REFCOMM GALVESTON
May 4-8, 2015

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New and Old Equations Tie Together 75 Years of FCC Standpipe Experience

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75 Years of FCC Standpipe Experience

Presentation Outline

- Framing the standpipe problem
- Standpipe performance issues
- Actual and apparent density
- Where aeration goes
- Theoretical aeration rates
- Different aeration mediums
- Catalyst properties
- Available tools
- Commercial examples

Niccum, P.K., Update on the catalytic cracking process and standpipes—Parts 1 & 2, Hydrocarbon Processing, March & April, 2015

Invention of Fluid Solids Standpipe

FCC Demonstration Plant in 1940

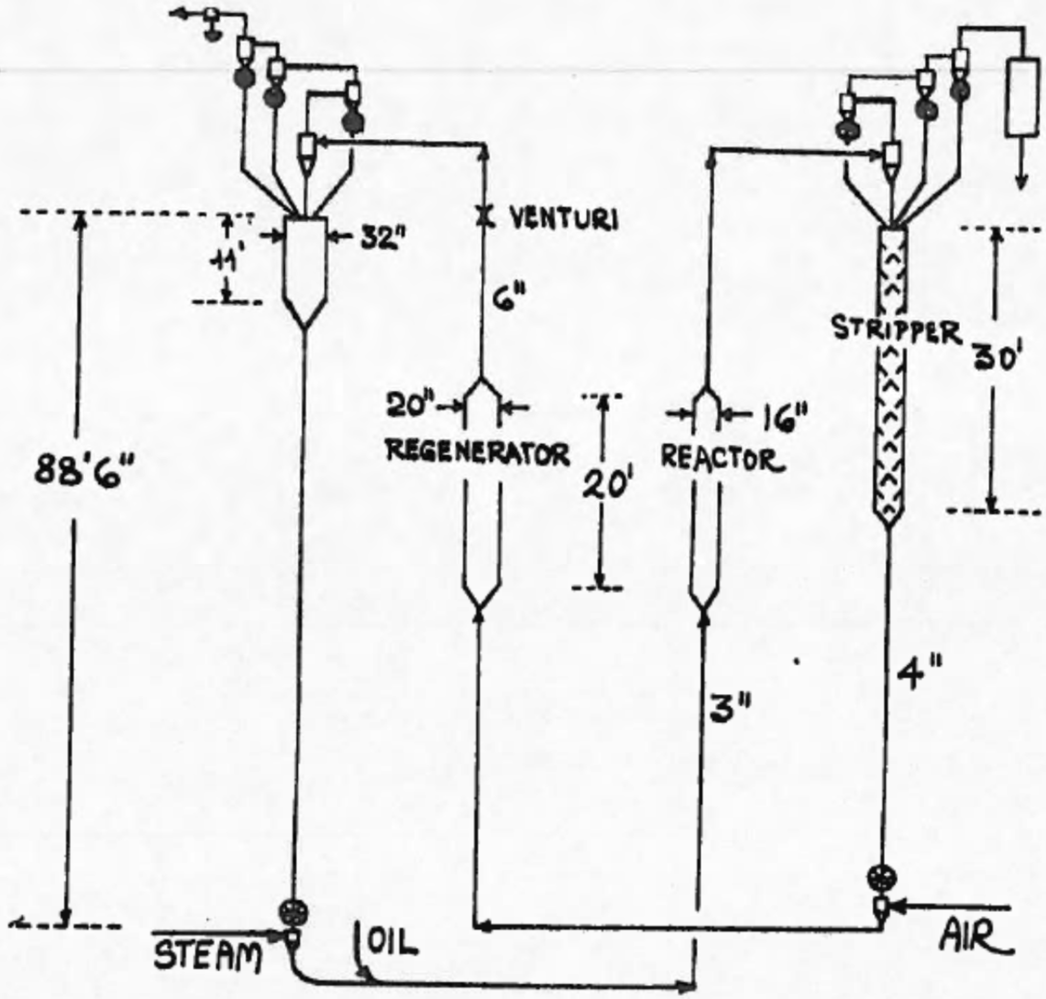
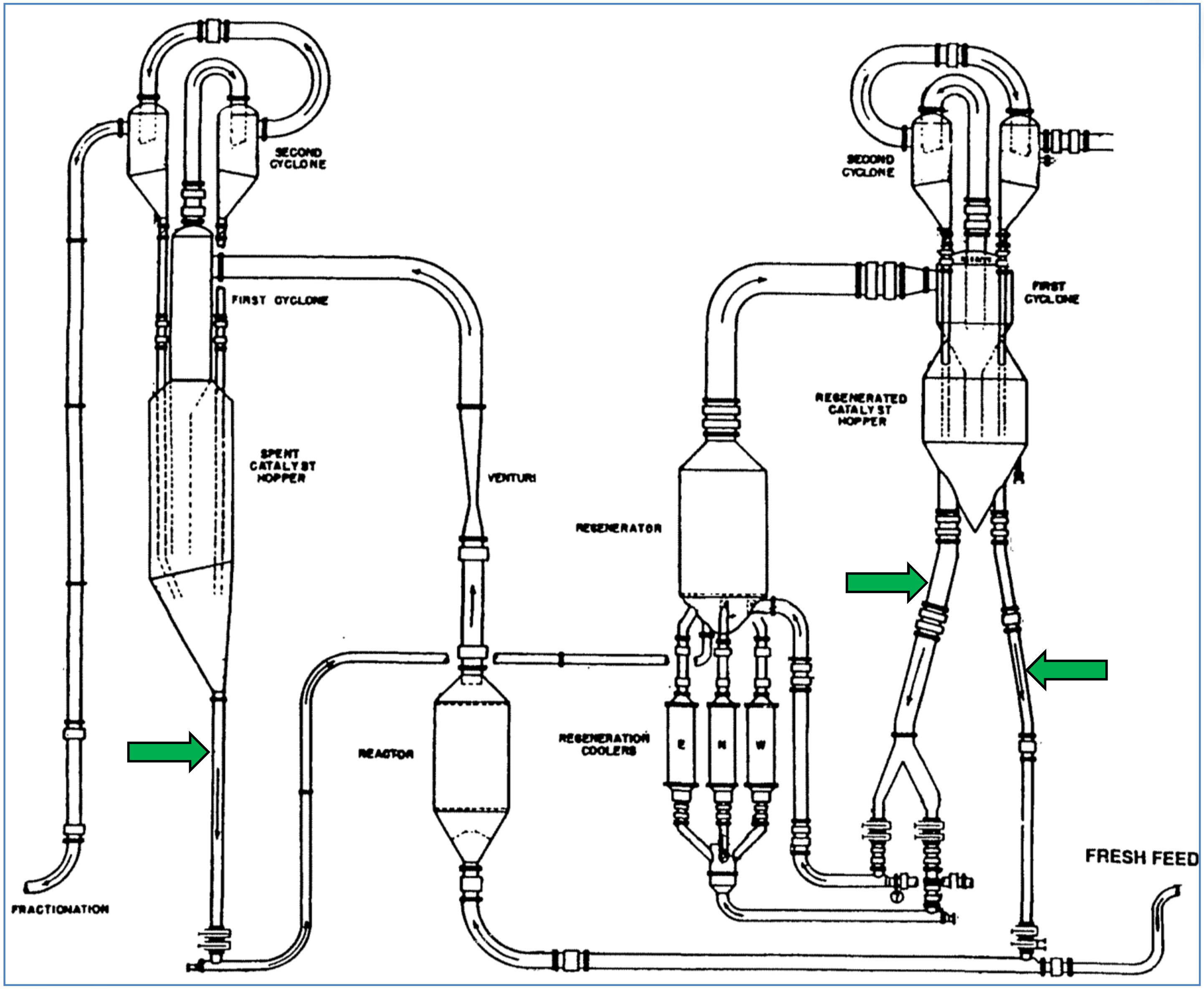


Fig. 4. Drawing (June 21, 1940) of new "standpipe system" for installation at PECLa. There was also a circuit for catalyst flow from the 32-inch hopper to a catalyst cooler and into the bottom of the regenerator.

Invention of Fluid Solids Standpipe

1942 - First Commercial FCC Unit



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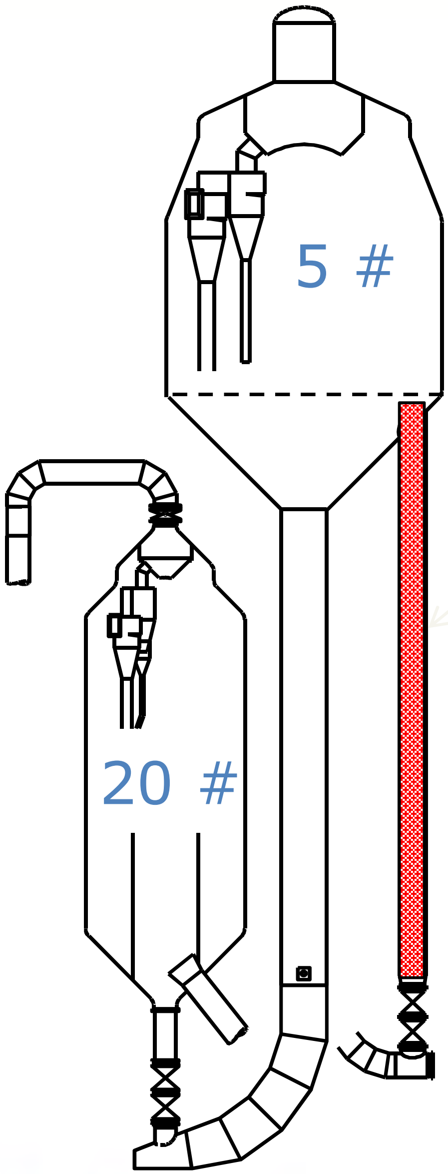
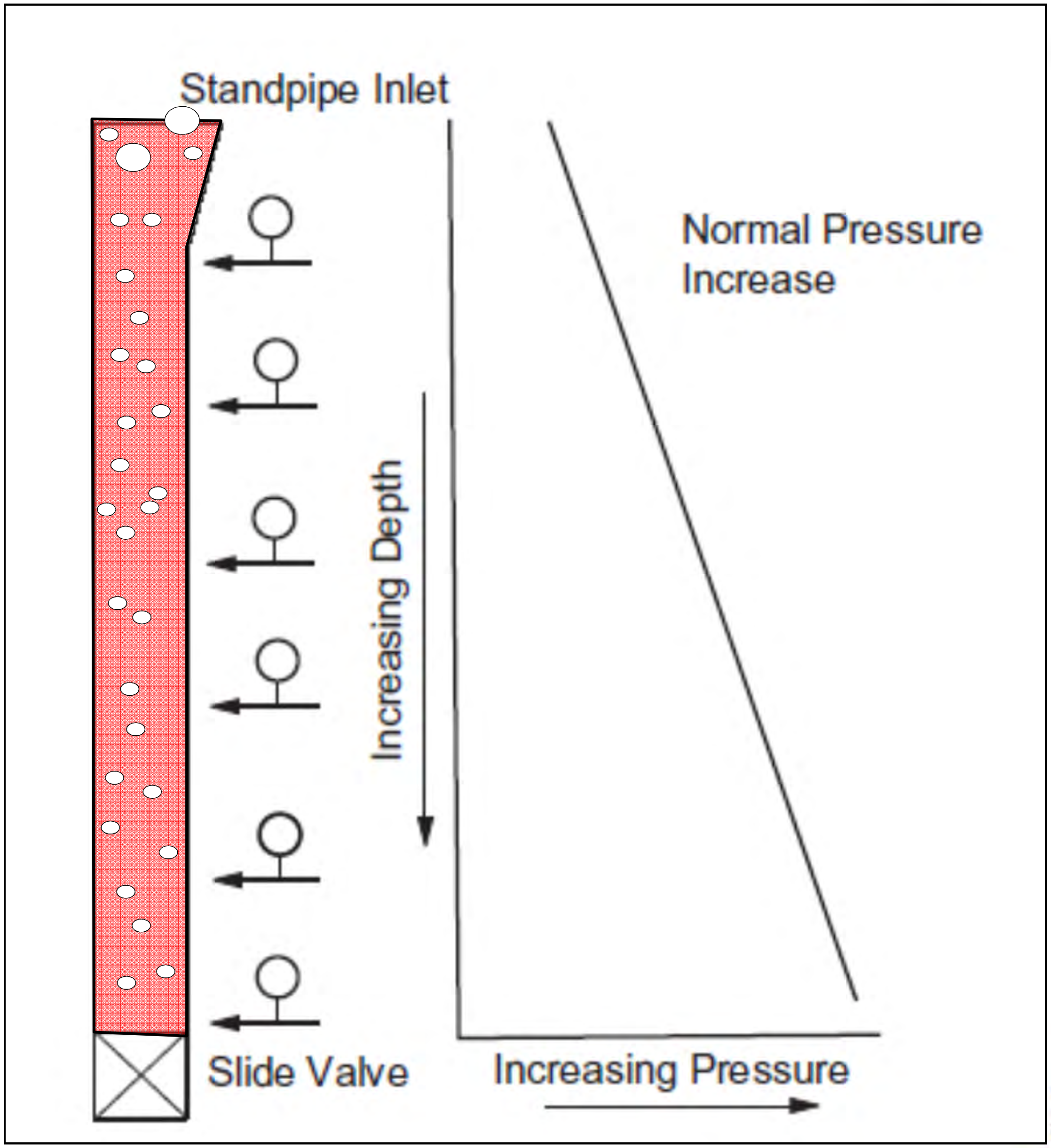
Idealized Fluid Solids Standpipe



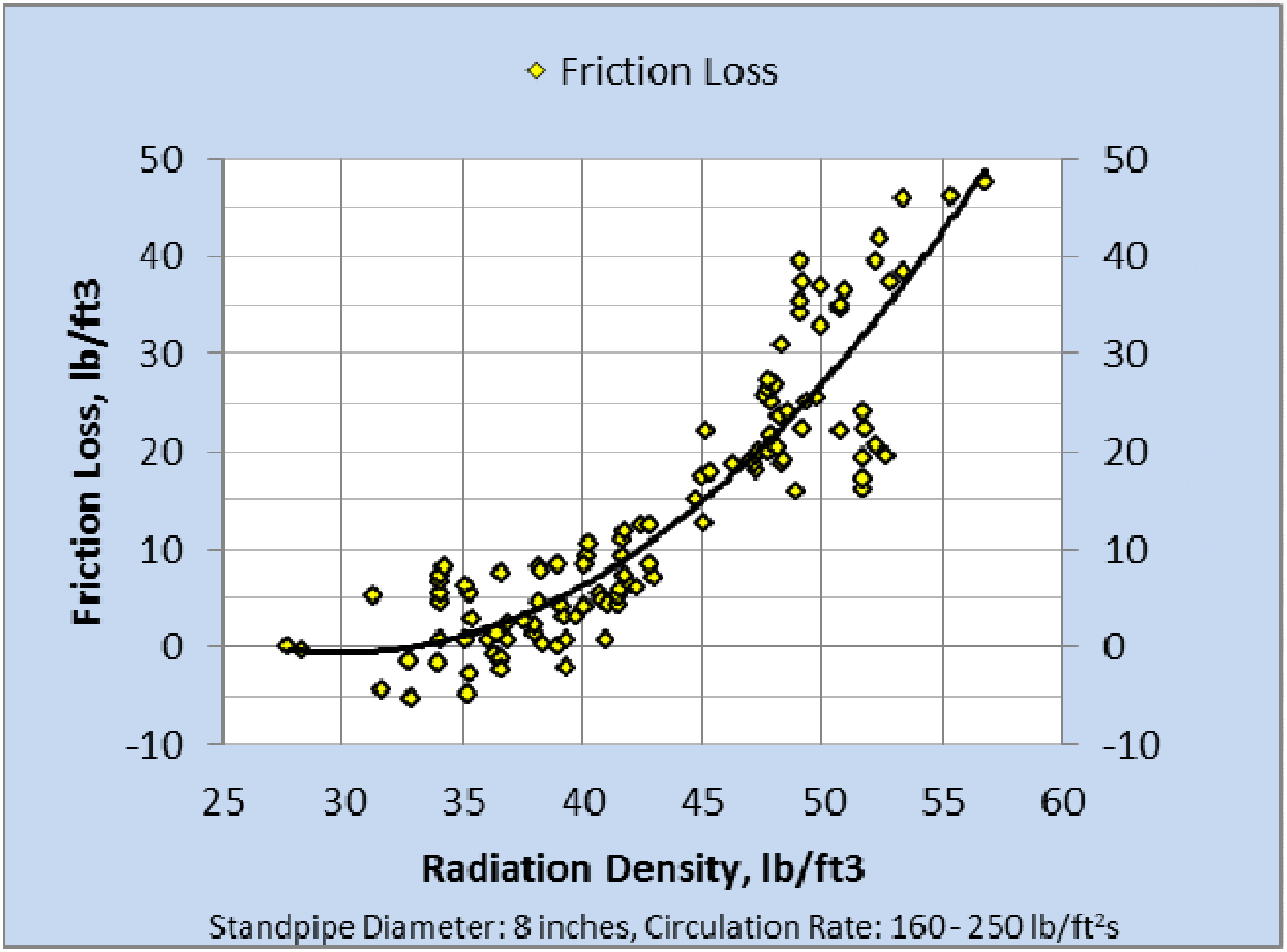
Static head builds pressure above catalyst valve



Recognizing Standpipe Performance Issues

- Symptoms of Standpipe Problems
  - Low or erratic standpipe pressure build-up
  - Over-sensitivity to changes in FCC unit operating conditions or catalyst physical properties.
- Common Problem Areas
  - Standpipe inlet design
  - Standpipe geometry
  - Standpipe aeration
  - Catalyst issues
- Not Standpipe Problems
  - Riser pressure drop is high
  - Reactor – Regenerator pressure differential is limiting
  - Required catalyst circulation rate has increased

Frictional Forces Offset Static Head

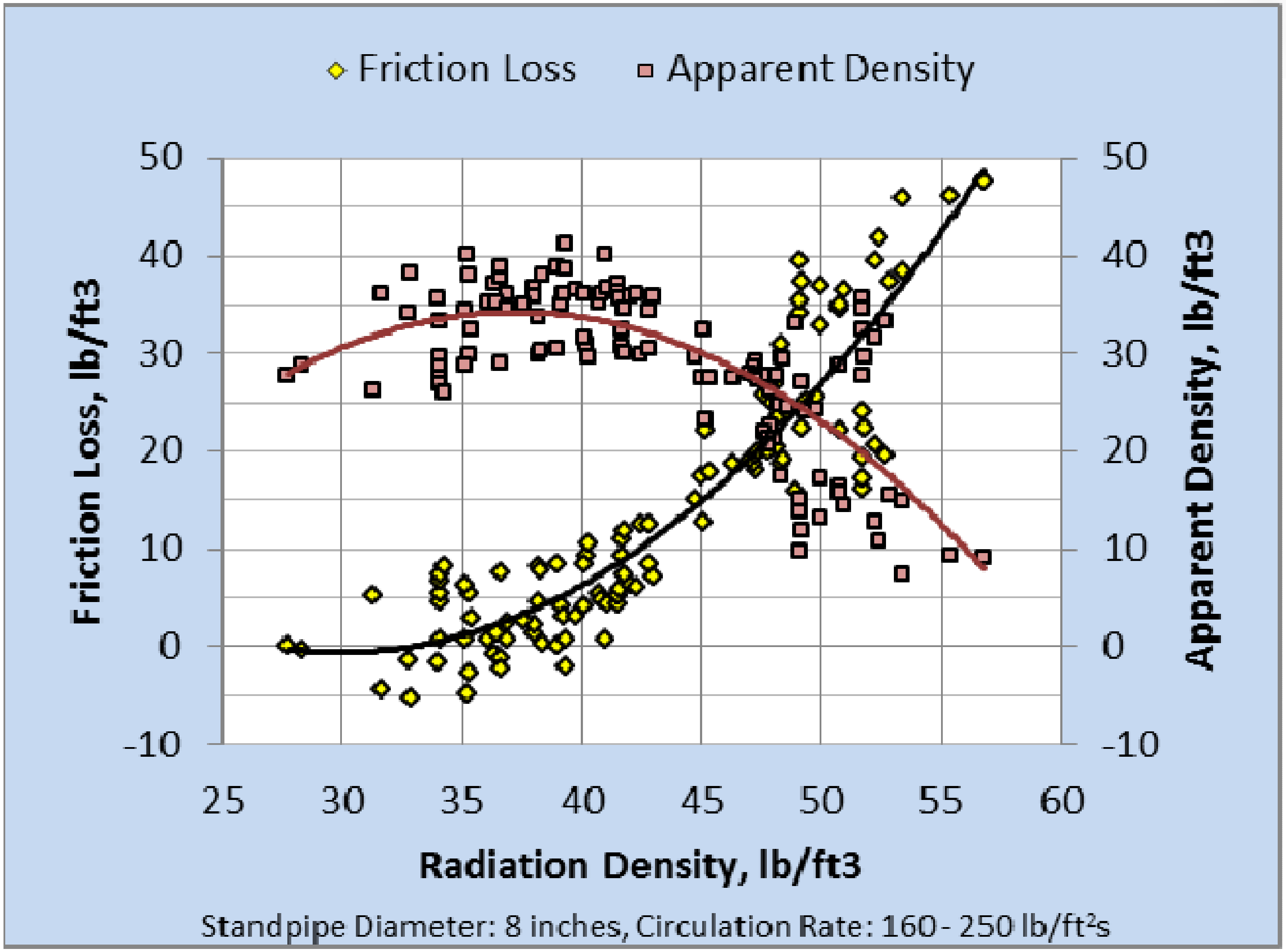


Minimum Fluidization Density: 41.0 lb/ft3, Loose Settled Density: 45.2 lb/ft3, Packed Density: 50 lb/ft3

John Matsen, "Some Characteristics of Large Solids Circulation Systems", Fluidization Technology, 1976

Actual vs. Apparent Standpipe Density

Actual density is not apparent from ΔP/ΔL



Minimum Fluidization Density: 45 lb/ft3, Loose Packed Density: 45 lb/ft3, Packed Density: 50 lb/ft3

John Matsen, "Some Characteristics of Large Solids Circulation Systems", Fluidization Technology, 1976

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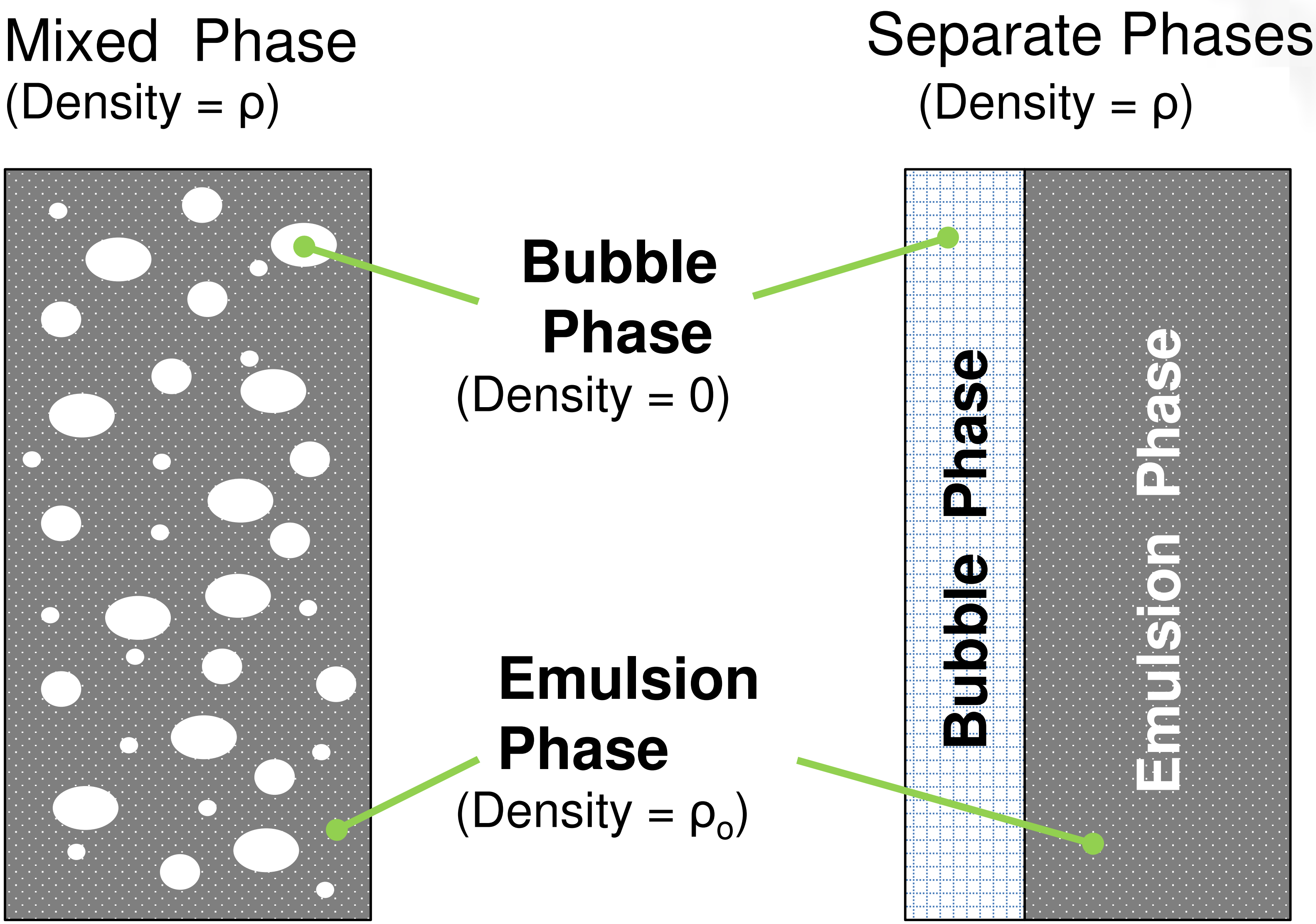
Simplified Solids and Gas Modeling



Phase Parameters – Without Slip

Derived from simple mass/volume balances

	Mixed Phase	Bubble Phase	Emulsion Phase
Phase Density	ρ	0	ρ_o
Phase Voidage	$1 - \rho/\rho_s$	1	$1-\rho_o/\rho_s$
Phase Fraction	1	$1-\rho/\rho_o$	ρ/ρ_o
Phase Velocity	w/ρ	w/ρ	w/ρ

Phase Parameters – With Slip

Derived from simple mass/volume balances

	Bubble Phase	Emulsion Phase
Phase Fraction	$1-\rho/\rho_o$	ρ/ρ_o
Phase velocity	$w/\rho + U_b$	w/ρ
Contribution to Gas SVV	$(w/\rho + U_b)\,(1-\rho/\rho_o)$	$w\,(1/\rho_o - 1/\rho_s)+U_o\,\rho/\rho_o$
Total SVV, U_t	$w\,(1/\rho - 1/\rho_s) + U_b\,(1-\rho/\rho_o) + U_o\,\rho/\rho_o$	

U_b – Relative Bubble Rise Velocity, U_o – Minimum Fluidization Velocity

Density as a Function of U_t and Mass Flux

$$U_t = U_b\left(1 - \frac{\rho}{\rho_o}\right) + w\left(\frac{1}{\rho} - \frac{1}{\rho_s}\right) + U_o\frac{\rho}{\rho_o}$$

$$\boldsymbol{\rho}^2 + \boldsymbol{\rho}\left[\frac{(U_t - U_b + w/\rho_s)}{(U_b - U_o)}\rho_o\right] - \frac{w\ \rho_o}{(U_b - U_o)} = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Quadratic equation can yield two roots

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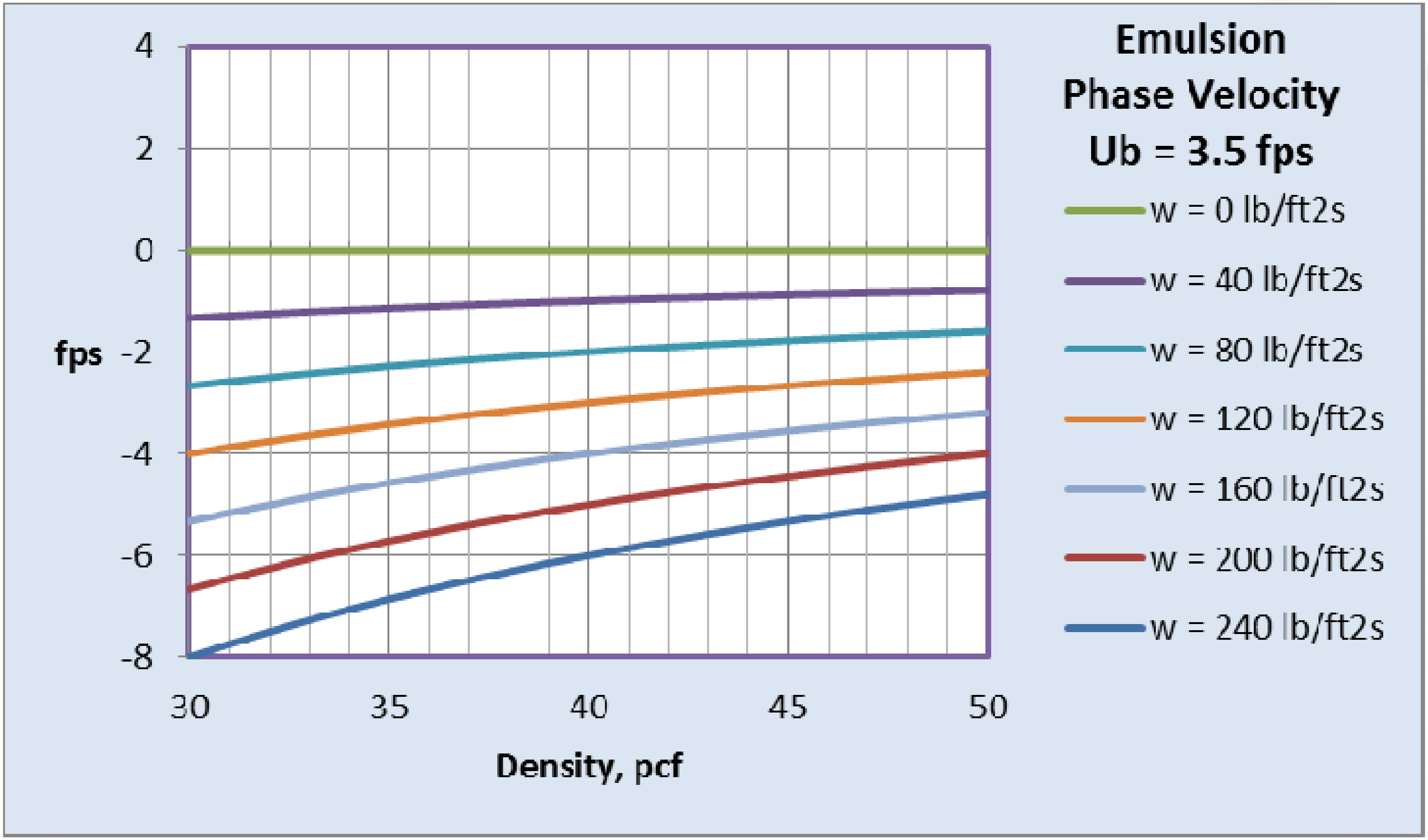
Velocity of Emulsion Phase

The emulsion phase always travels down



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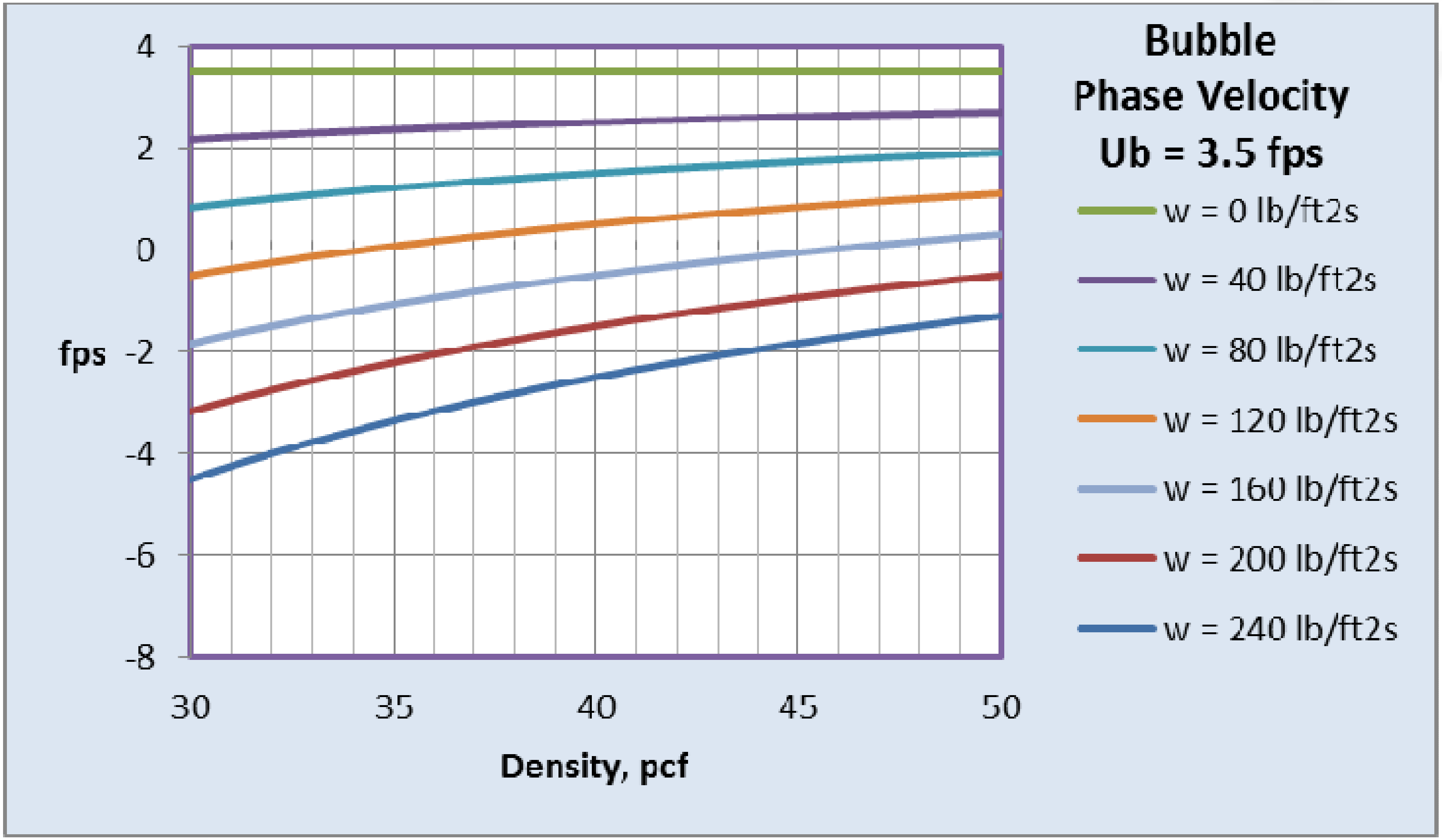
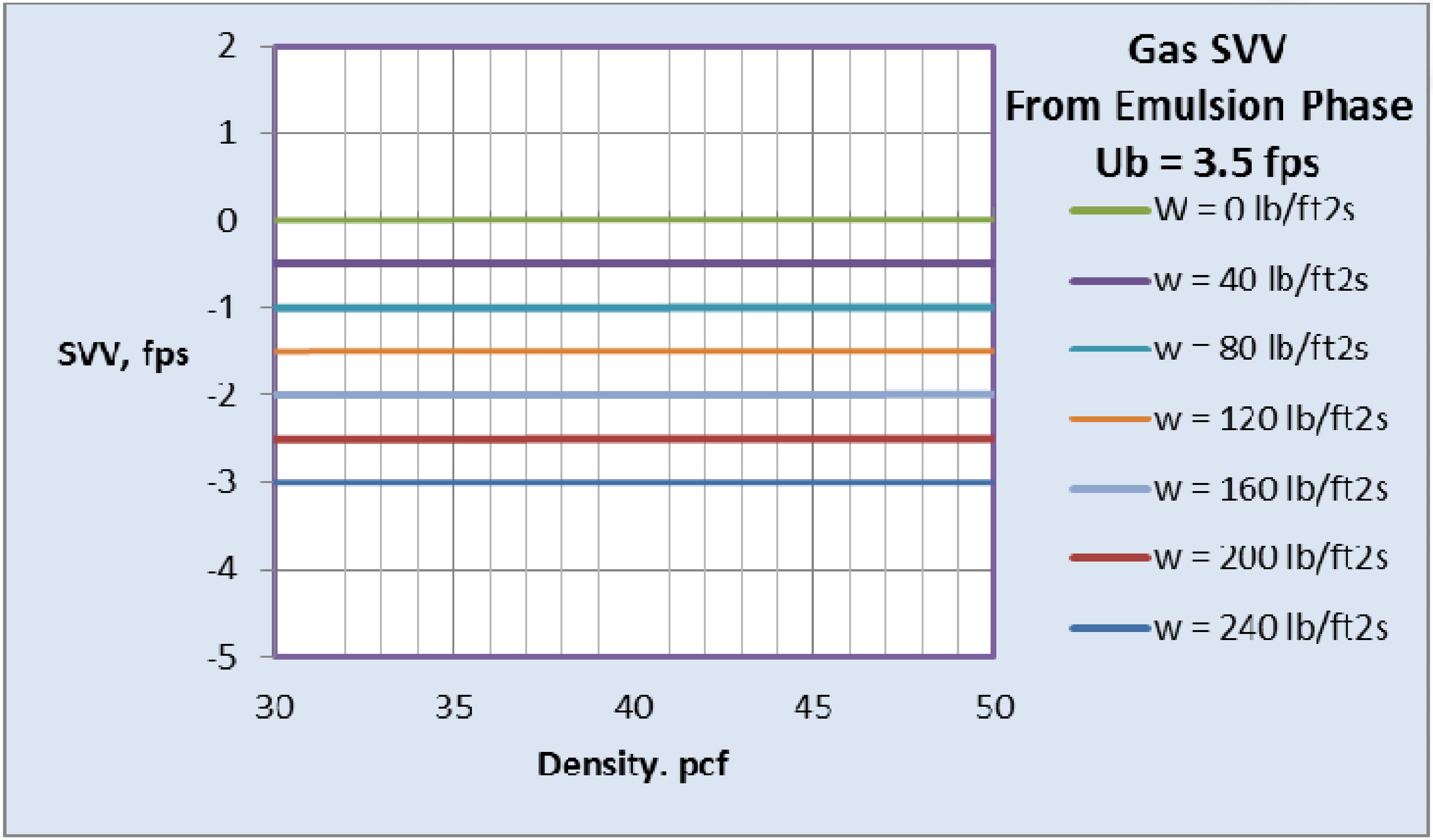
Velocity of Bubble Phase

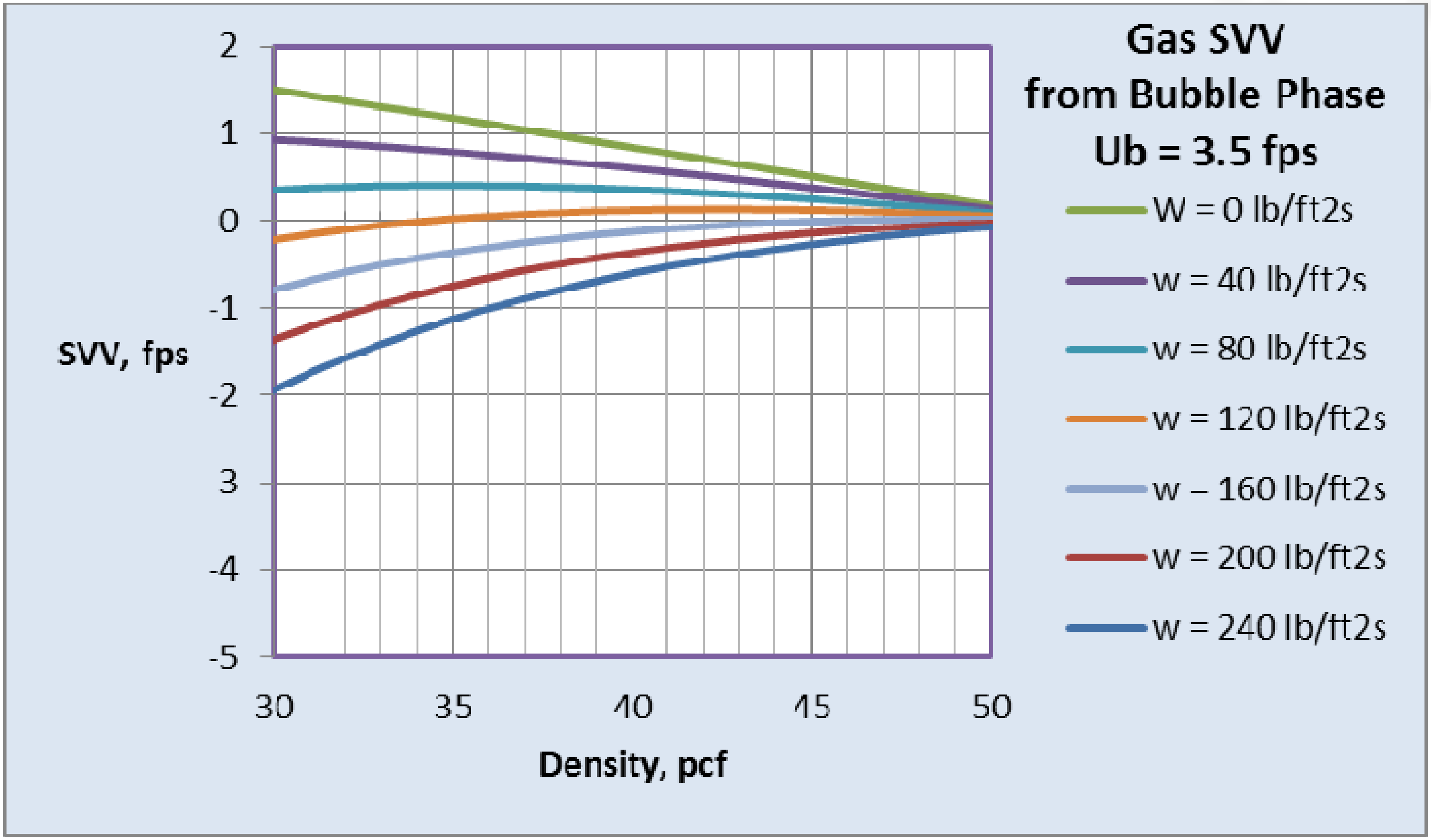
The bubble phase can travel up or down



SVV Contribution from Emulsion Phase

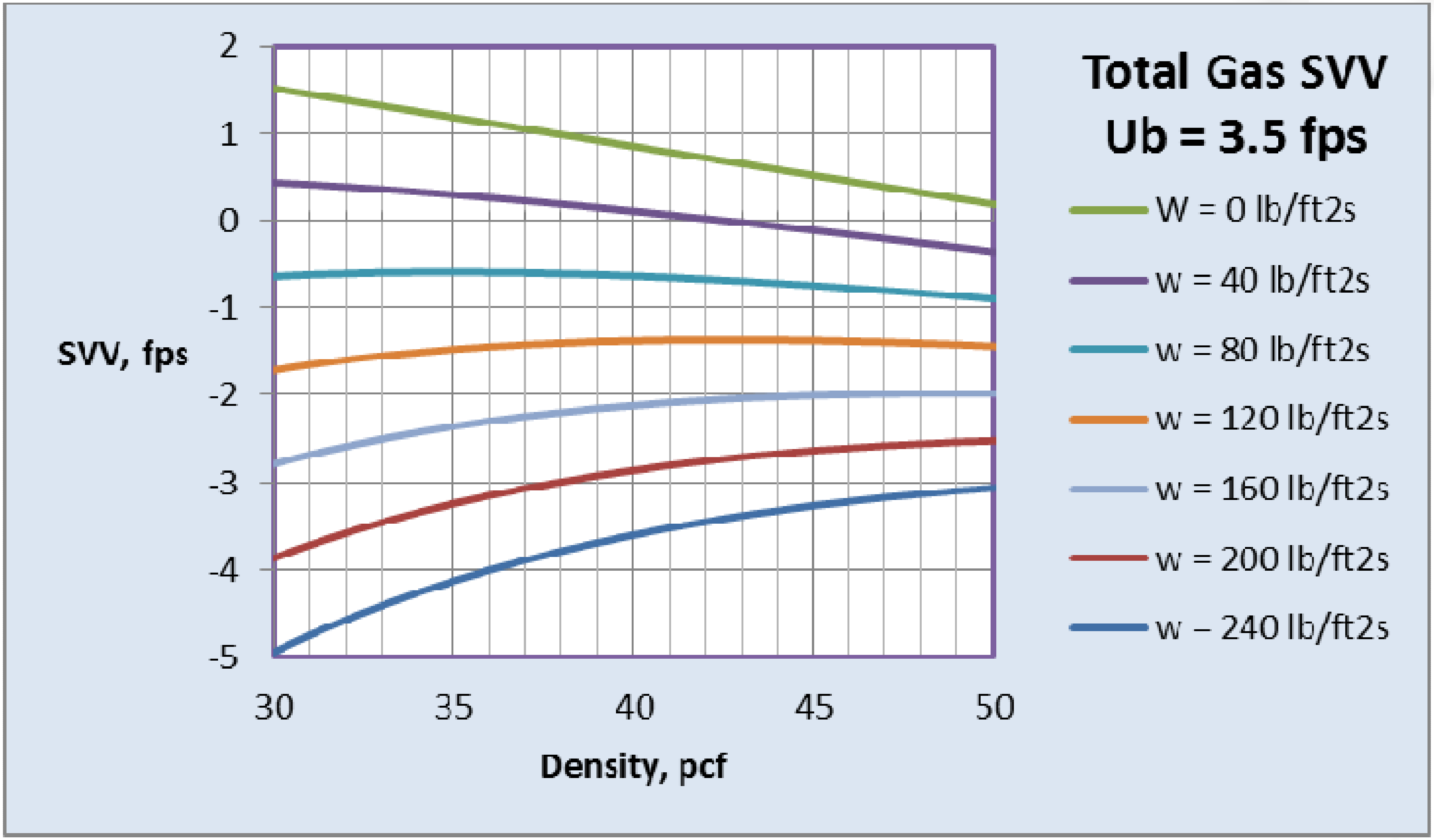


SVV Contribution from Bubble Phase



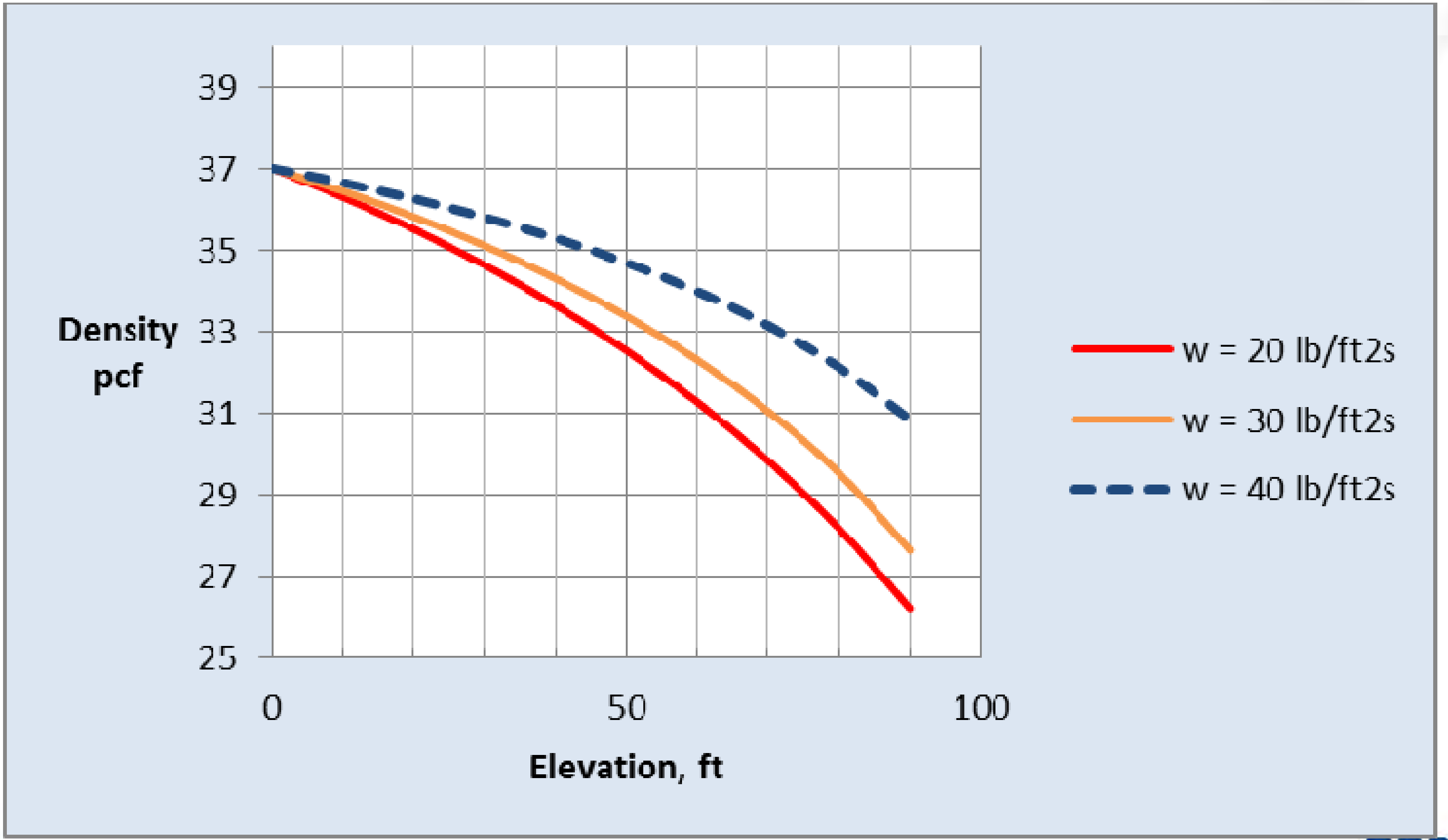
Total SVV Through Standpipe

Sum of emulsion and bubble phase contributions



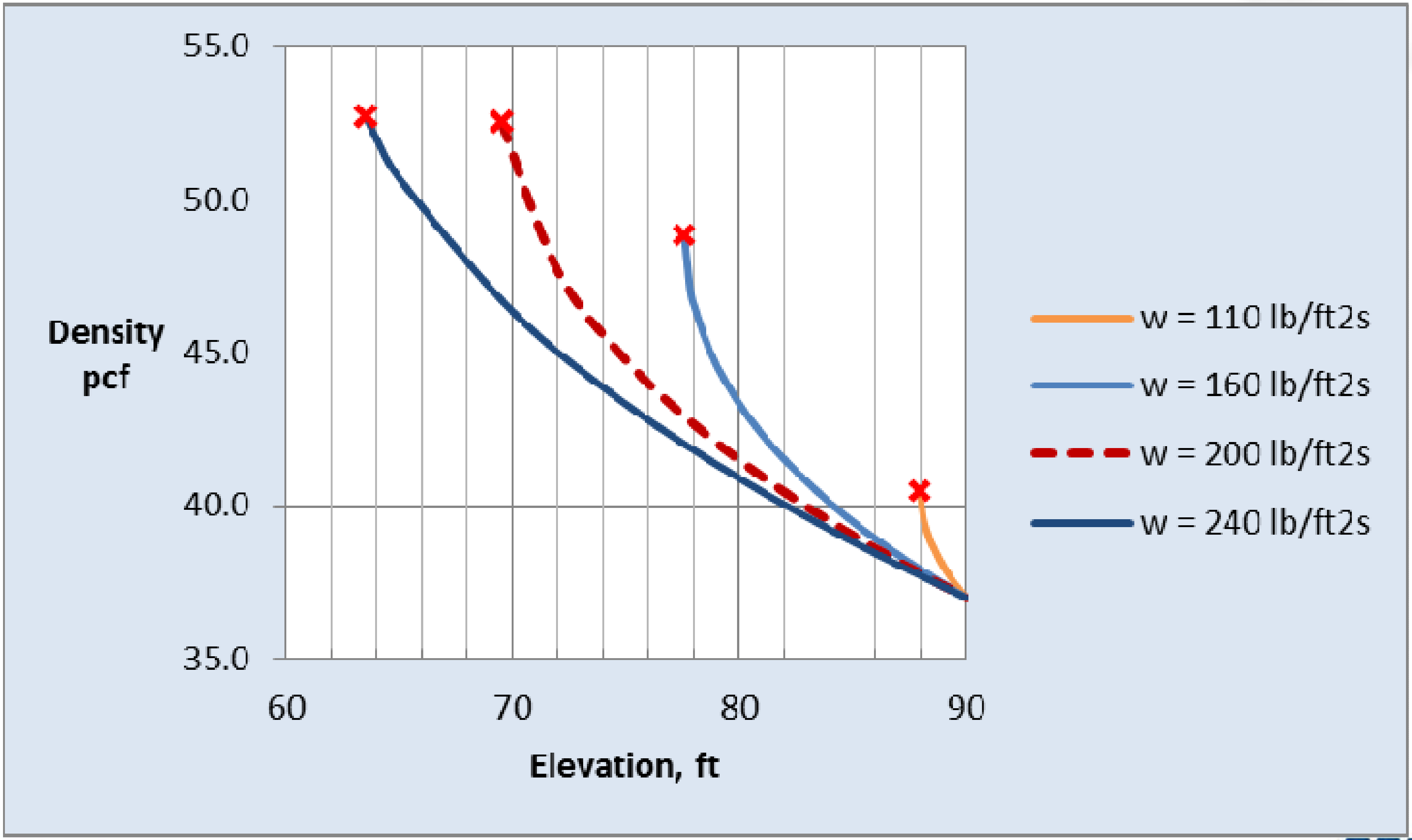
Density in Gas Upflow Standpipe

Gas velocity increases as the gases move up



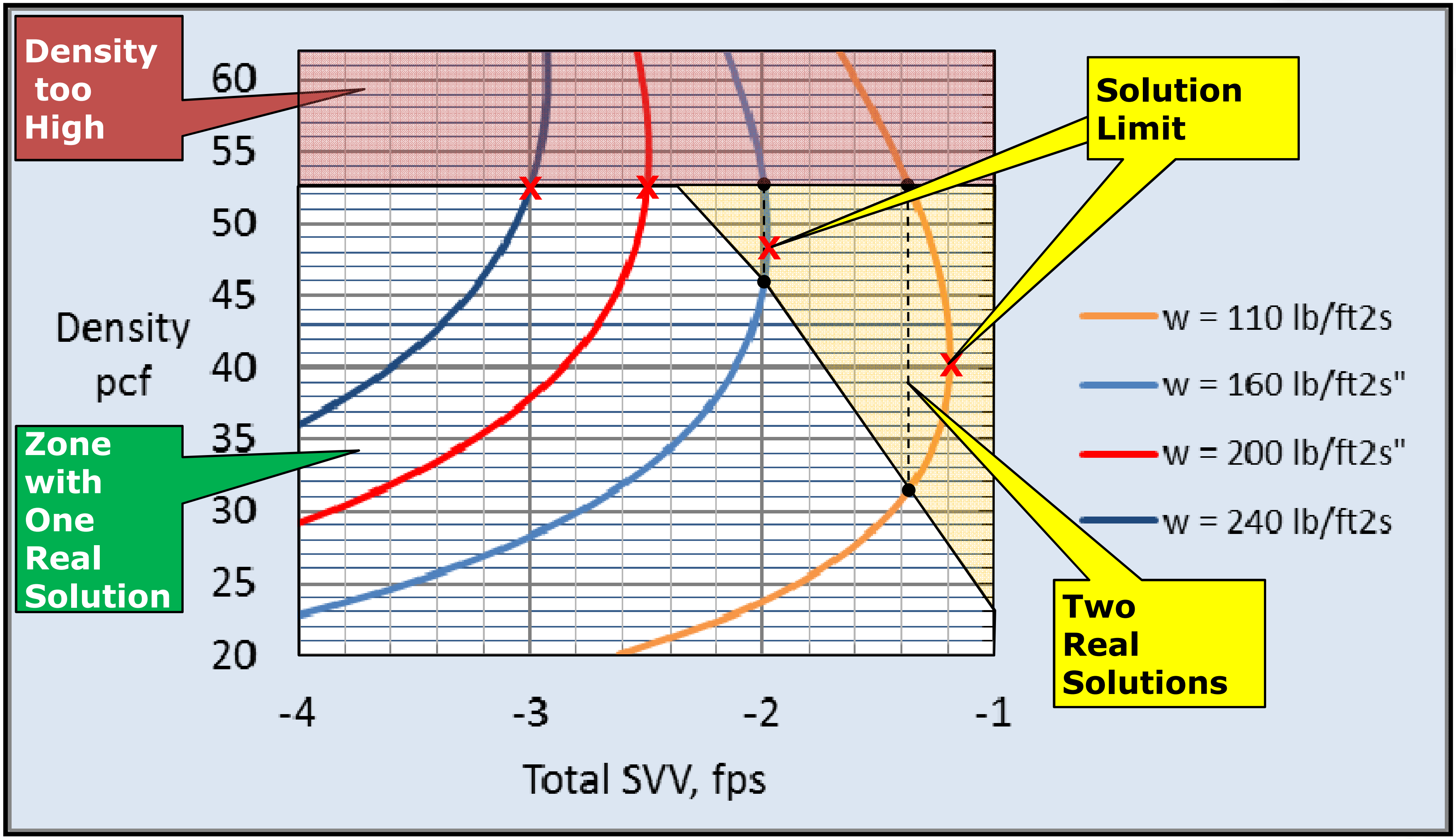
Density in Gas Downflow Standpipe

Without aeration, gas slows as it moves down



Density in Gas Downflow Standpipe

Based on U_b = 3.5 fps



Theoretical Aeration Rate

Derived from equations to keep U_t constant

$$\Delta R = U_t\, A \left(\frac{520}{T + 460}\right) \times \left(\frac{\rho\, \Delta L}{144 \times 14.7}\right)$$

$$U_t = U_b \left(1 - \frac{\rho}{\rho_o}\right) + w\left(\frac{1}{\rho} - \frac{1}{\rho_s}\right) + U_o \frac{\rho}{\rho_o}$$

Theoretical Aeration Rate

Derived from equation for U_t

$$\frac{\Delta R}{\Delta L} = \frac{A\,520\,\rho\left[U_b\left(1-\frac{\rho}{\rho_o}\right)+w\left(\frac{1}{\rho}-\frac{1}{\rho_s}\right)+U_o\frac{\rho}{\rho_o}\right]}{2116\,(T+460)}$$

Multiply by 60 for SCFM

$$\frac{\Delta R}{\Delta L} = \frac{A\,520\,\rho \times w\left(\frac{1}{\rho}-\frac{1}{\rho_s}\right)}{2116\,(T+460)}$$

Simplified Equation Ignoring Slip

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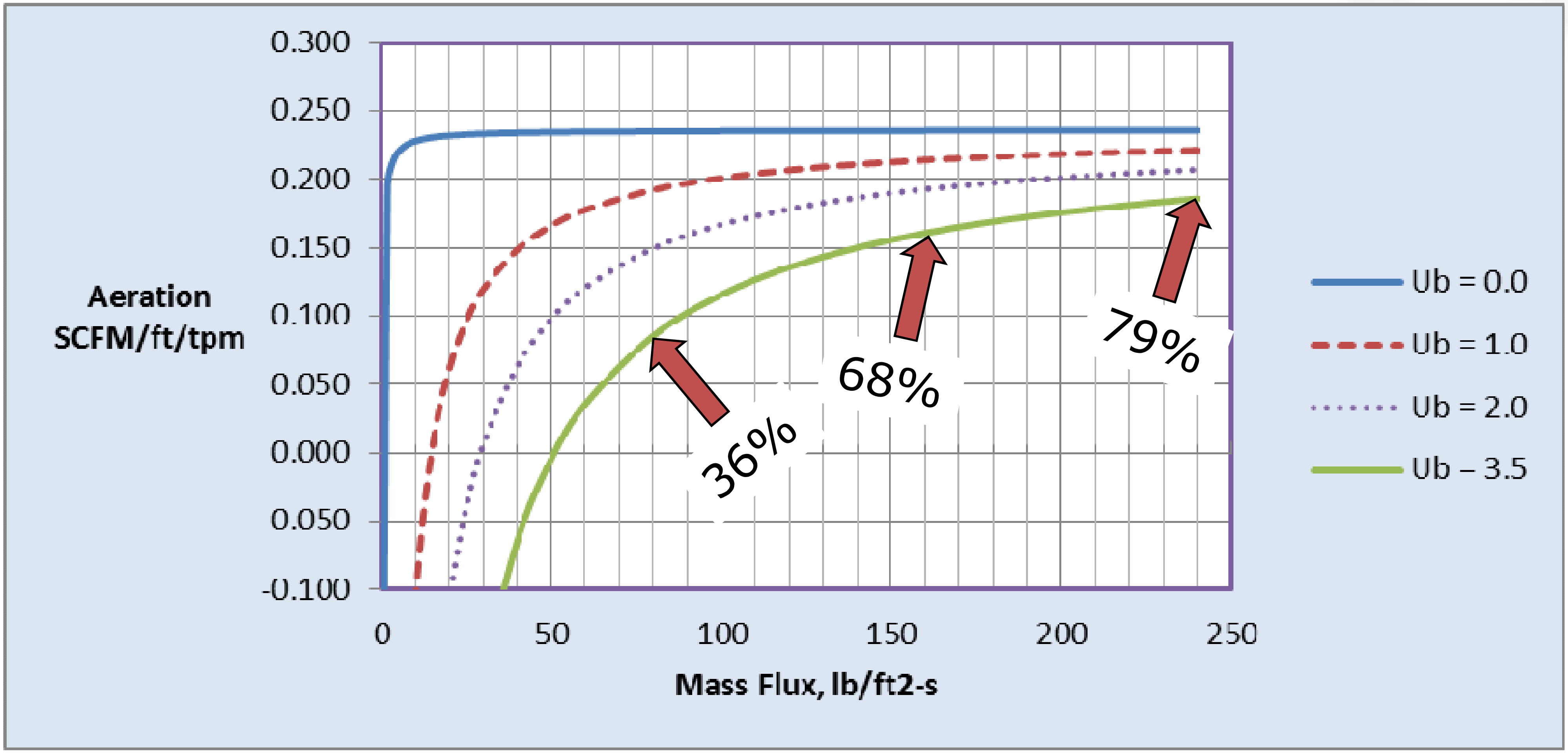
Theoretical Aeration Rates at 37 lb/ft^3

Required to maintain constant SVV and density



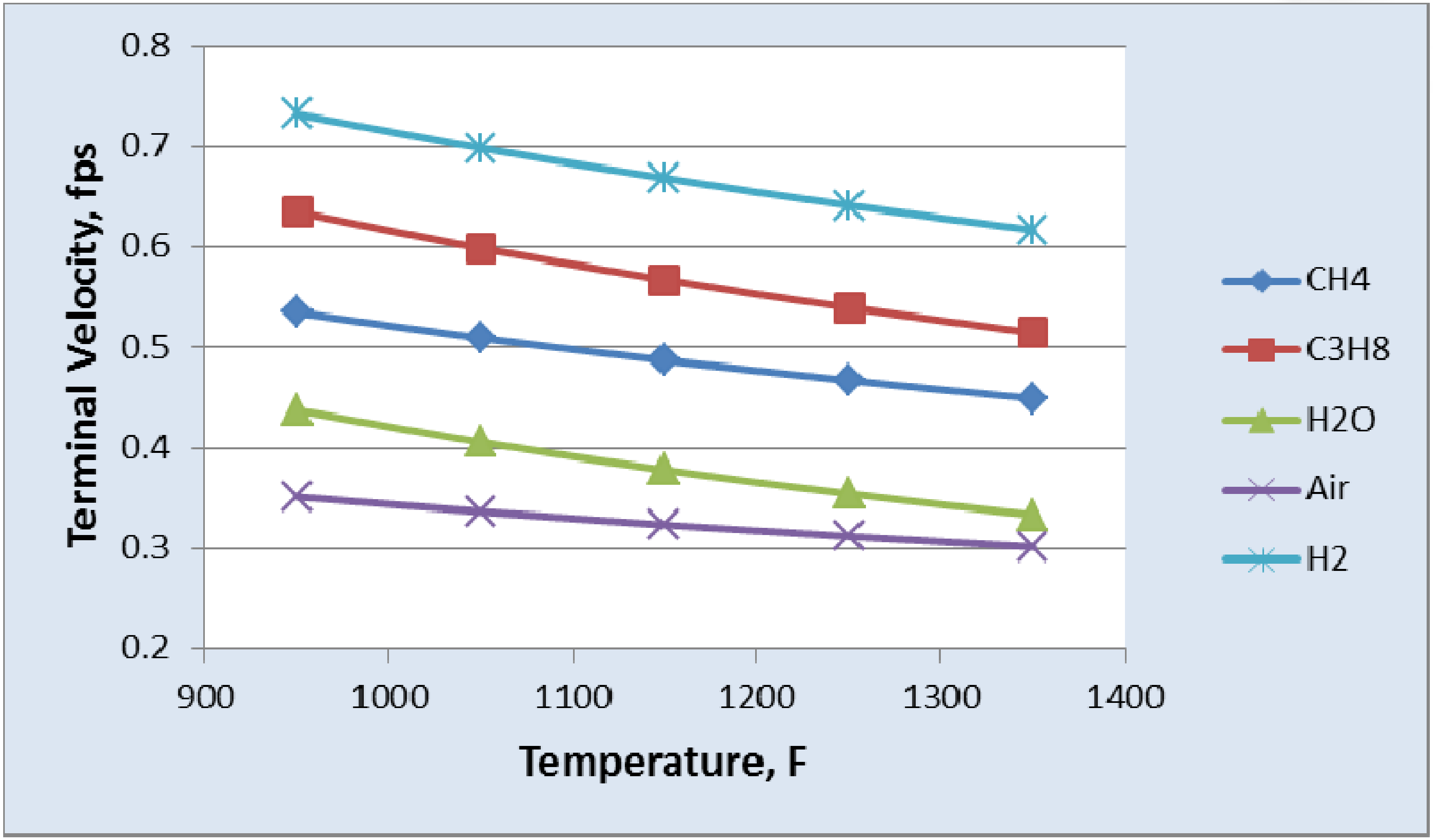
Standpipe Inlet

Good fluidization at inlet is of prime importance

- Feed Standpipe Well Fluidized Catalyst
  - Draw catalyst from a well fluidized area of bed
  - Disengage excess bubbles
  - Target desired standpipe density
- Inlet Types
  - Hole in the bottom head of vessel
  - Internal hopper
  - Externally fluidized side-draw hoppers

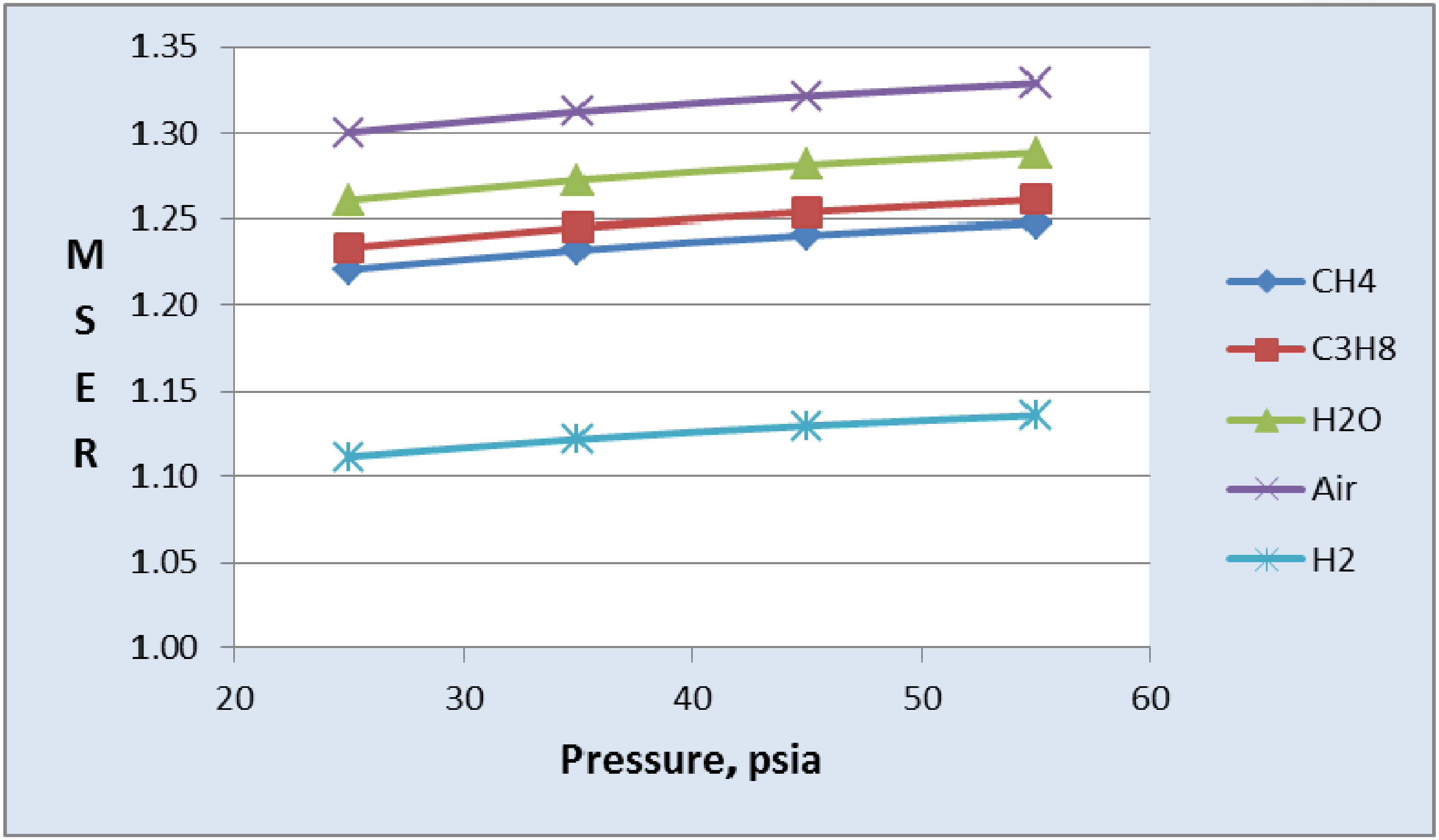
Impact of Aeration Medium

Based on a 70 micron FCC catalyst particle



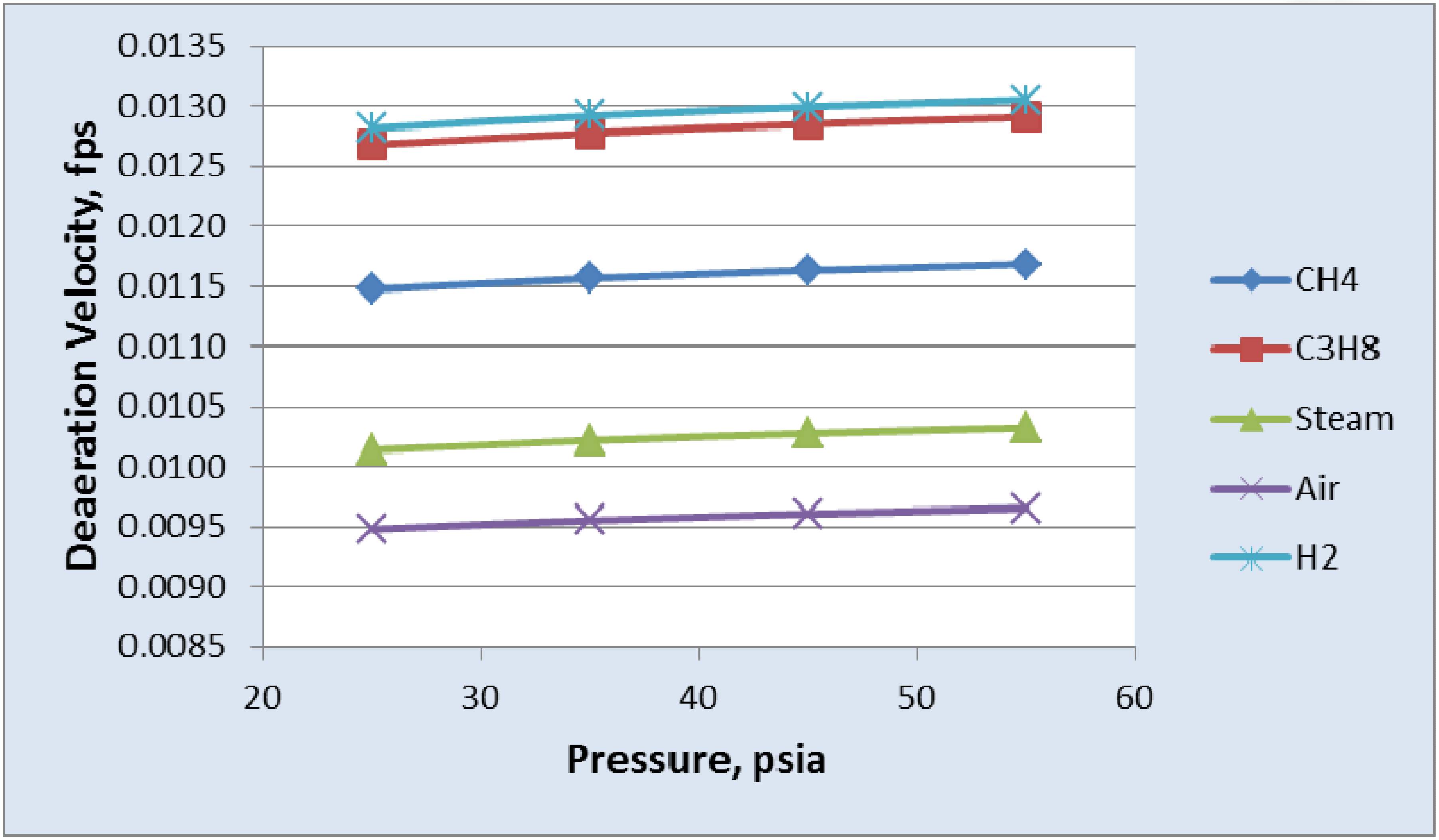
Impact of Aeration Medium

Based on representative FCC catalyst at 1150 °F



Impact of Aeration Medium

Based on a representative FCC catalyst at 1150 °F



Conclusion: Impact of Aeration Medium

Based on three indicators

- Air or Nitrogen
  - Best Aeration Mediums
- Steam
  - Not as effective as air
  - Condensation complicates application
- Hydrocarbons
  - Low gas viscosity makes hydrocarbons ineffective as aeration mediums
- Hydrogen
  - Low gas viscosity and very low density makes hydrogen a very ineffective aeration medium

Impact of Fines, D_P and Density

Based on MSER changes over range of interest

Fraction < 45 microns	MSER % of base
0.20	103.2
0.15	102.4
0.10	101.6
0.05	100.8
0.00	100.0

Particle Density, g/cc	MSER % of base
0.80	102.9
0.83	102.1
0.86	101.4
0.89	100.7
0.92	100.0

Dp, microns	
65	104.8
70	103.5
75	102.2
80	101.1
85	100.0

- Conclusion
  - All three parameters are important

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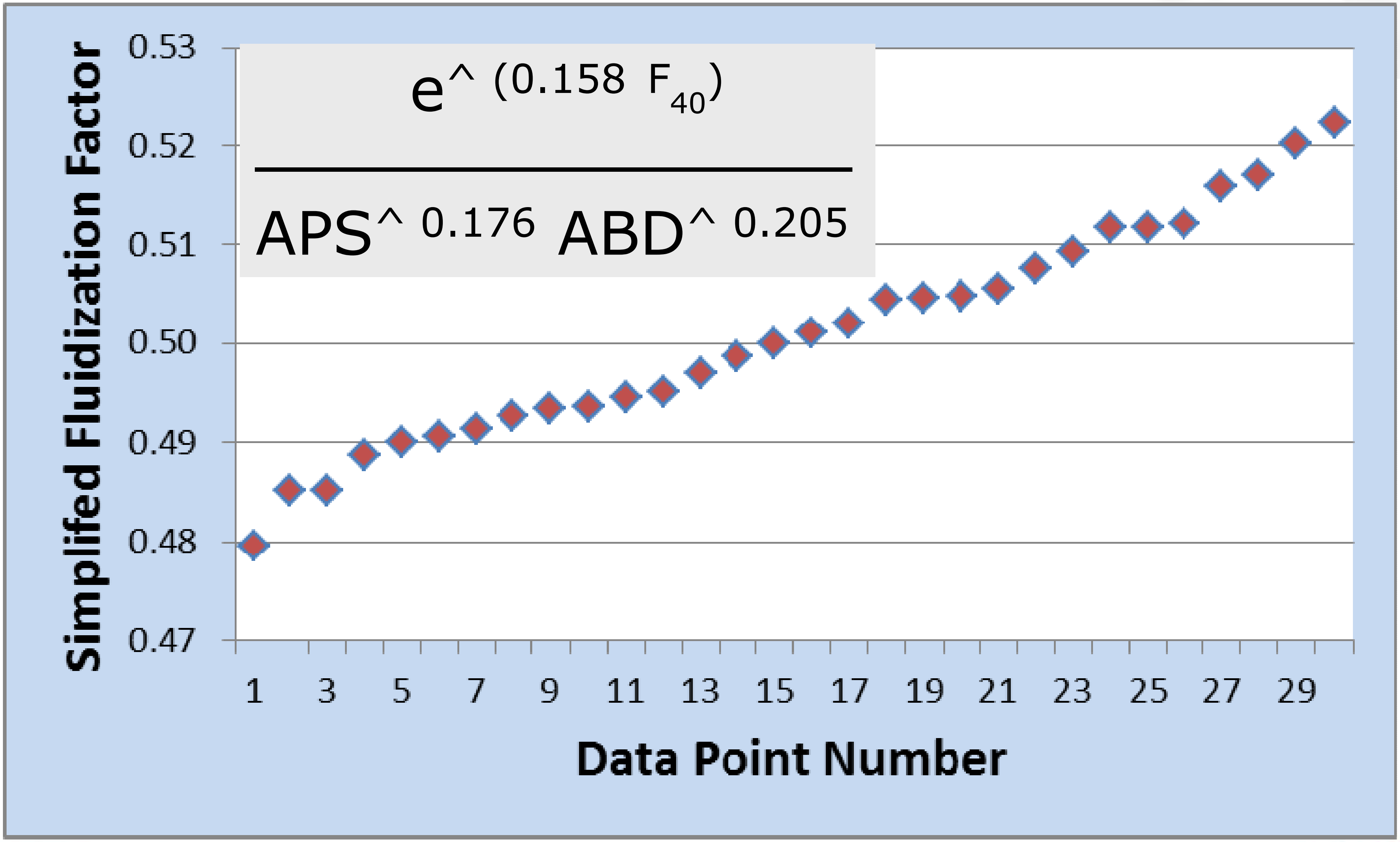
Simplified Fluidization Factors

Based on E-cat data from 15 FCC units

$$\frac{e^{(0.158\ F_{40})}}{APS^{0.176}\ ABD^{0.205}}$$



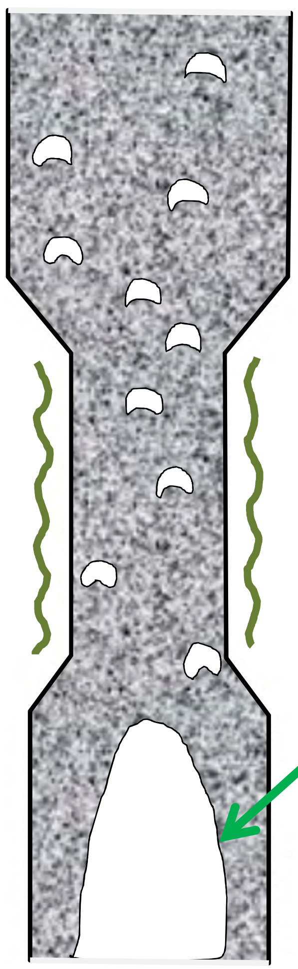
Available Tools

For diagnosing standpipe issues

- Pressure Profile Data
  - Single gauge pressure surveys
  - DCS data print-outs and trends
  - High speed multipoint data recordings
- Aeration and Fluidization Gas Rate Trials
- Computational Fluid Dynamic (CFD) and Cold Flow Modelling Studies
- Gamma Ray Scans

Example 1: Geometric Gas Trap

Preventing upward migration of bubbles



58 Inch ID
1.9 fps Solids Velocity
80 lb/ft^{2}s Mass Flux

35.5 Inch ID
5.4 fps Solids Velocity
227 lb/ft^{2}s Mass Flux

Bubble held stationary by down-flowing solids

45.5 Inch ID
3.1 fps Solids Velocity
129 lb/ft^{2}s Mass Flux

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Example 2: Geometric Trap

Preventing bubble migration

- Vertical Section
  - Catalyst drags bubbles down
- Inclined Section
  - Catalyst slides down under rising bubbles
- Process Dynamic
  - Bubbles accumulate in bend until catalyst circulation is reduced enough that the bubble finally vents upward
  - The process then repeats itself

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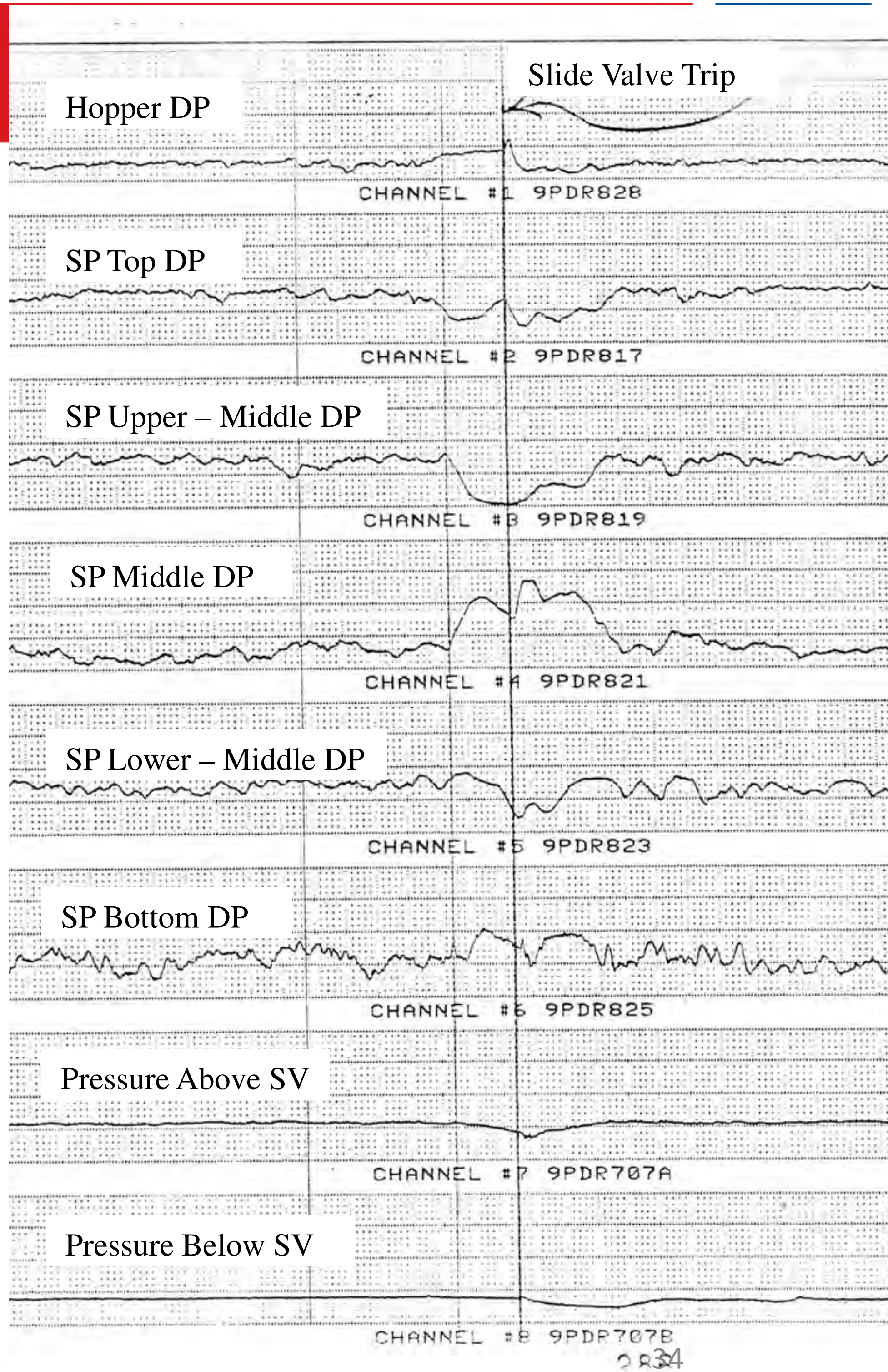
Example 3: Data Analysis

Clues from 80 ft standpipe

- Located the Origin of Trouble
  - Loss of standpipe DP started with high DP in the hopper
- Used Feedback to Guide Optimization
  - Changed aeration and fluidization gas rates
  - Changed fluid bed levels
  - Mechanical modifications improved fluidization around hopper
  - More changes to aeration and fluidization gas rates



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Example 3: Results

- Standpipe Characteristics
  - 25 inch ID
  - 136 lb/ft2s
  - 80 ft total length from hopper to slide valve

After optimization and mechanical changes

Pressure Delta Measurement Locations (Δ L)	DP, psi	Apparent Density, lb/ft3
Hopper (7 ft)	1.8	36.3
SP Top (14 ft)	3.5	36.9
Upper SP (14 ft)	3.6	35.9
Middle SP (14 ft)	3.9	41.5
Lower SP (14 ft)	4.1	42.0
SP Bottom (14 ft)	4.8	50.3
Total Standpipe (70 ft)	20.6	42.3

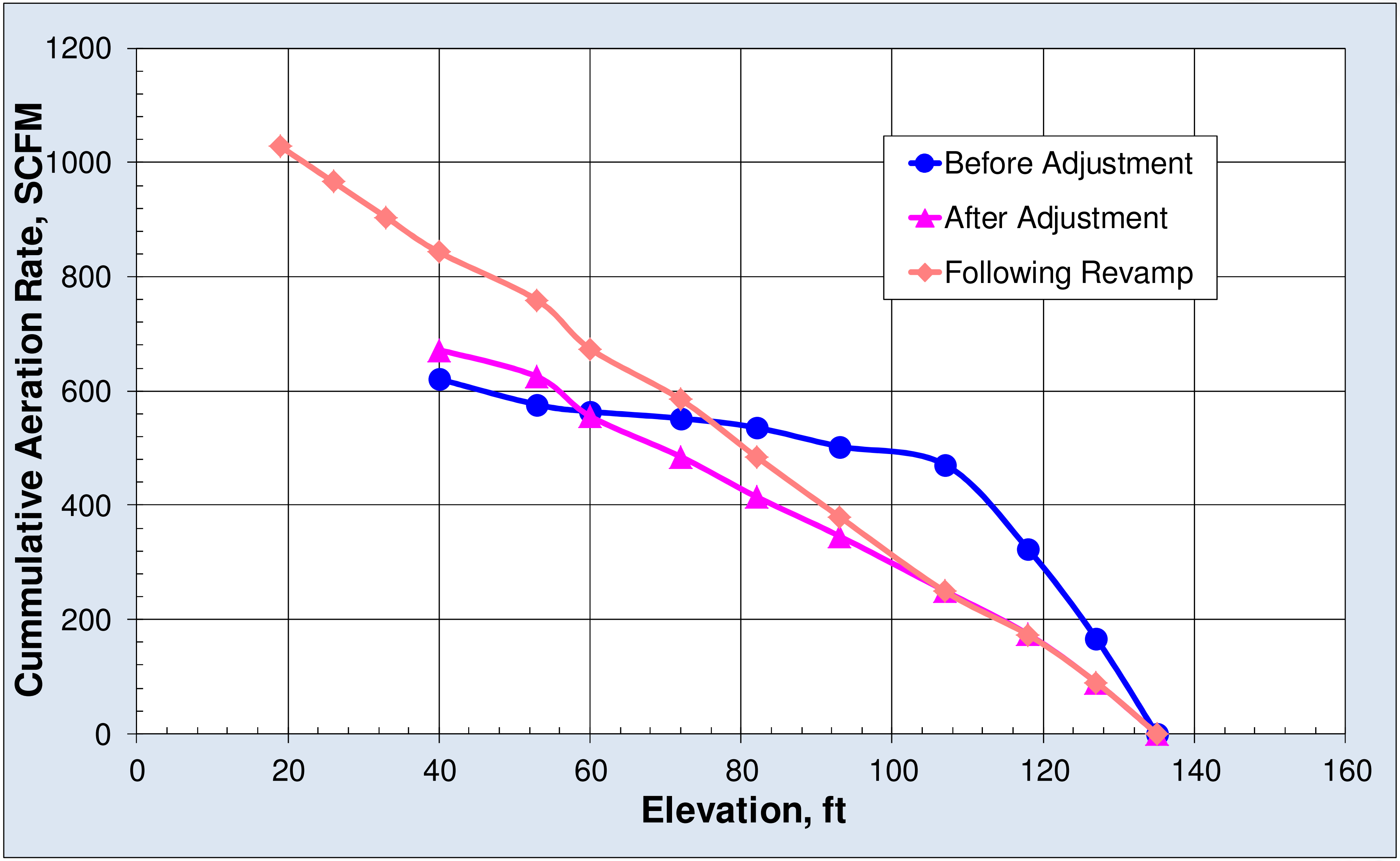
Example 4: Change of Aeration Medium

Air replaces steam

- History of Regenerated Catalyst Standpipe
  - Steam used for aeration
  - Pressure build-up erratic
  - Efforts to optimize rates and ensure dry steam provided little improvement
  - Resisted recommendations to switch from steam to air
- Change Made to Air for Standpipe Aeration
  - Improvement in standpipe pressure build-up and stability were immediate and marked

Example 5: Upgrading Aeration System

Applying theoretical aeration rates



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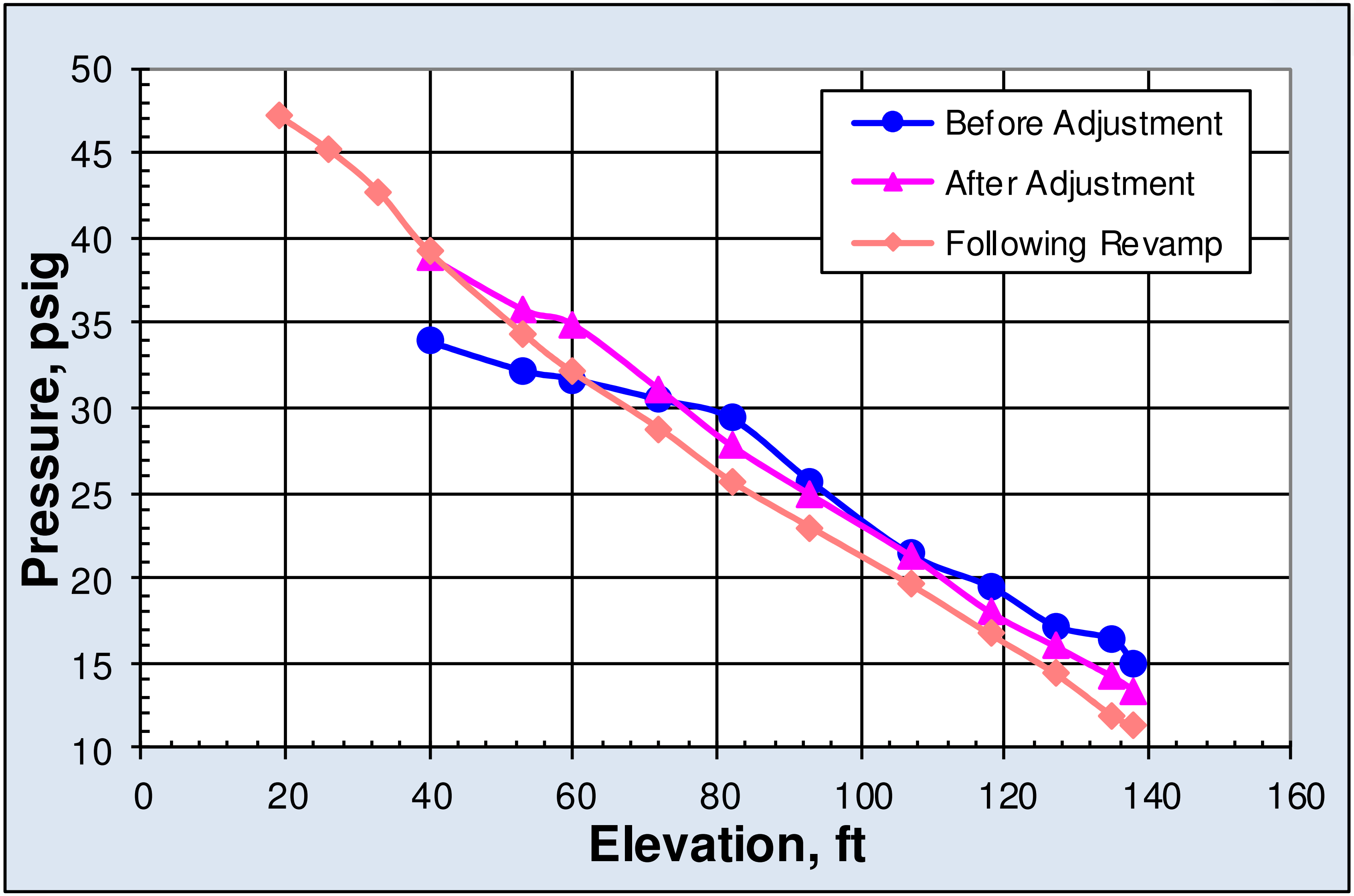
Example 5: Upgrading Aeration System

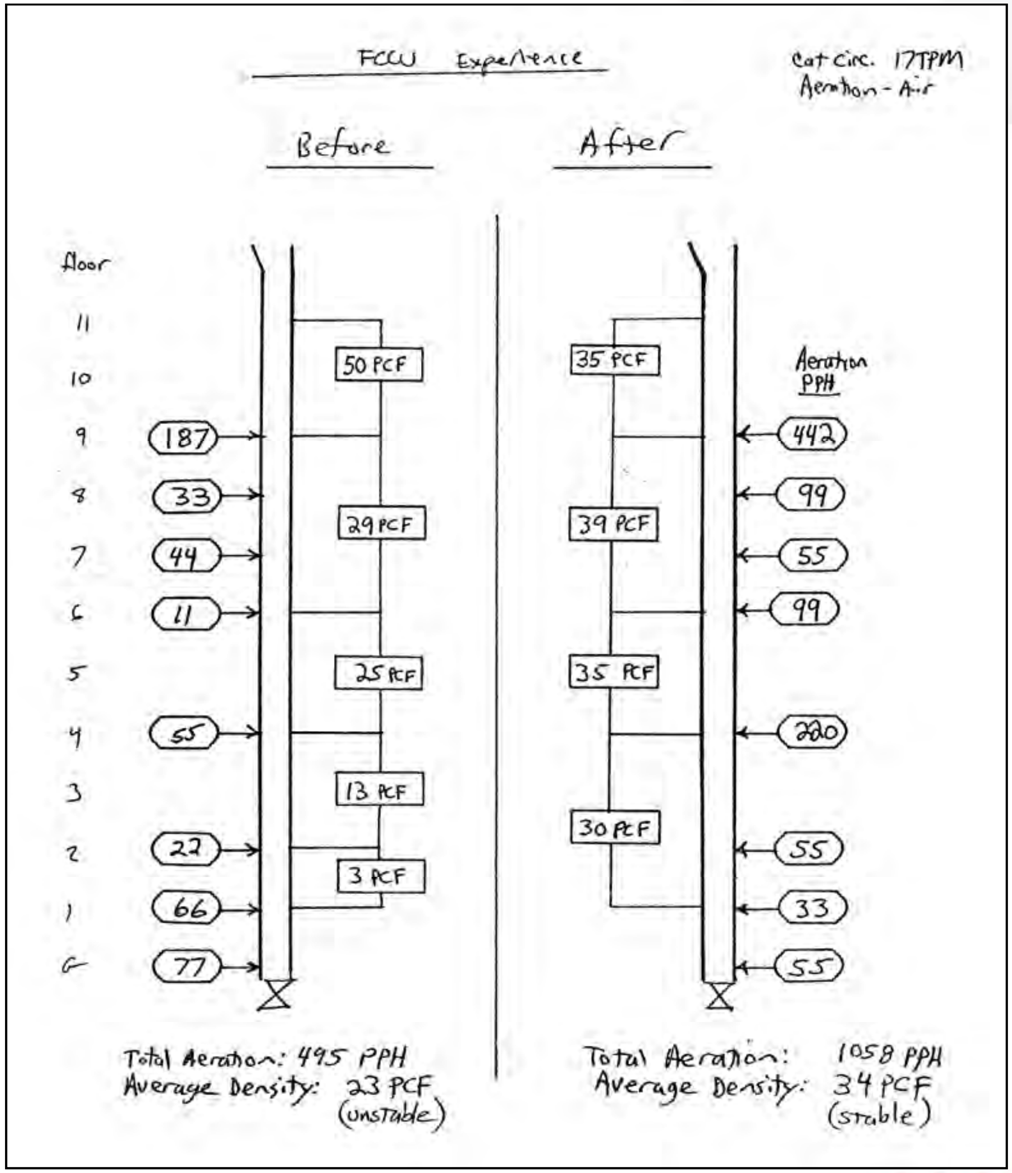
Applying theoretical aeration rates



Example 6: Optimizing Aeration Rates

Empirical optimization leads to solution

- Before
  - 24 lb/ft3 apparent density
  - Erratic pressure build-up
  - High vibration
- After
  - 35 lb/ft3 apparent density
  - Steady pressure build-up
  - Little vibration
- Standpipe Design Data
  - ID: 20 Inches
  - Mass Flux: 217 lb/ft2s



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Stay Positive – Get Started

- Recognize the Root of the Problem
  - Consider issues upstream and downstream of the standpipe
  - Is the standpipe really to blame?
- Compare Historic vs. Recent Catalyst and Operating Data
- Apply Available Tools
  - Tabulate pressure data
  - Perform aeration trials
  - CFD and cold flow modeling
  - Gamma ray scans

Conclusions

- Standpipe Performance Can Be Improved
  - Cat must be fluidized before entering standpipe
  - Standpipe sizing / geometry must not trap gas
  - Aeration must be correctly applied
  - Catalyst properties should support fluidization
- Empirical Optimization is Required
  - Guided by feedback from trials and unit modifications in addition to theory
- Quick Success is Less Common than Success Following Months of Focused Work
  - And maybe some unit modifications

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