

Two Phase “Bubbly” Fluid Flow in a Vertical Chamber

A Finite Element Analysis (FEA) Numerical Model

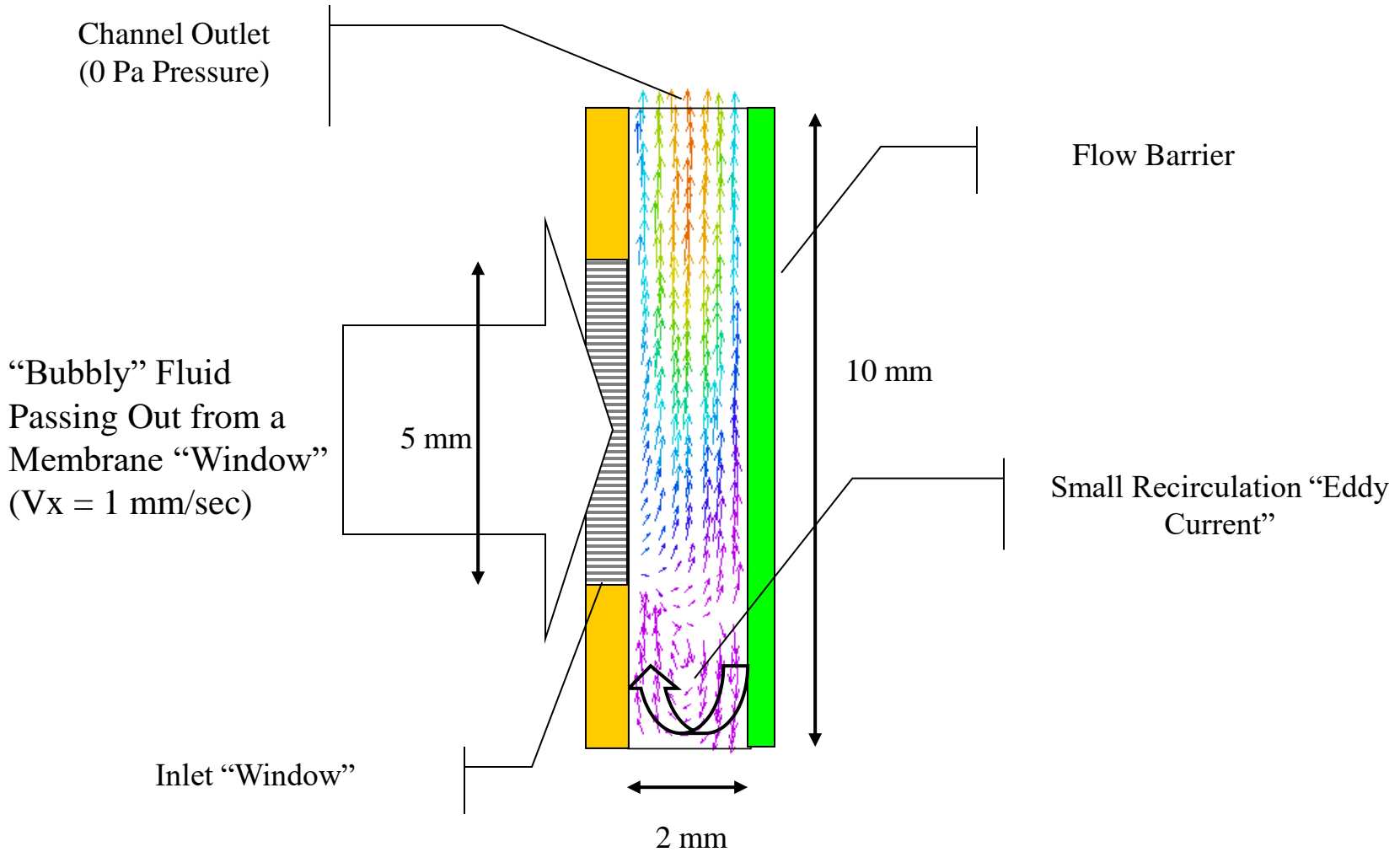
Craig E. Nelson - Consultant Engineer

Purpose of the Computational Fluid Dynamic Experiment:

1. Learn how gas-liquid “bubbly flow” patterns evolve and change as a function of a porous membrane outlet gas fraction
2. Develop a sense for how gas-liquid velocity varies as a function of gas fraction
3. Develop understanding of how intra-channel pressure varies as a function of gas fraction

Model Assumptions for Computational Fluid Dynamic Experiment:

1. The Liquid is Water
2. Channel dimensions are large enough that surface tension may be neglected.
3. The gas exists in the form a of nebulous cloud of small, particle like bubbles that convect and diffuse into the surrounding water much like smoke particles would.
4. Bubbly liquid “sticks” to the channel walls in the same manner as all normal fluids would when channel dimensions are not of nano scale



Model Geometry and General Flow Description

0 % Gas

10 % Gas

20 % Gas

30 % Gas

40 % Gas

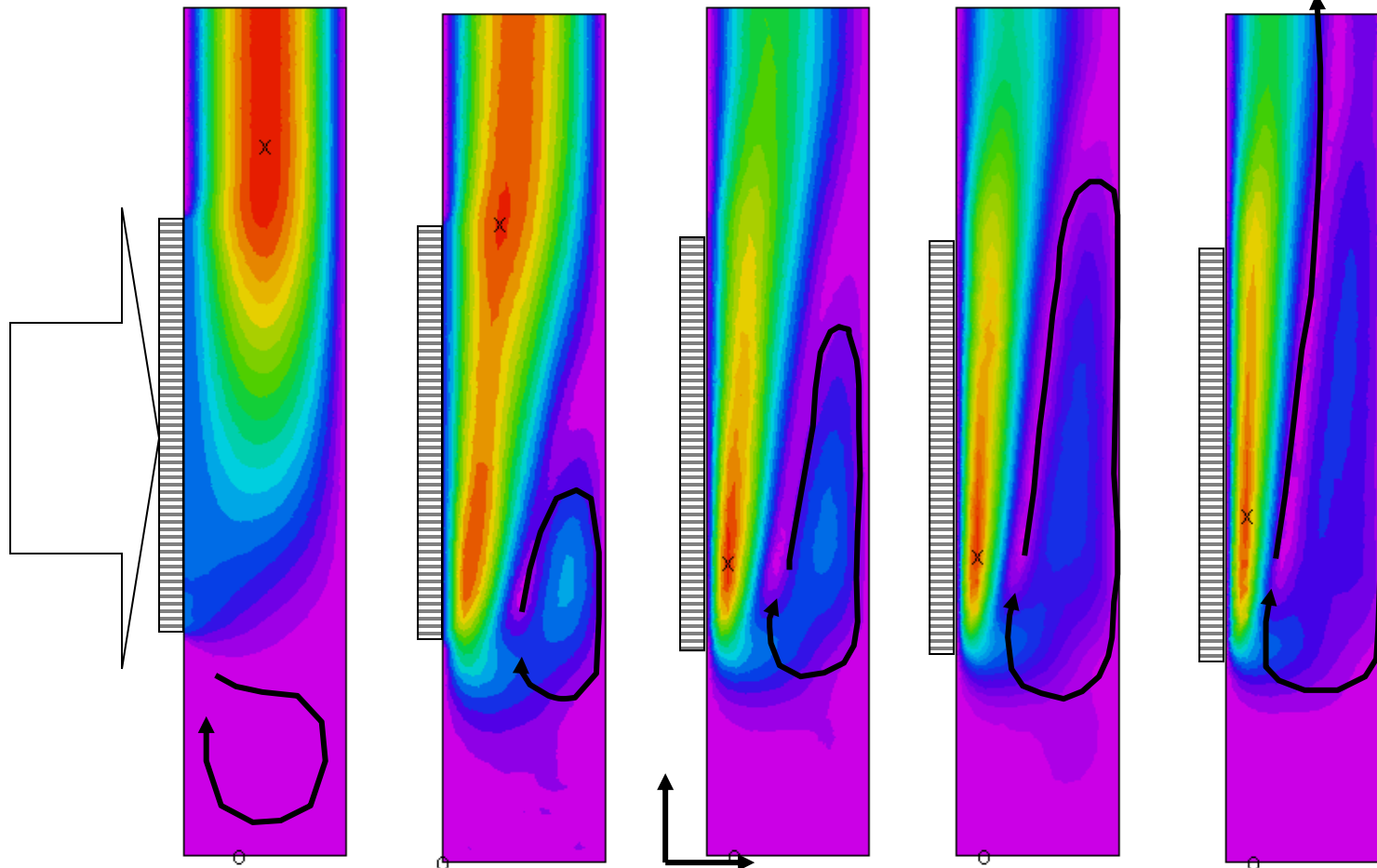
$V_{max} = 3.0$
mm/sec

$V_{max} = 4.0$
mm/sec

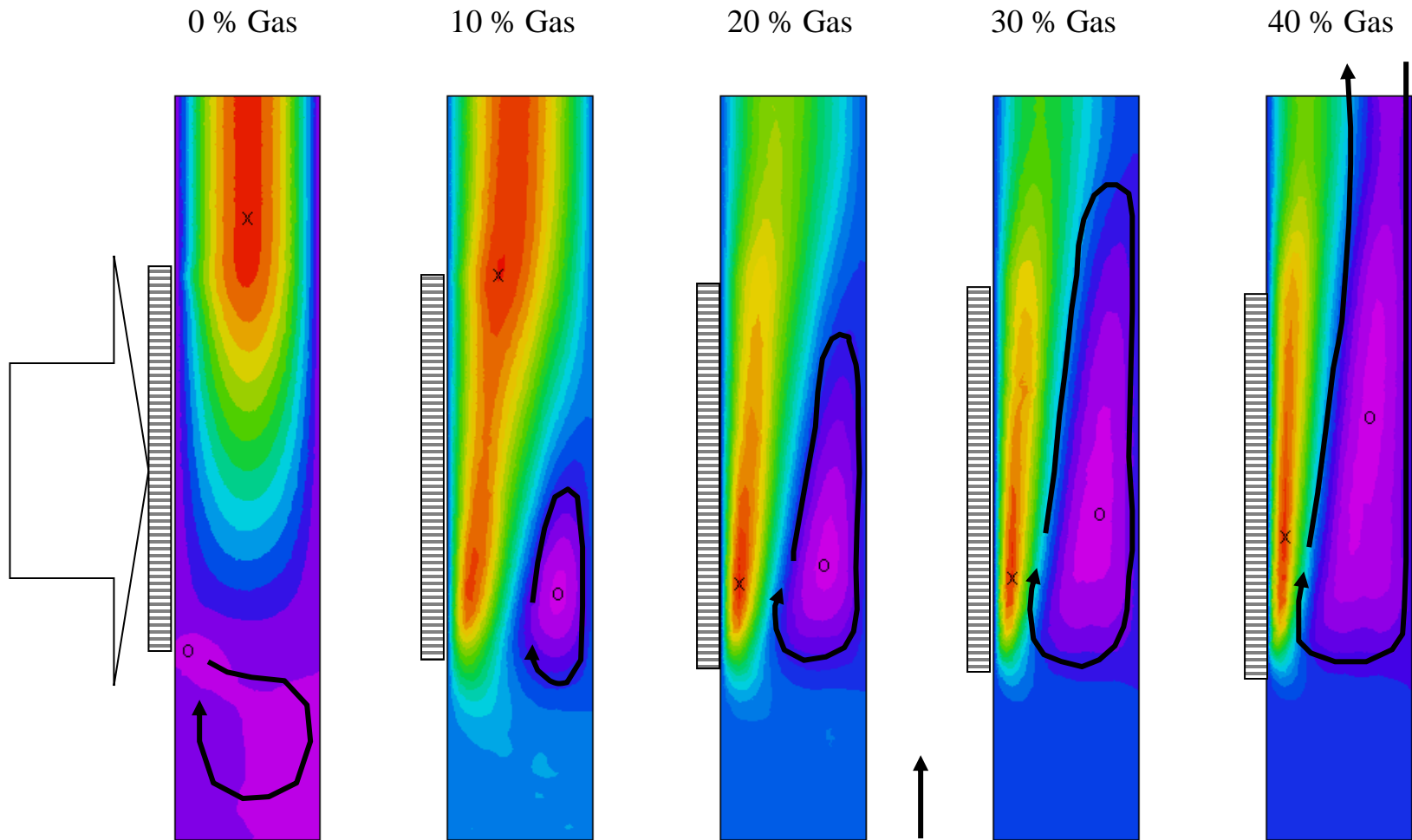
$V_{max} = 4.2$
mm/sec

$V_{max} = 6.6$
mm/sec

$V_{max} = 9.5$
mm/sec



Flow Velocity Vector Magnitude for Several “Bubbly” Fluid
Gas-Liquid mixture Concentrations



Vertical Flow Velocity Amplitude for Several “Bubbly” Fluid

Gas-Liquid mixture Concentrations

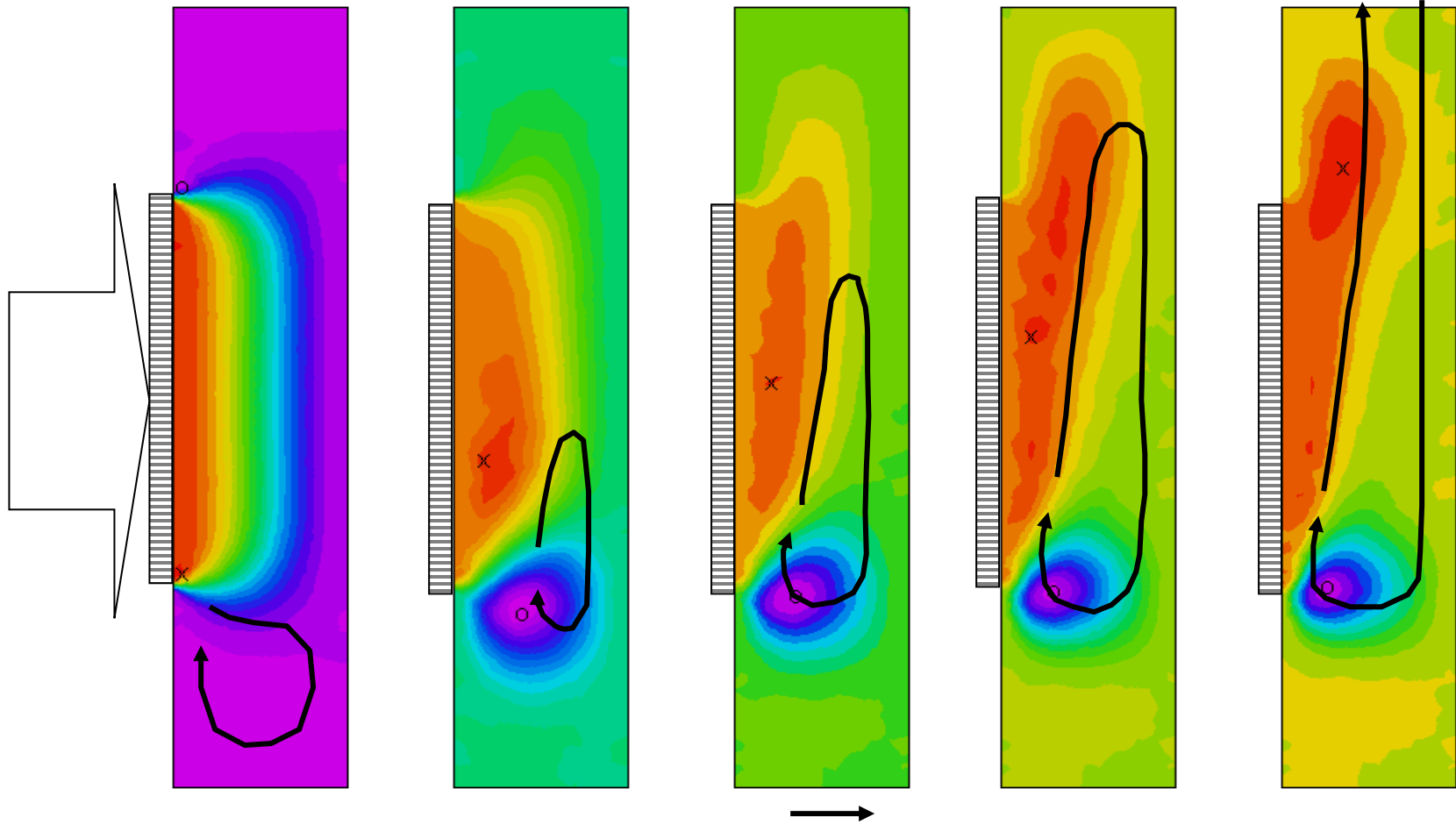
0 % Gas

10 % Gas

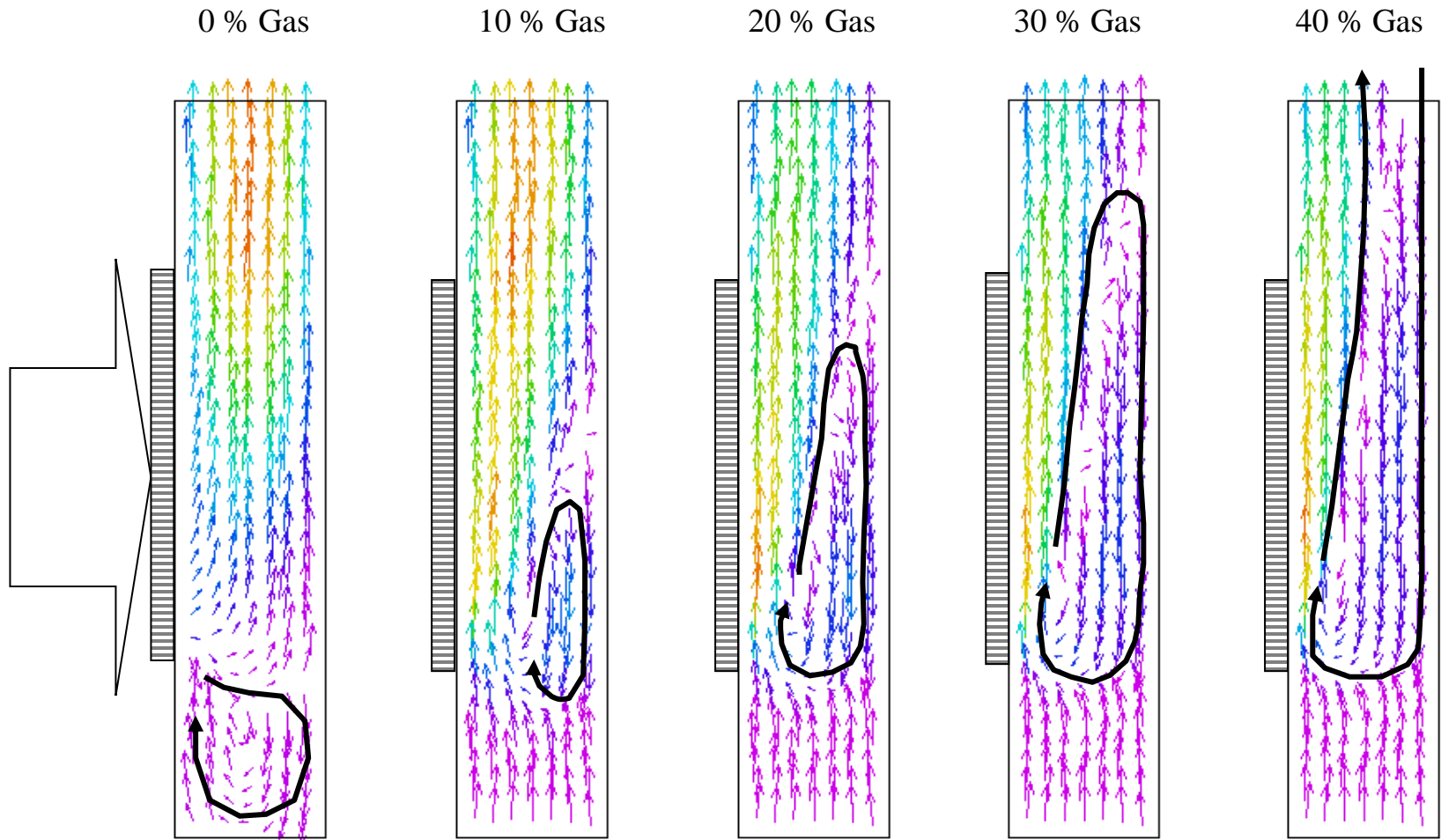
20 % Gas

30 % Gas

40 % Gas

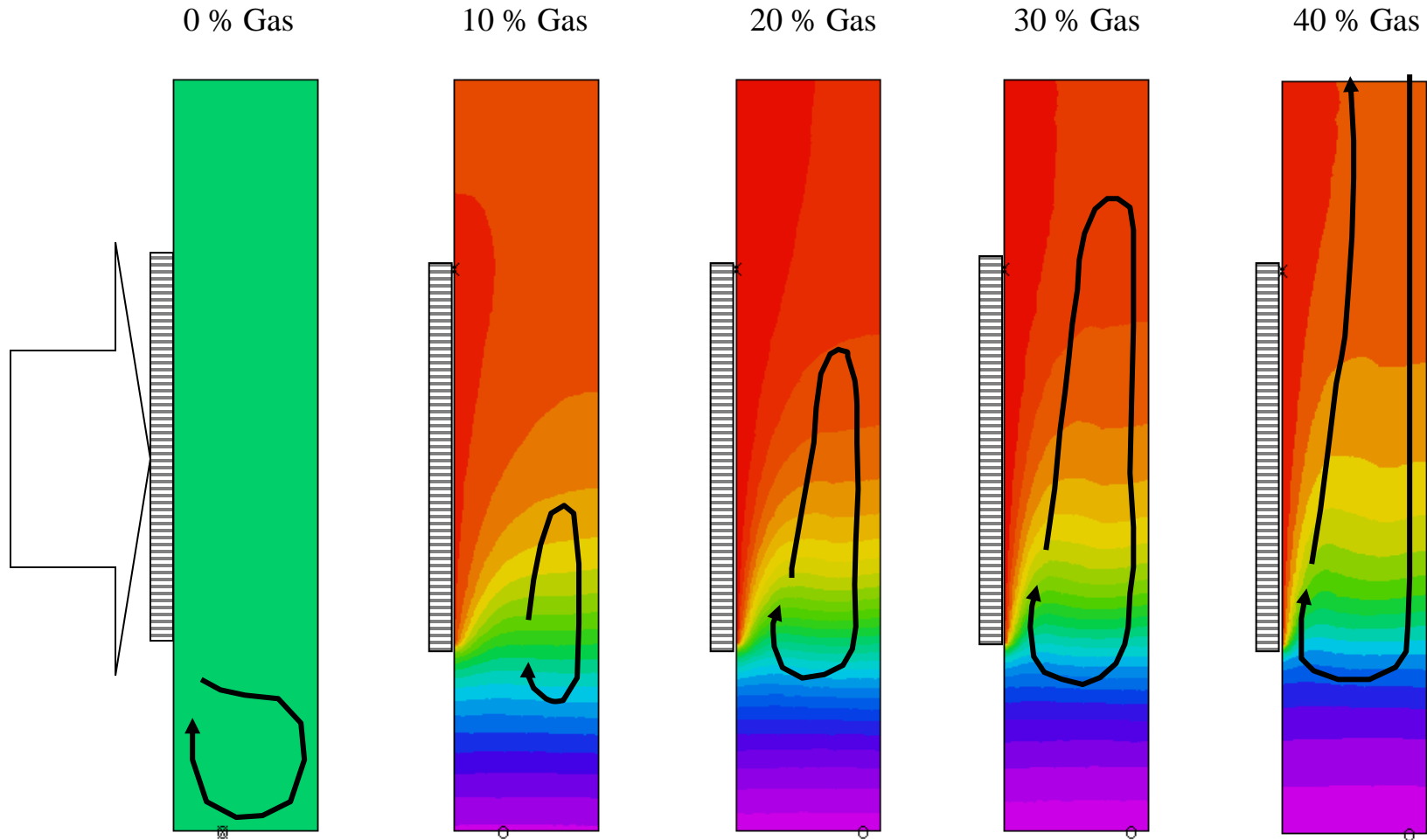


Horizontal Flow Velocity Amplitude for Several “Bubbly” Fluid
Gas-Liquid mixture Concentrations

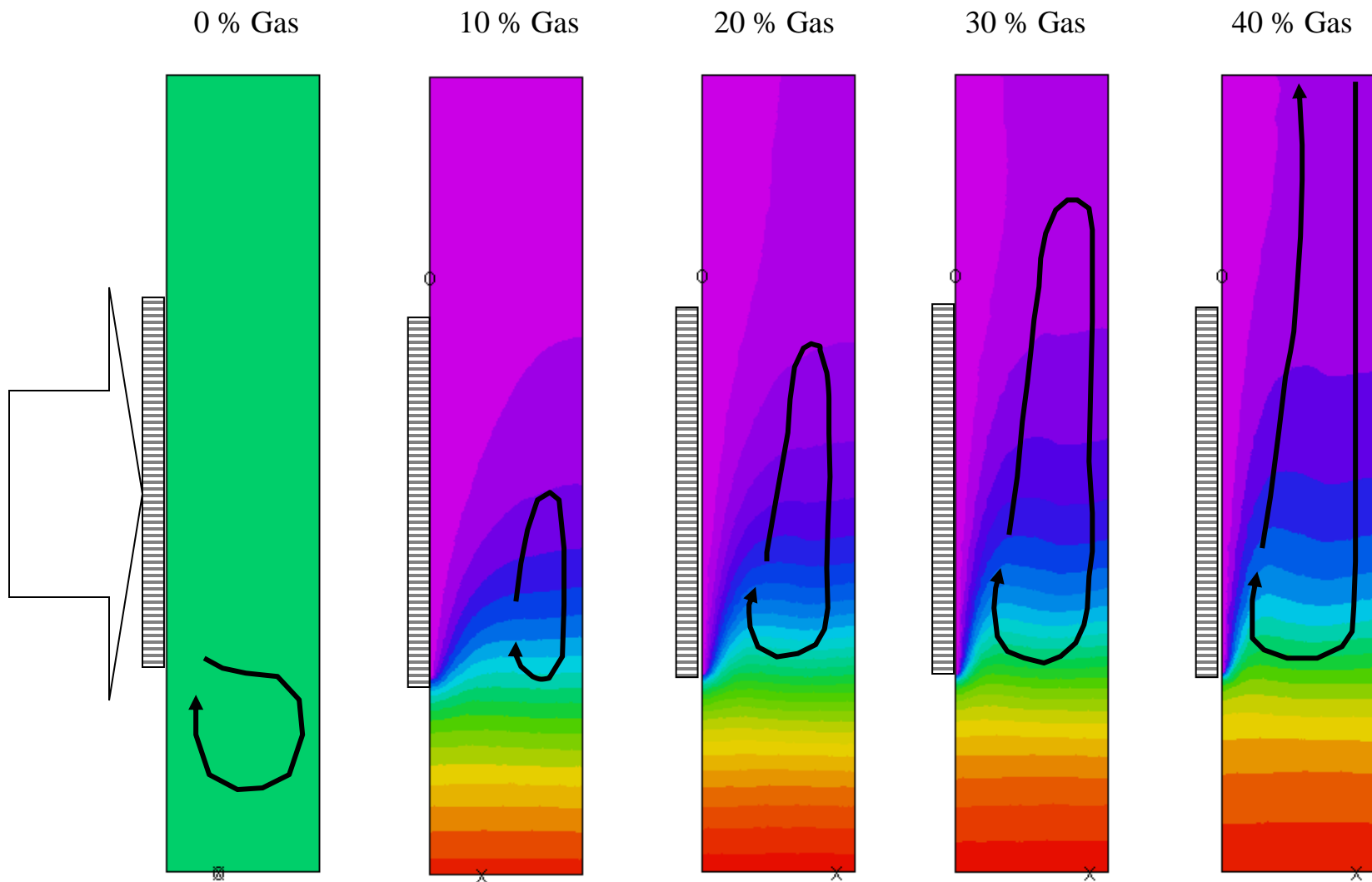


Flow Velocity Vectors for Several “Bubbly” Fluid
Gas-Liquid mixture Concentrations

Notice How the Small Initial Eddy Current Grows as the Gas Fraction Increases

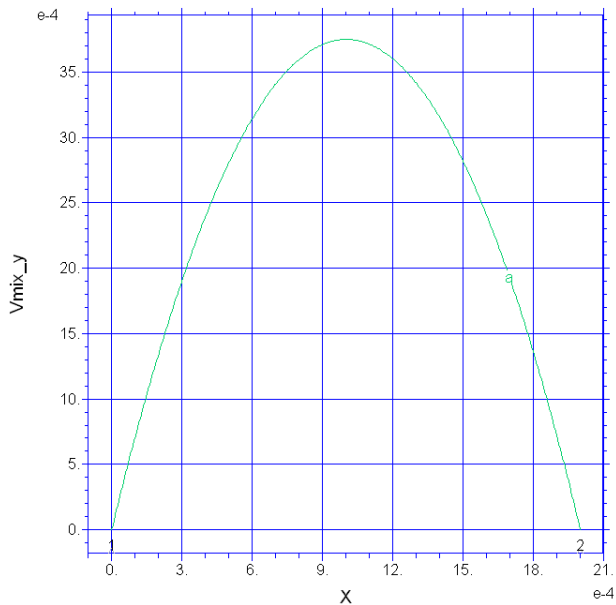


Gas Fraction for Several “Bubbly” Fluid
Gas-Liquid mixture Concentrations



Fluid Mixture Density for Several “Bubbly” Fluid
Gas-Liquid mixture Concentrations

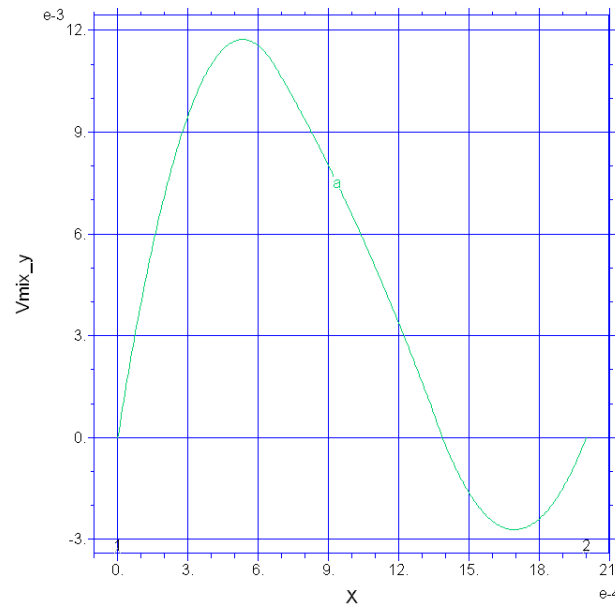
Two Phase Flow (Gas - Liq) in a Channel



Mixture- VOF - 040518F: Grid#4 p2 Nodes=353 Cells=156 RMS Err= 9.5e-4
Stage 1 Integral= 4.999380e-6

0 % Gas Fraction

15:55: Flex Two Phase Flow (Gas - Liq) in a Channel



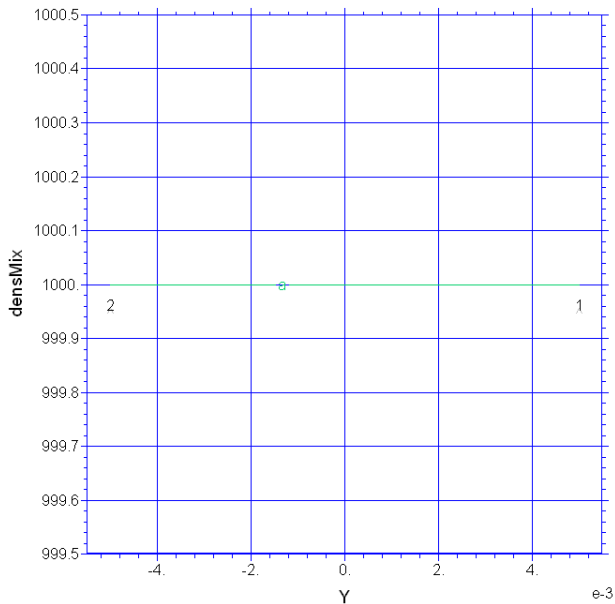
Mixture- VOF - 040518F: Grid#2 p2 Nodes=528 Cells=237 RMS Err= 6.5e-4
Stage 5 Integral= 8.862460e-6

40 % Gas Fraction

Fluid Mixture Channel Outlet Velocity Profiles for 0 % and 40% Gas Fraction

Notice that the 40% Gas Fraction Mixture Exhibits Reverse Flow Over Part of the Channel Outlet

Two Phase Flow (Gas - Liq) in a Channel



15:55:5
FlexP

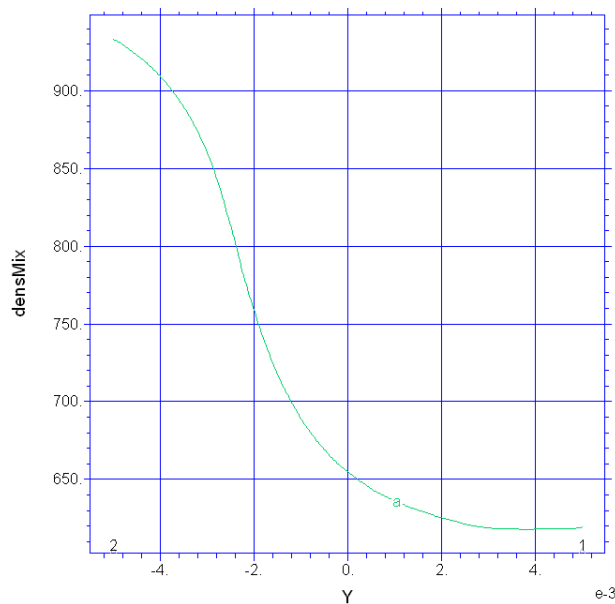
densMix
from (Hchan/4,Lchan/2)
to (Hchan/4,-Lchan/2)

a: densMix

Mixture- VOF - 040518F: Grid#4 p2 Nodes=353 Cells=156 RMS Err= 9.5e-4
Stage 1 Integral= 10.00000

0 % Gas Fraction

Two Phase Flow (Gas - Liq) in a Channel



15:55:57 5/19/04
FlexPDE 3.01f

densMix
from (Hchan/4,Lchan/2)
to (Hchan/4,-Lchan/2)

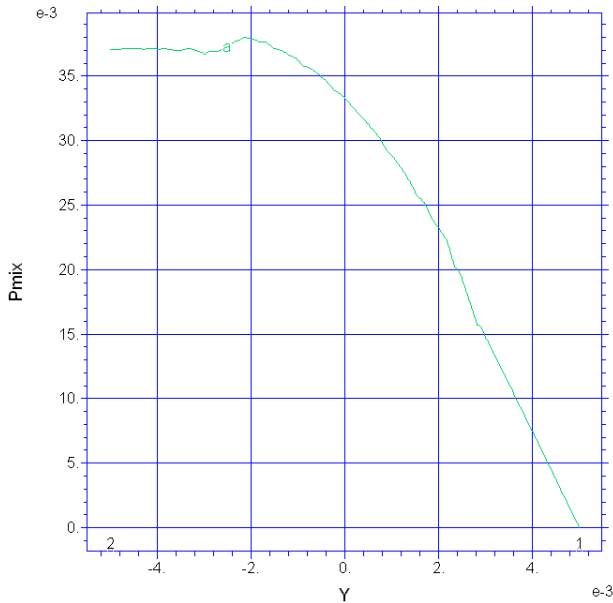
a: densMix

Mixture- VOF - 040518F: Grid#2 p2 Nodes=528 Cells=237 RMS Err= 6.5e-4
Stage 5 Integral= 7.143207

40 % Gas Fraction

Fluid Mixture Longitudinal “Cut” Density Profile for 0 % and 40% Gas Fraction

Two Phase Flow (Gas - Liq) in a Channel



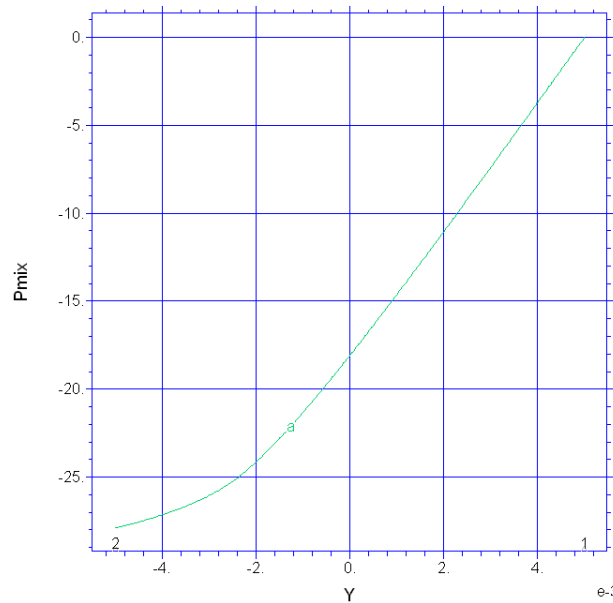
Pmix
from (Hchan/4,Lchan/2)
to (Hchan/4,-Lchan/2)
a: Pmix

Mixture- VOF - 040518F: Grid#4 p2 Nodes=353 Cells=156 RMS Err= 9.5e-4
Stage 1 Integral= 2.745608e-4

0 % Gas Fraction

15:55:5
FlexP

Two Phase Flow (Gas - Liq) in a Channel



Pmix
from (Hchan/4,Lchan/2)
to (Hchan/4,-Lchan/2)
a: Pmix

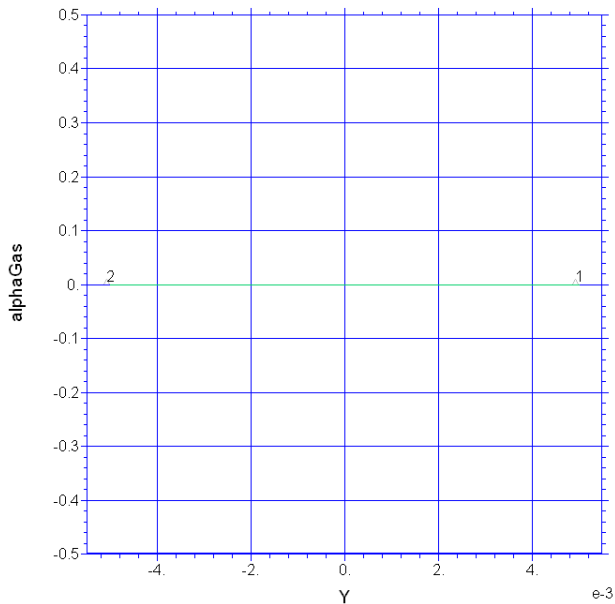
Mixture- VOF - 040518F: Grid#2 p2 Nodes=528 Cells=237 RMS Err= 6.5e-4
Stage 5 Integral= -0.167580

40 % Gas Fraction

Fluid Mixture Longitudinal “Cut” Pressure Profile for 0 % and 40% Gas Fraction

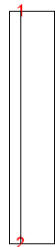
Notice that the 40% Gas Fraction Mixture Exhibits Negative Pressure at the Channel Bottom End Relative to the Upper Channel Outlet while the 0% case Exhibits Positive Pressure in the Same Region

Two Phase Flow (Gas - Liq) in a Channel



15:55:5
FlexP

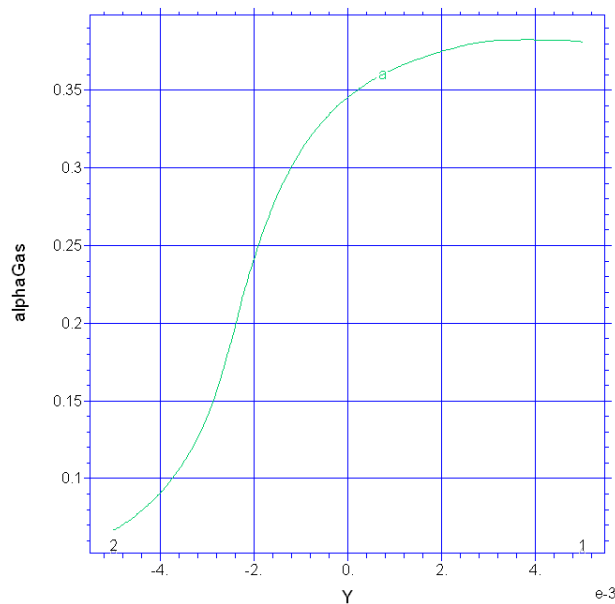
alphaGas
from (Hchan/4,Lchan/2)
to (Hchan/4,-Lchan/2)
a: alphaGas



Mixture- VOF - 040518F: Grid#4 p2 Nodes=353 Cells=156 RMS Err= 9.5e-4
Stage 1 Integral= 0.00

0 % Gas Fraction

Two Phase Flow (Gas - Liq) in a Channel



15:55:57 5/19/04
FlexPDE 3.01f

alphaGas
from (Hchan/4,Lchan/2)
to (Hchan/4,-Lchan/2)
a: alphaGas



Mixture- VOF - 040518F: Grid#2 p2 Nodes=528 Cells=237 RMS Err= 6.5e-4
Stage 5 Integral= 2.859653e-3

40 % Gas Fraction

Fluid Mixture Longitudinal “Cut” Gas Fraction Profile for 0 % and 40% Gas Fraction

Summary of Results for Computational Experiment:

1. As gas fraction increases, the “bubbly” fluid flow pattern gradually changes from “straight up and out” to “up and out with relatively strong “recirculation”.
2. As gas fraction increases, maximum “bubbly” fluid flow velocity increases and the location of the velocity maximum moves closer to the porous window outlet surface and “lower down” in the outlet channel.
3. As cell power increases, the pressure at the bottom of the outlet channel becomes progressively more negative – Out flowing Bubbly fluid apparently “pulls a vacuum” on the lower outlet channel region

Additional Comments:

1. Almost no gas bubbles ever reach the “bottom” of the outlet flow Channel
2. As gas fraction increases, the change in fluid density at the top end of the outlet channel is rather dramatic – Under these circumstances, aggravating bubble coalescence may be expected
3. The change in fluid volume flow rate as gas fraction increases is large due to the “expansion” of the overall fluid volume. A negative relative pressure at the channel outlet would be a good idea for effective removal of a high gas fraction fluid mixtures.