Miscible Fluid Flow Past a Knife's Edge

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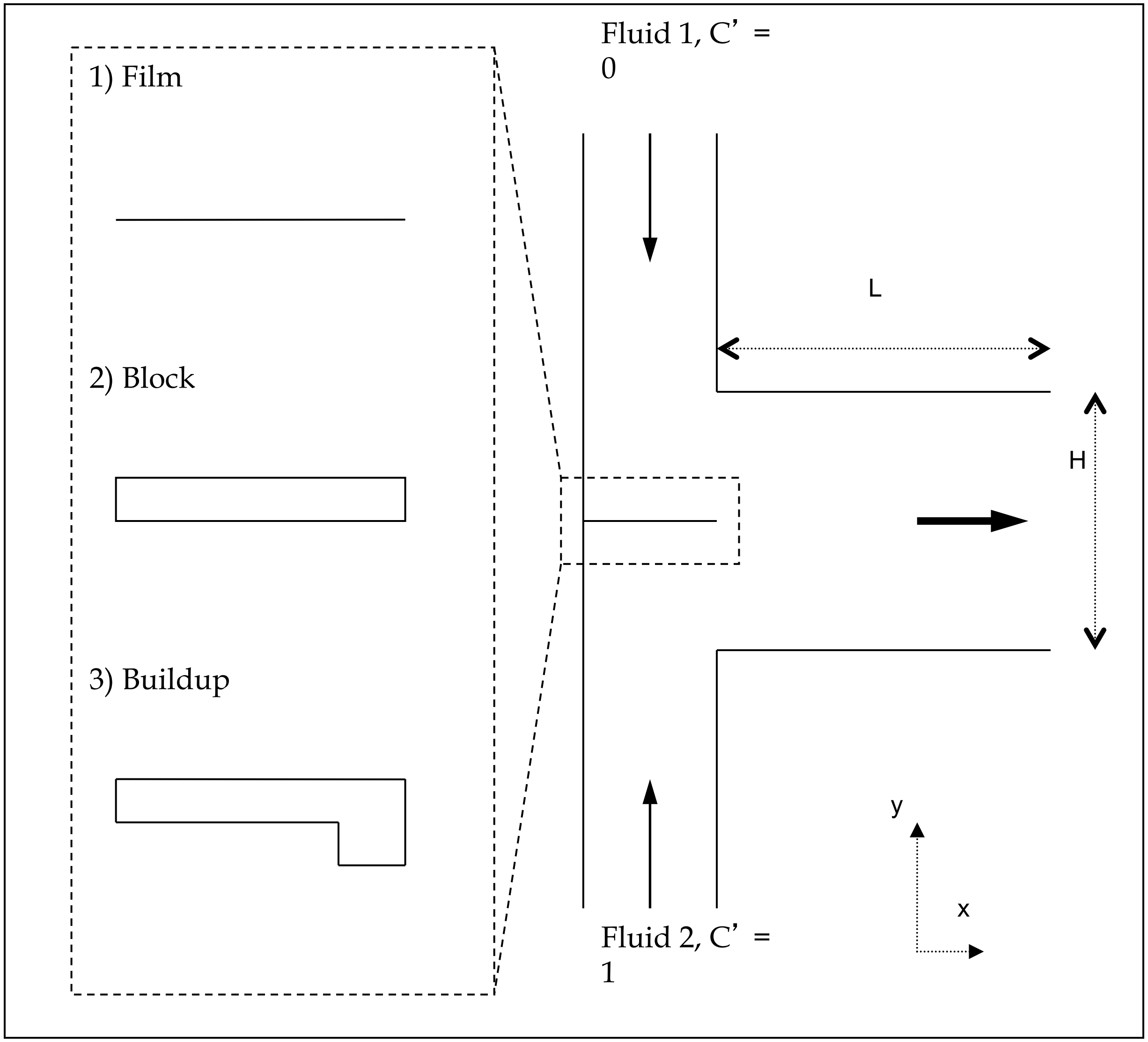
June 2003

Objective

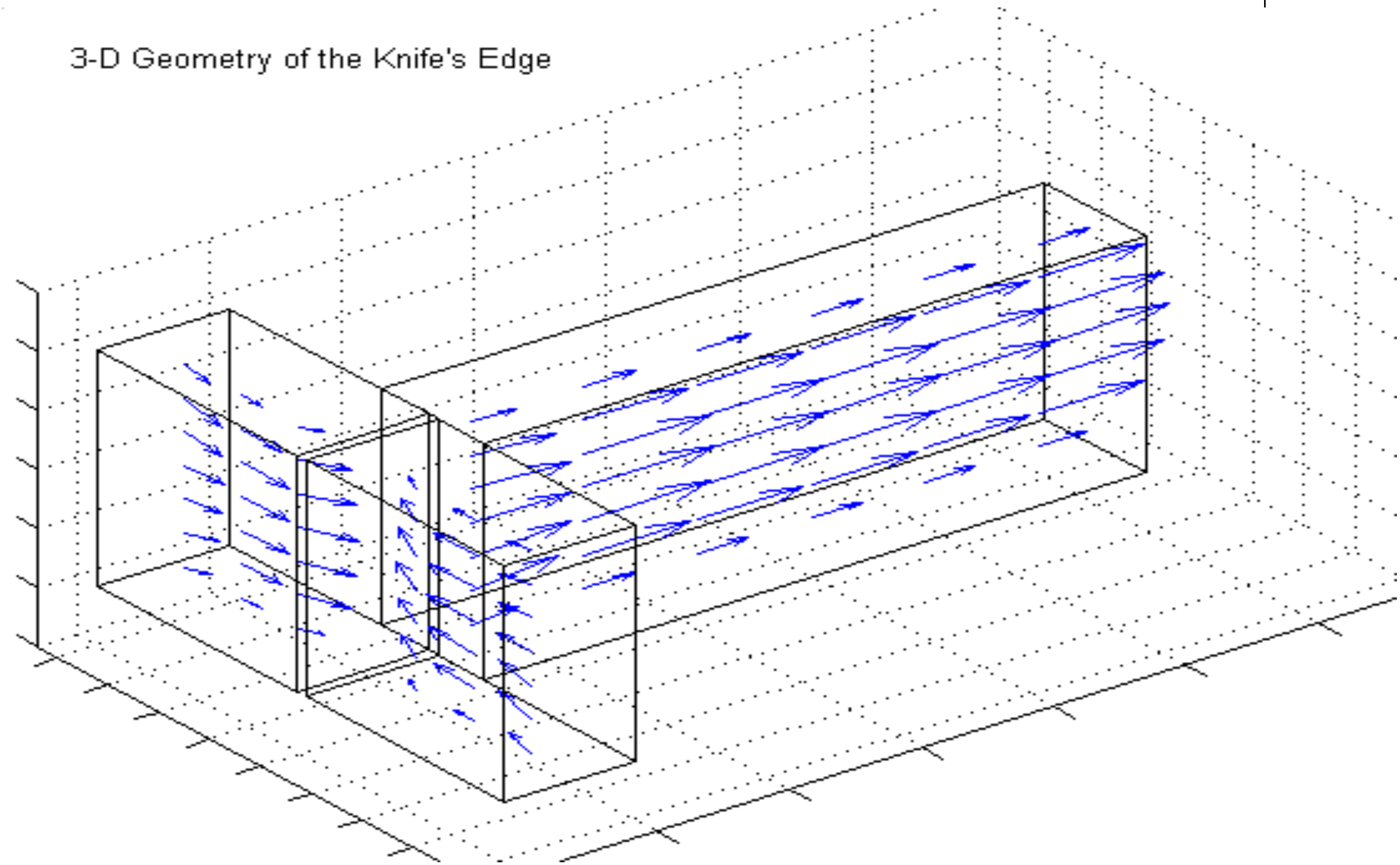
- Construct Knife’s Edge Geometry in FEMLAB
- Analyze the degree of mixing and dispersion of 3 knife’s edges:
  - Infinitesimally thin
  - Finite thickness
  - Finite thickness with a bump
- Plot solutions as function of Peclet number
- Compare 2-D and 3-D models

2-D Geometry



1) Film – ideal 1-D separation medium with no build up present
2) Block – a 2-D separation medium with no build up present
3) Buildup – separation is uneven and inflow is partially blocked

3-D Geometry



Key Equations – Peclet number

$$Pe = \frac{\langle u \rangle H}{D}$$

- Uses
  - Specify conditions of the fluid
- Variables
  - H - length of flow outlet
  - u - average outlet fluid flow velocity
  - D - diffusivity coefficient
- Range
  - 0 - 1000

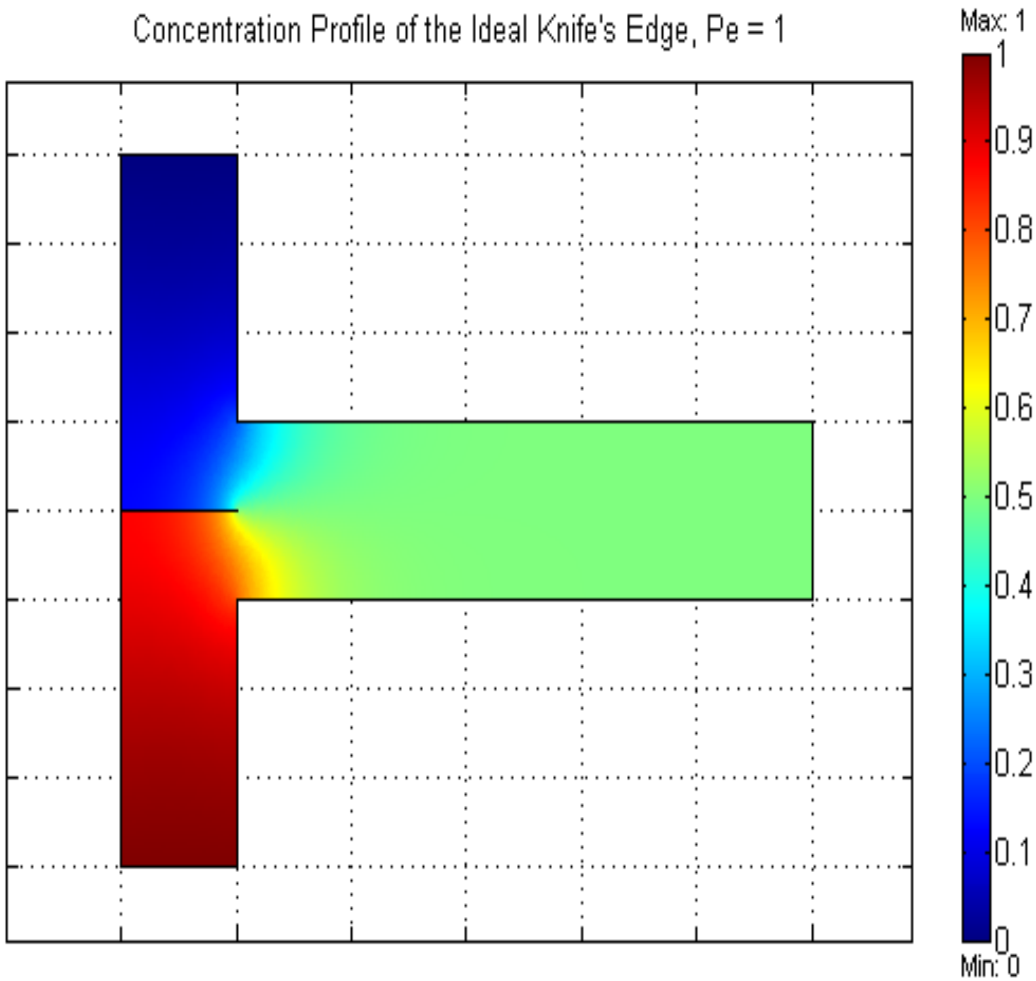
Key Equations – Variance

$$\sigma^2 = \frac{\int_0^H \left(c - \bar{c}\right)^2 u \cdot dy}{\int_0^H u \cdot dy}$$

$$\bar{c} = \frac{\int_0^H cu \cdot dy}{\int_0^H u \cdot dy}$$

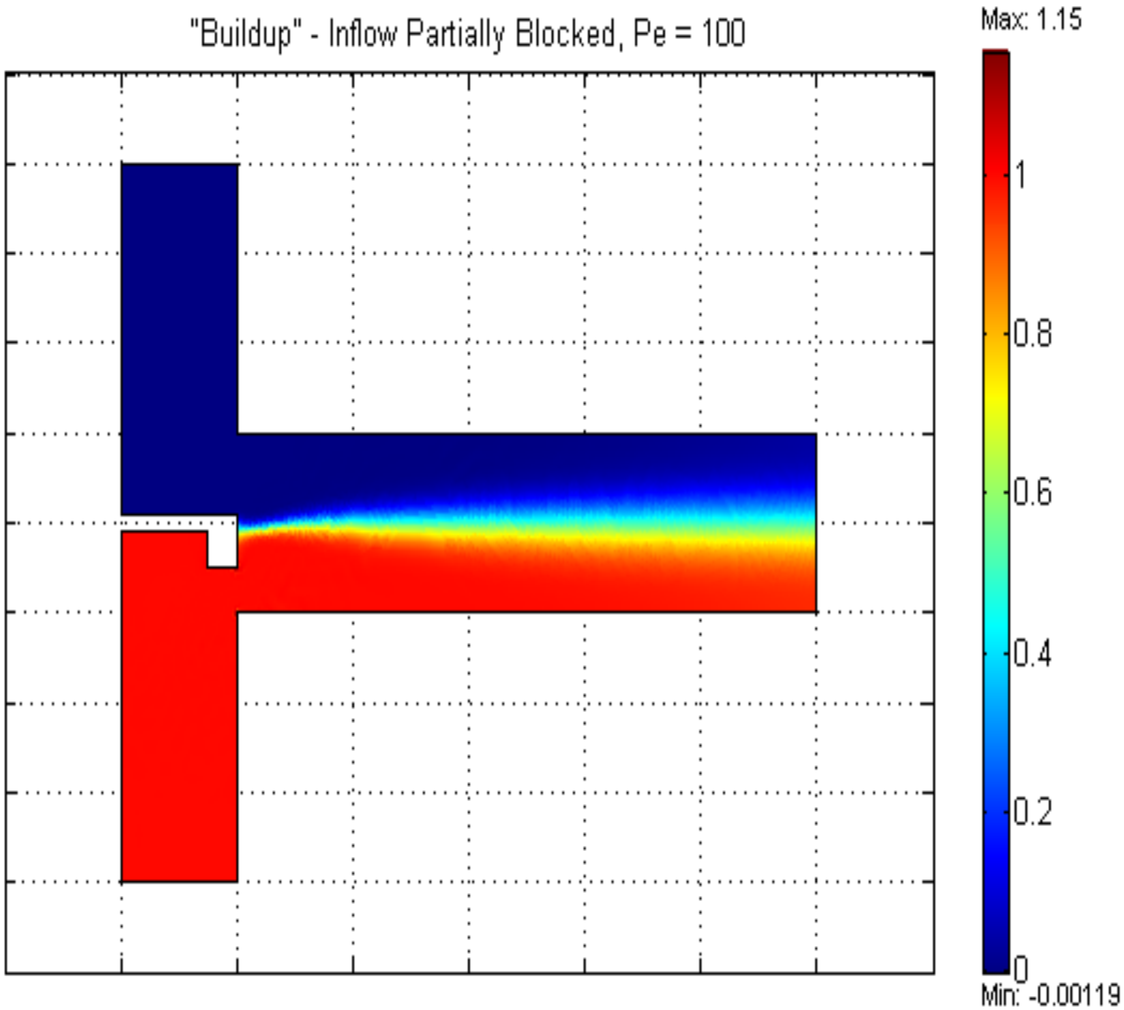
- Uses
  - Determine degree of mixing
- Variables
  - c – fluid concentration
  - u - average outlet fluid flow velocity
  - H - length of flow outlet
- Range
  - 0 – perfect mixing
  - 0.25 – no mixing

Sample Solution – "film"
Pe = 1



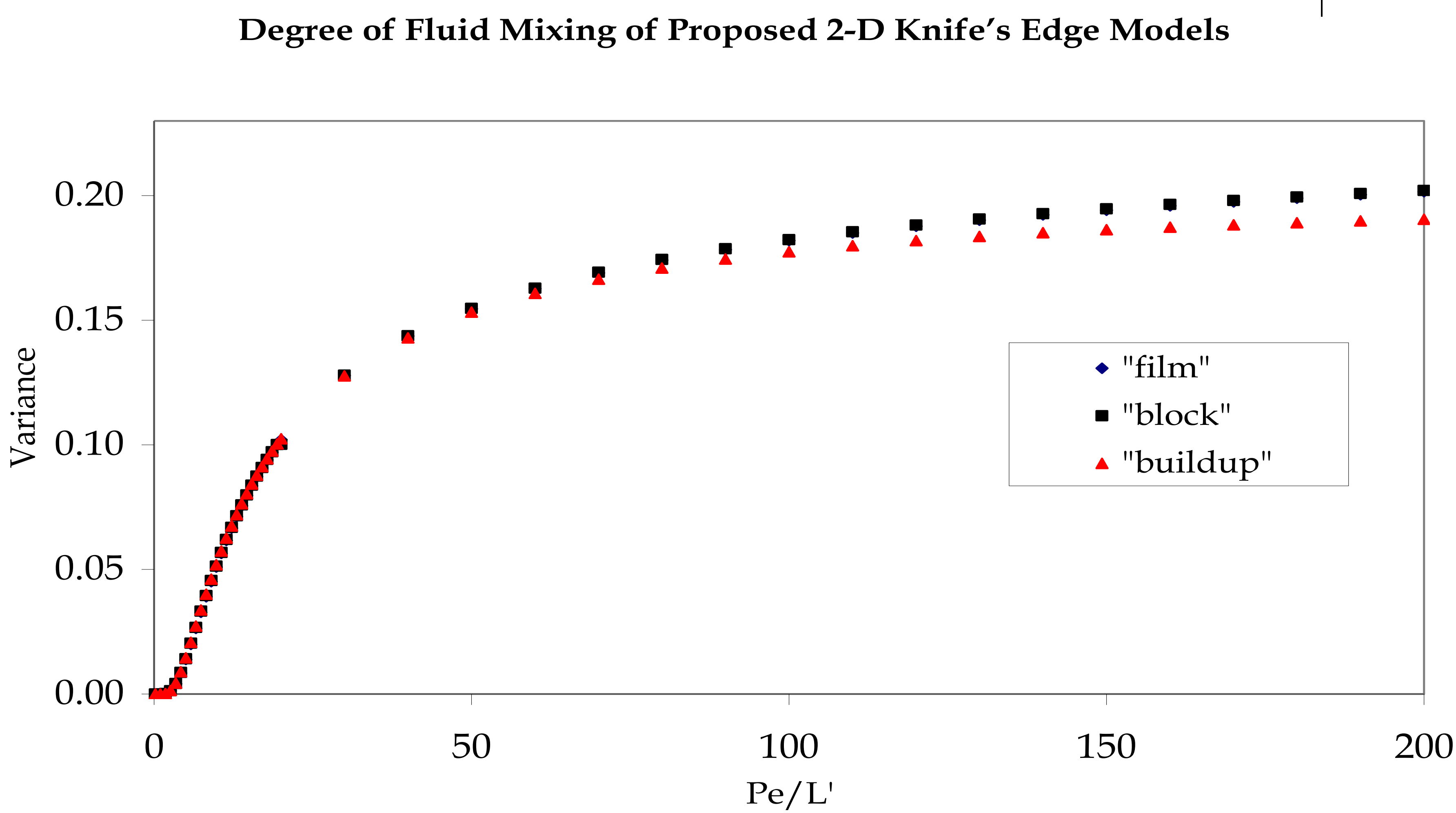
- 4390 mesh elements
- 2385 nodes
- 29862 DOF
- The variance resulted to be 2.26×10^{-8}
- This figure depicts results for near perfect mixing

Sample Solution – “buildup” Pe = 100



- 3242 mesh elements
- 1742 nodes
- 21917 DOF
- The variance resulted to be 0.10
- This figure depicts results for relatively poor mixing.

Results (2-D)


Degree of Fluid Mixing of Proposed 2-D Knife's Edge Models
Variance
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
Pe/L'
"film"
"block"
"buildup"

Results (3-D)

Pe	**2-D Variance**	**3-D Variance**	**$\Delta\sigma^2$**
50	0.0509	0.0447	0.0062
100	0.1020	0.0914	0.0106
150	0.1279	0.1178	0.0101
200	0.1437	0.1348	0.0089
With 98% confidence, the mean $\Delta\sigma^2$ (between 2-D and 3-D models) is: **$0.0045 \leq \Delta\sigma^2 \leq 0.0134$**			

Conclusions

- Particle buildup on knife’s edge tip aids fluid mixing and dispersion
- Changing the thickness of the knife’s edge does not impact the degree of mixing
- 2-D geometries of the knife’s edge sufficiently model cases in 3-D

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Questions?