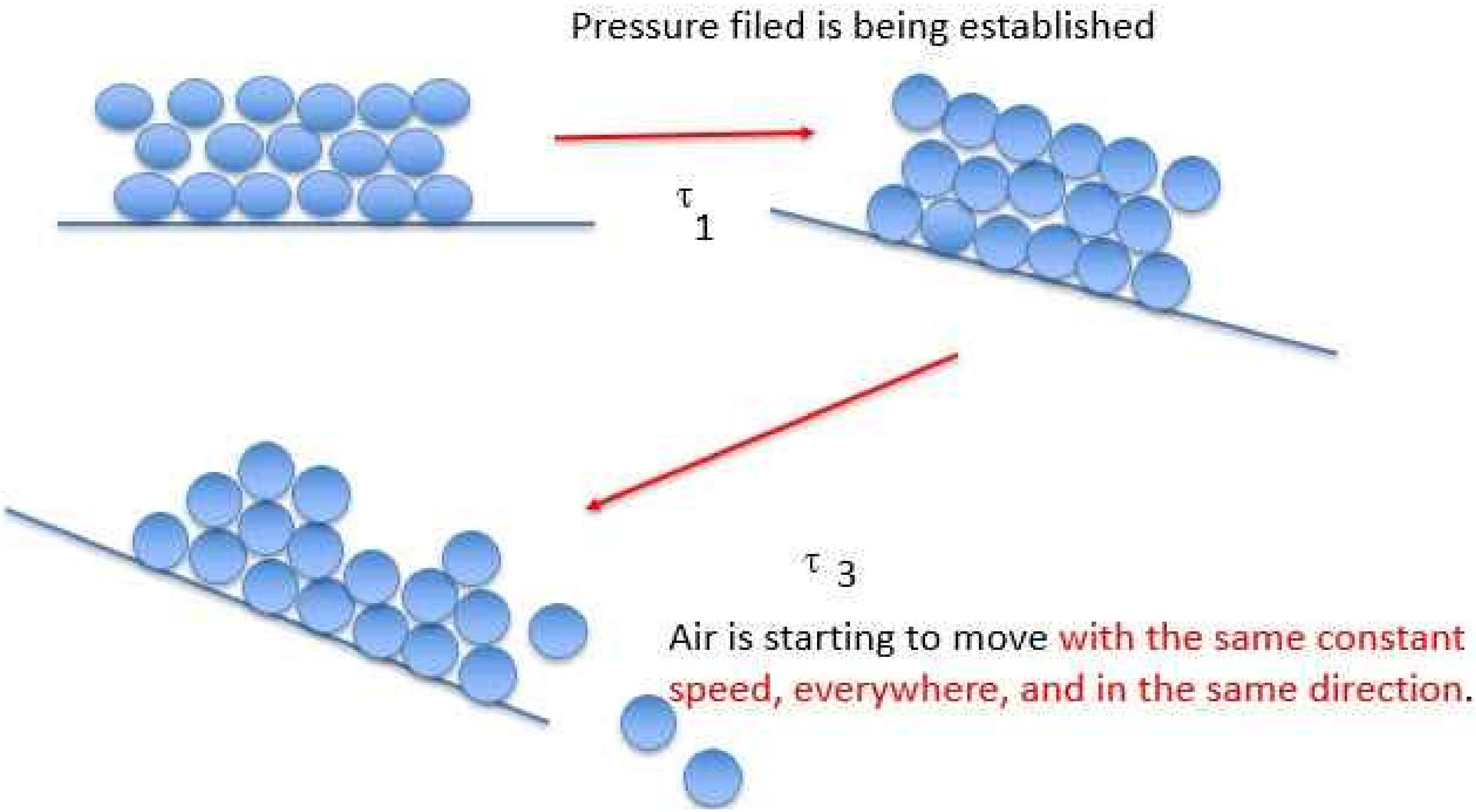
k= permeability through the pores, mu= viscosity for the fluid

Use Energy conservation

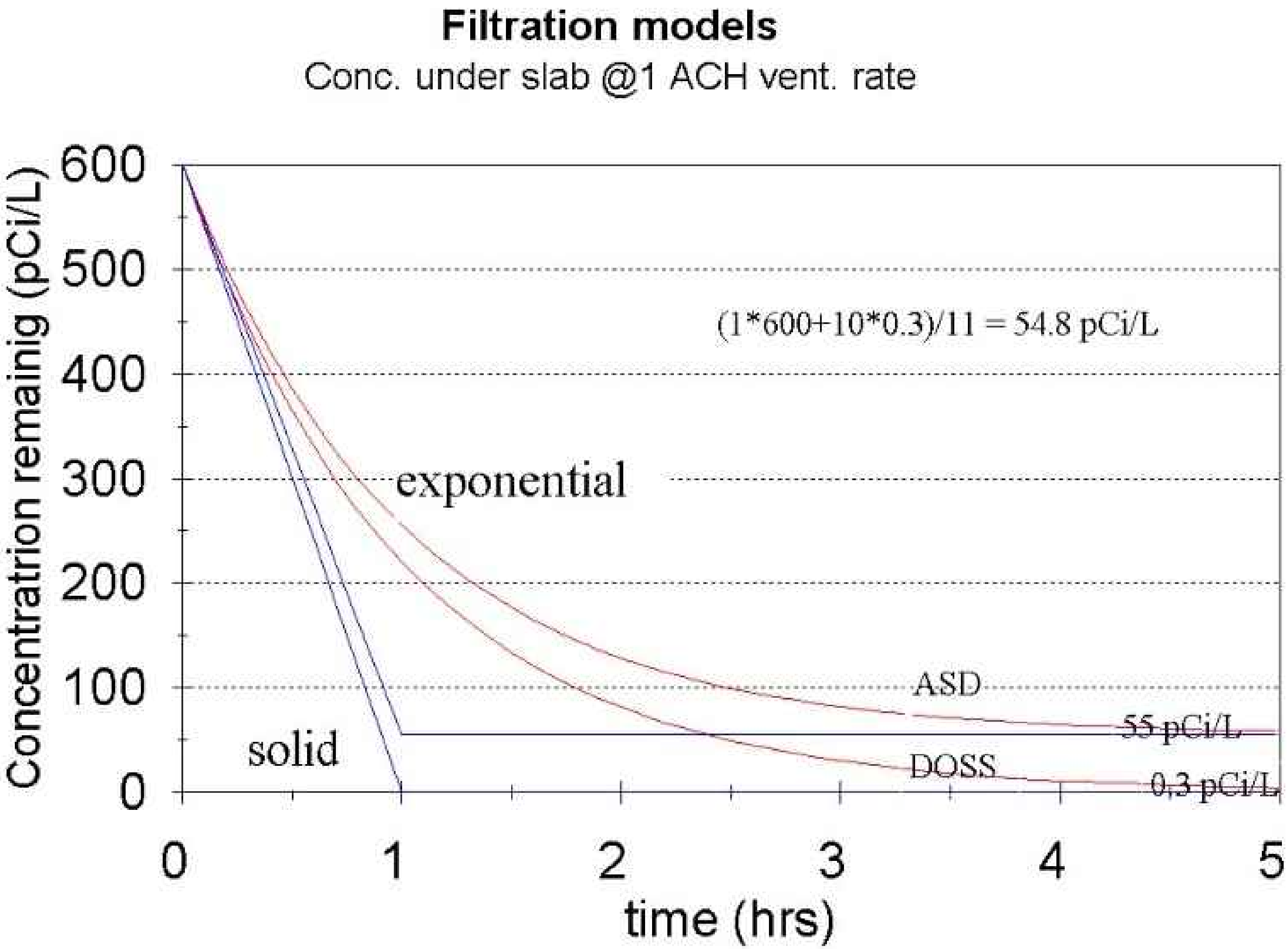
- $p(x, y, z, t) = p_0\left(\frac{z}{L}\right) + terms\ dying\ off\ quickly$
- How quickly?
- $\tau_{c1} < \frac{\alpha}{\left(\frac{\pi}{D}\right)^2} = \alpha\left(\frac{D}{\pi}\right)^2 = \left(\frac{\theta_a \mu}{kP_0}\right)\left(\frac{D}{\pi}\right)^2 \equiv \tau_{c2}$
- $\vec{f}_z = -\vec{\nabla} p_\infty(z) = -\frac{p_0}{L}\,\vec{e}_z$
- 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

“Dumptruck” Model

(for DOSSV only, not for ASD)



Efficiency for radon removal of DOSSV is better than ASD



Summary

- New, DOSSV proposed for new construction allows solving a much simpler 1- dim problem, (Steady State solution) for 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 DOSSV in New Home Construction:

- Final radon concentrations are expected lower than with ASD.
- # of main extraction vent pipes in large footprint buildings, or large open work areas can be reduced.
- Lower power fans can be as effective for similar buildings.
- Allows optimization during architectural phase by the gravel choice.
- The same configuration can be used to minimize Vapor Intrusion more effectively into the building.