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TWO-DIMENSIONAL SIMULATIONS OF MAGMA INTERACTION WITH SUBSURFACE TUNNELS

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2011 International High-Level Radioactive Waste Management Conference

OUTLINE OF PRESENTATION

- Problem Overview
- Background
- Objectives
- Technical Approach
- Simulation Results
    - Parametric Analysis
- Conclusions

BACKGROUND

- Potential Hazards Due To Igneous Intrusion May Need To Be Considered in Safety Assessments for Geologic Repositories for High-Level Radioactive Waste

- Magma Flow Through a Subvolcanic Plumbing System Is a Complex Process
  - Controlled by magma pressure, viscosity, and exsolved gas
  - Conduit shape and size
  - Type of volcanic eruption

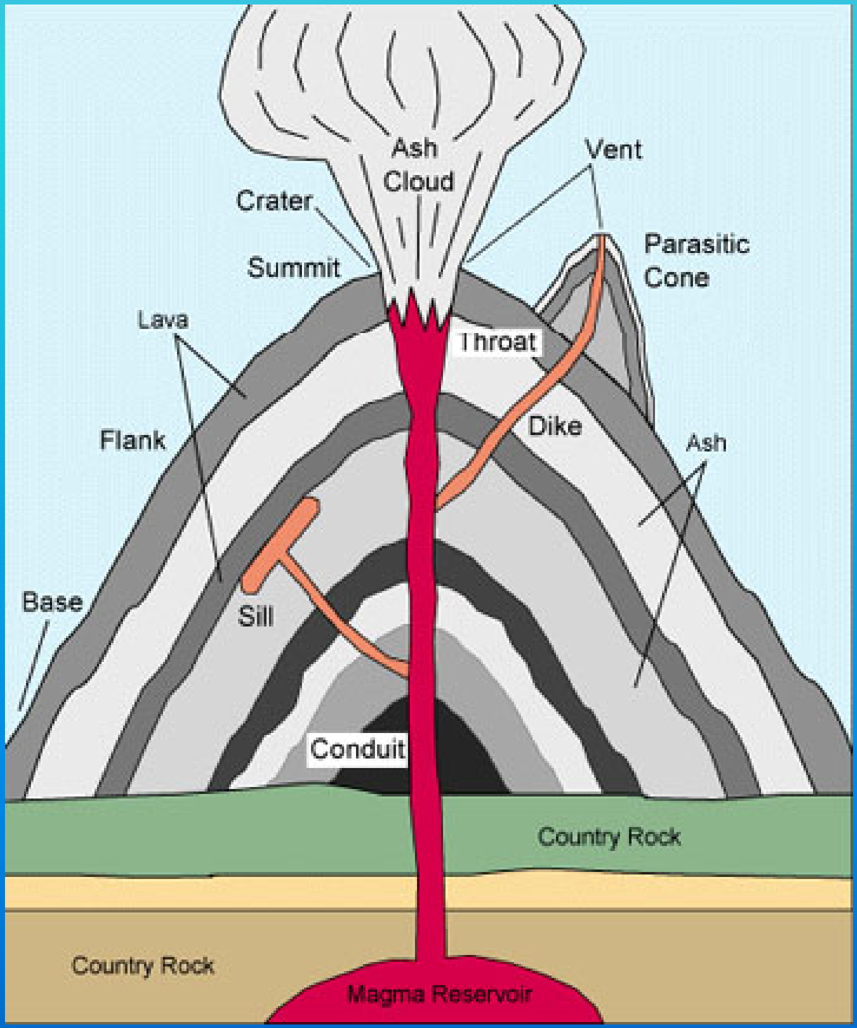
- Magma Generation to Eruption: Influenced by Different Phases and Processes Such as Nucleation, Bubble Growth, and Fragmentation

- Effusive Magma Flow: Low Viscosity Magma

- Pyroclastic Magma Flow: Explosive Eruption of More Viscous Silicic Magma

- Numerical Simulation of Magma Flow Through Subvolcanic Plumbing System: Challenging

MAGMA RISE THROUGH CONDUIT



SIGNIFICANCE OF RESEARCH

- Understanding How Magma Will Interact With Subsurface Tunnels
- Hazards Should a Subsurface Tunnel in a Region of Active Volcanism Be Invaded by a Dike
- Analyze the Physical Conditions of the Magma (Pressure, Velocity, and Temperature) Inside the Subsurface Tunnel and How They Are Influenced by Magma

HOW HAS MAGMA NUMERICAL SIMULATION RESEARCH EVOLVED?

- Has Evolved Significantly Over the Last Two Decades

- Major Research Focuses on One-Dimensional Single-Phase Flow of Magma
  - Other assumptions include isothermal, nonequilibrium flows

- Growing Interest in Magma Flow in Conduit and Subsequent Eruptions
  - Two-/three-dimensional simulations

  Multiphase flows: more physics

- Increased Use of Computational Fluid Dynamics in Magma Simulations
  - Full Navier-Stokes equations
  - Better and faster numerical schemes: both spatial and temporal
  - Full multiphase model treatment now available

- However, Analysis of Effrusive Magma Flow and Its Interaction With a Subsurface Tunnel in the Presence of Obstacles Has Not Been Attempted Before

RESEARCH GOALS

- Numerically Simulate Interaction of Effusive Magma Flow With Subsurface Tunnels: With and Without Obstacles
- Analyze the Circulation Pattern Developing Inside the Tunnel in Presence of Obstacles
- Perform Parametric Studies
  - Ascent velocity of magma
  - Distance between obstacle and dike-tunnel intersection point
- Determine the Interplay Between Ascending Magma and the Location of the Obstacles

NUMERICS

- Used General Purpose Fluid Dynamics Solver Fluent®, Version 6.3
- Two-Dimensional Navier-Stokes Equations
- Multiphase: Volume of Flow Method Used for Air and Magma
- Unsteady Simulations
- Second-Order Upwind Spatial Differencing
- Pressure-Based Solver
- SIMPLEC Scheme for Pressure-Velocity Coupling

MODEL VALUES AND GRIDS

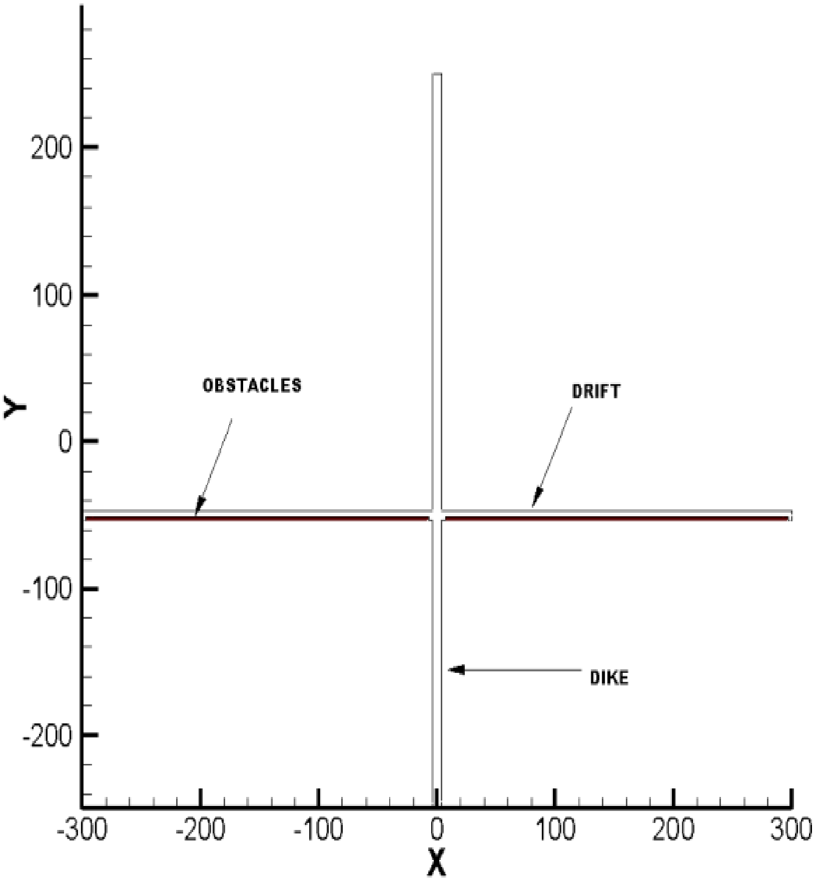
Model Values

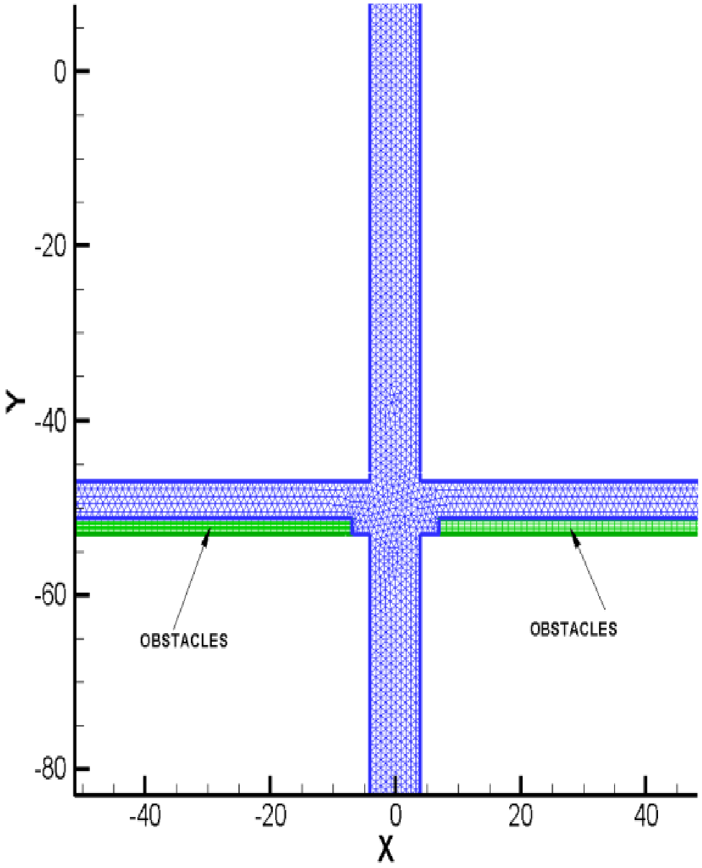
Variable	Value
Drift Length	600 m [1,970 ft]
Drift Height	6 m [20 ft]
Dike Length Below Drift	>500 m [1,640 ft]
Dike Width	8 m [26 ft]
Extension of Dike Above Drift	300 m [980 ft]
Obstacles Total Length	290 m [950 ft]
Obstacles Total Height	1.8 m [5.9 ft]

Computational Grid

Construct	Grid Dimension ($N_x \times N_y$)*
Drift	20 × 500
Dike	600 × 15
Obstacles (each)	290 × 8
*N_x = Number of cells in the x-direction and N_y = Number of cells in the y-direction	

GEOMETRY AND GRID





FLOW PHYSICS AND BOUNDARY CONDITIONS

♦ Laminar Flow Based on Reynolds Number

♦ Wallrock or Surrounding Subsurface Material Is Assumed To Be Tuff

♦ Tunnel Is Assumed To Be Initially Filled With Air

♦ Magma Is Considered To Be Degassed: No Latent Heat of Crystallization

♦ Velocity Inlet Boundary Condition at Dike Bottom Inlet

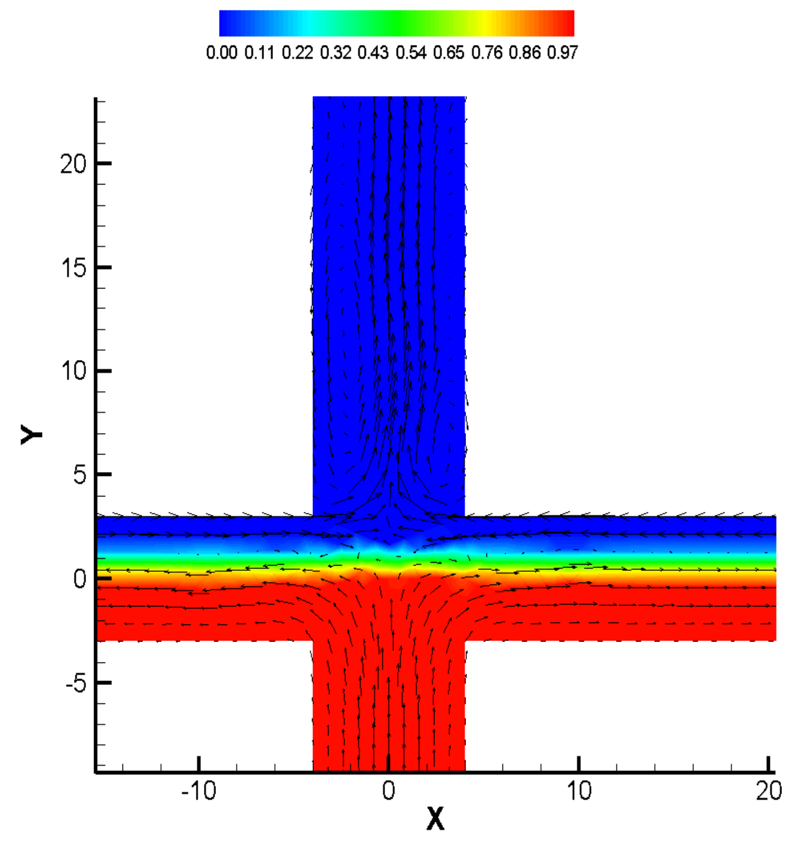
♦ Pressure Outlet Boundary Condition at the Dike Top Outlet: Atmospheric Pressure

♦ No Slip Boundary Condition at Walls: Zero Permeability at Walls

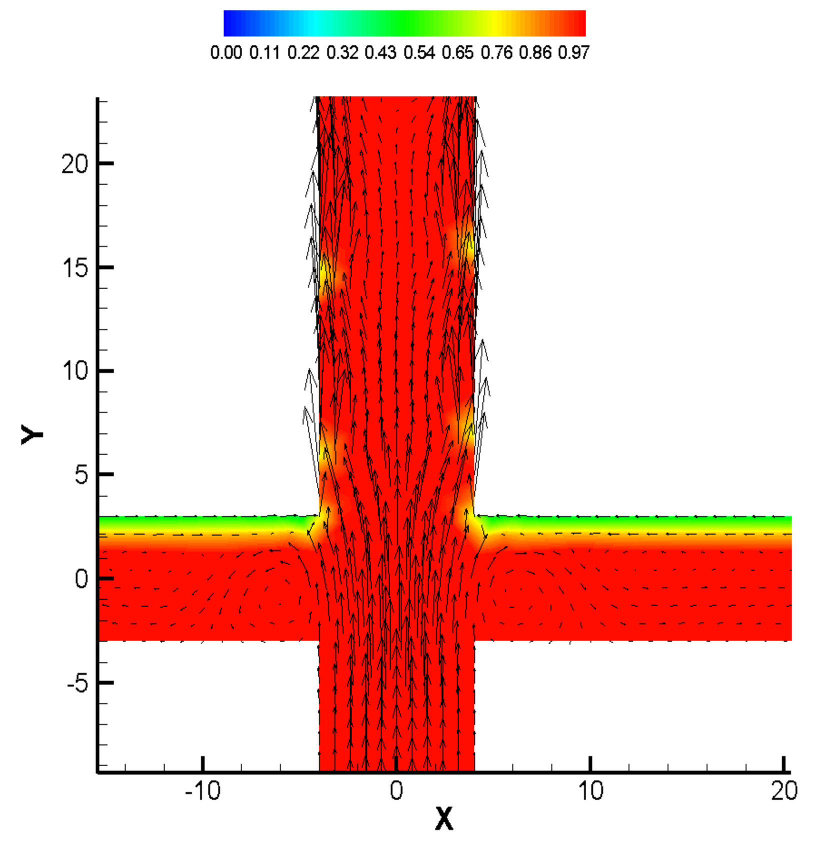
PARAMETRIC STUDIES

- Magma Ascent Velocity Considered in the Simulations
  - 1 m/s, 2 m/s, and 3 m/s
- Distance Between Dike and Obstacle
  - 4 m and 7 m
- Two Large Obstacles (290 m × 1.8 m): Each One Was Placed on Either Side of the Intersected Dike
- Computational Grid: 25,000 Cells
- Time Step: Varied Between 0.01 and 0.05 Seconds

GENERAL FLOWFIELD
(WITHOUT OBSTACLES)

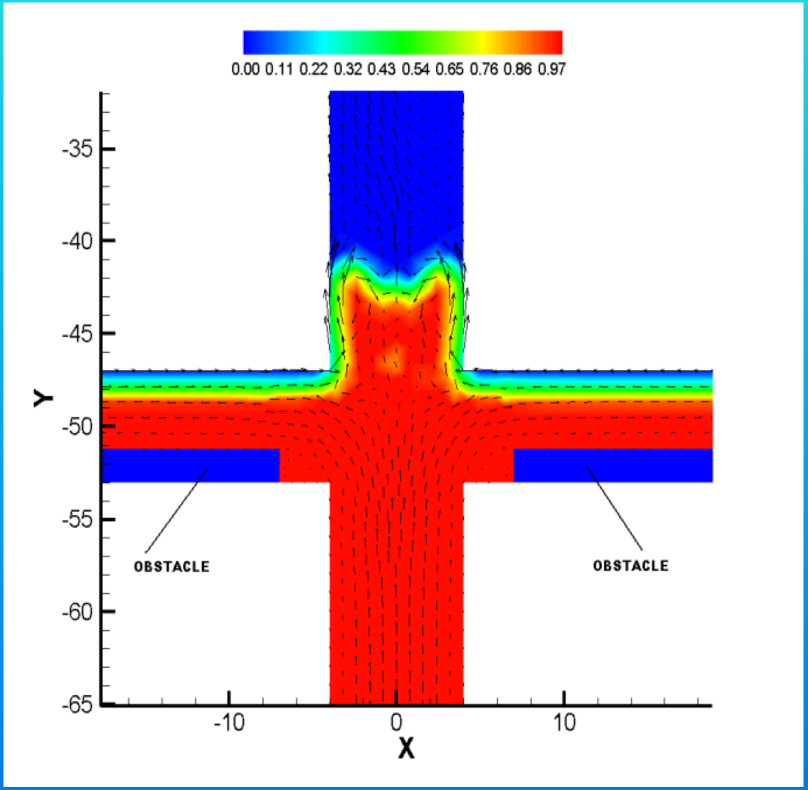


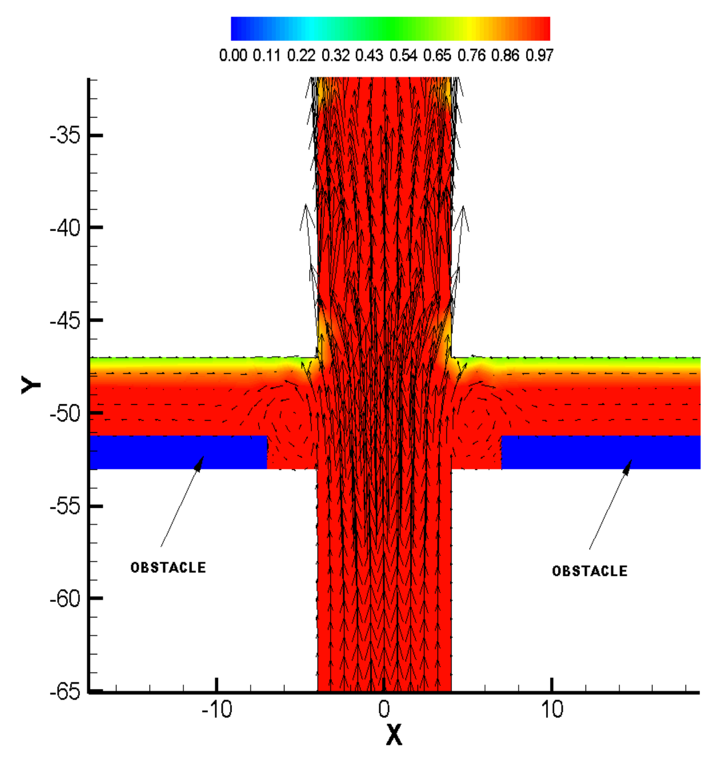
T = 1,000 seconds



T = 2,500 seconds

GENERAL FLOWFIELD
(WITH OBSTACLES)

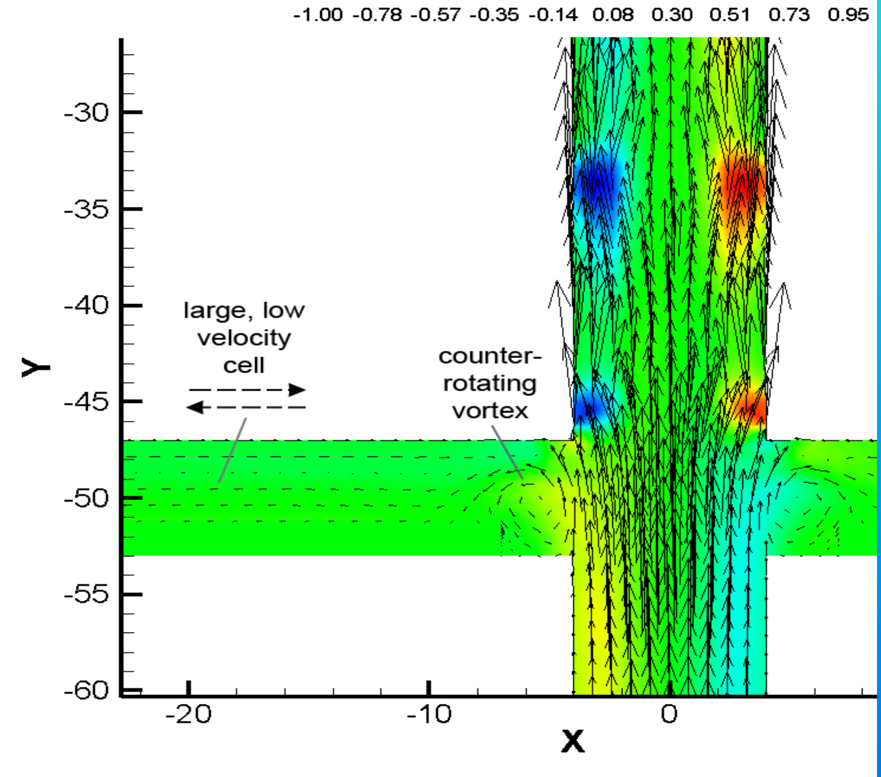




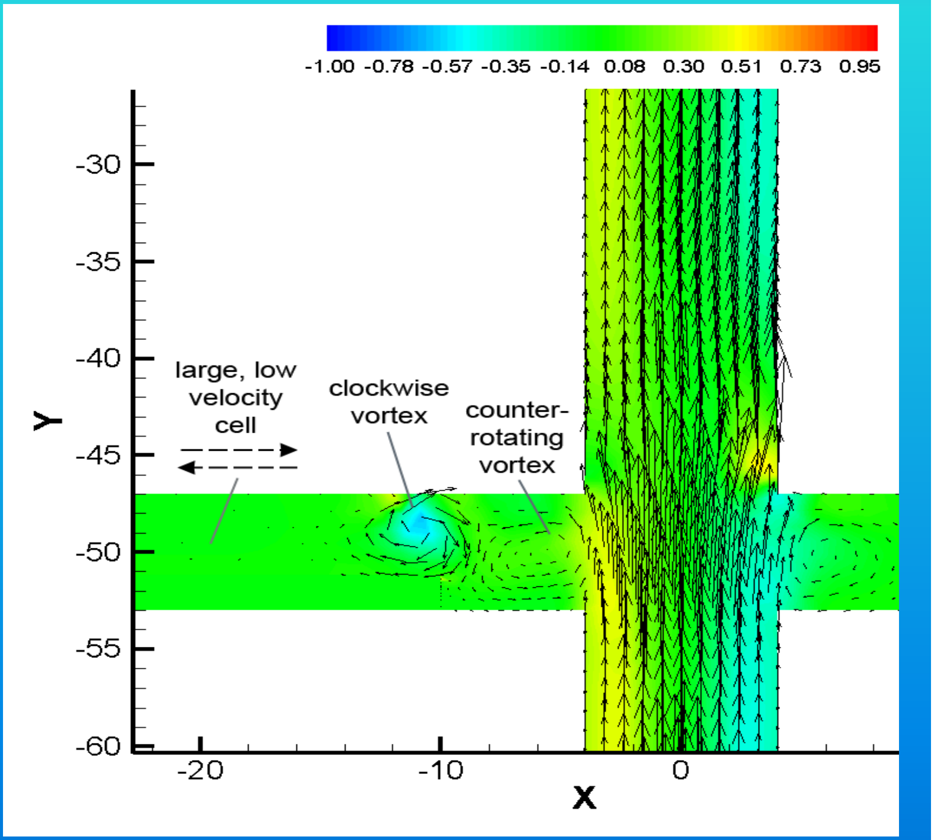
T = 1,000 seconds

T = 2,500 seconds

EFFECT OF DISTANCE

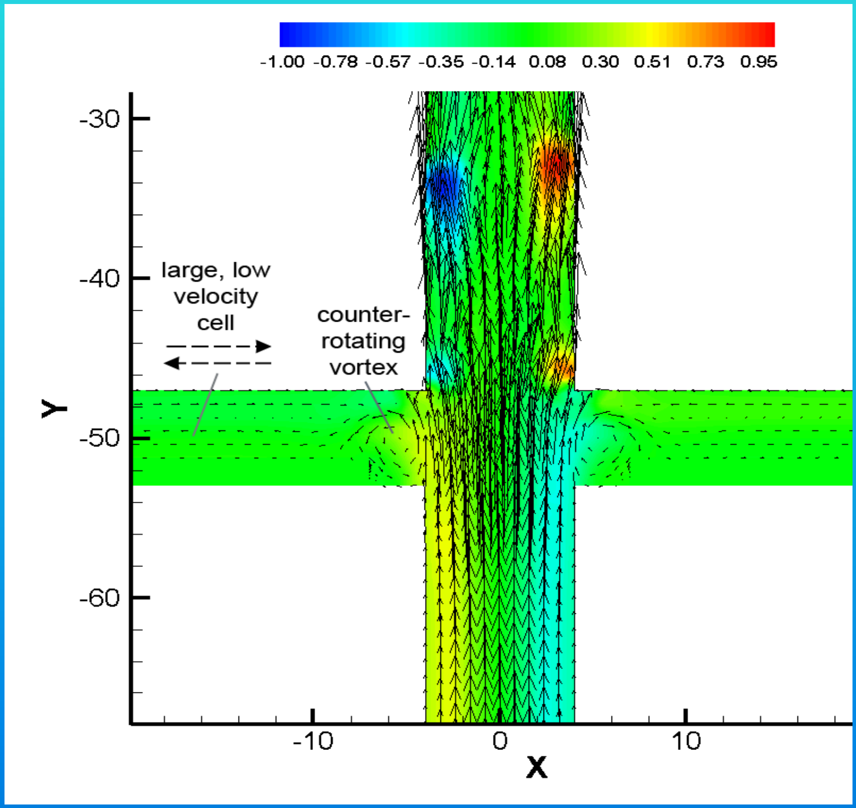


Distance Between Dike and Obstacle: 4 m



Distance Between Dike and Obstacle: 7 m

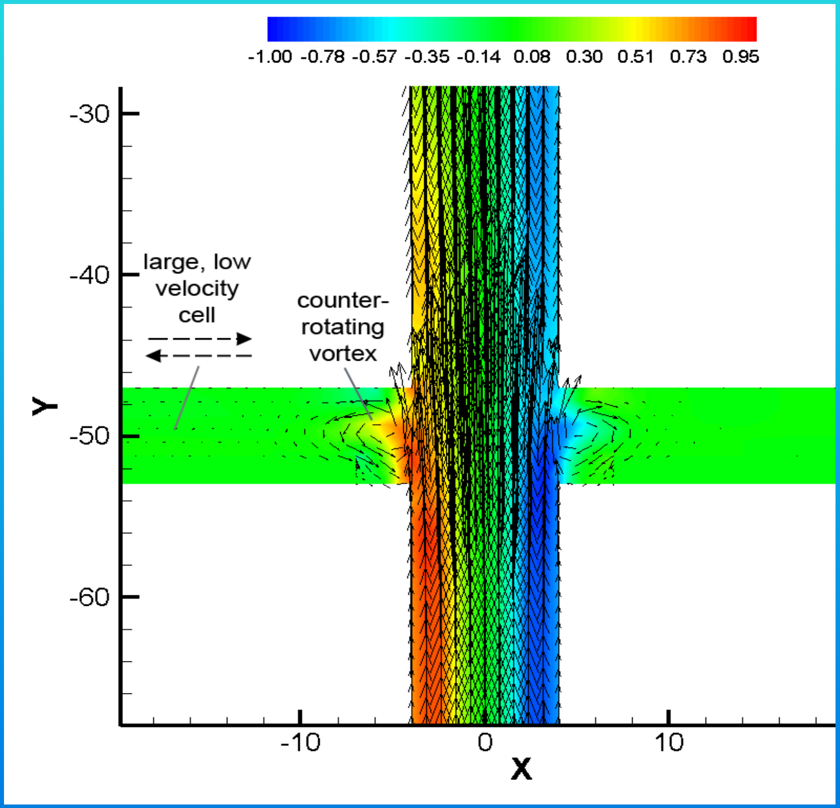
EFFECT OF MAGMA ASCENT VELOCITY



large, low velocity cell

counter-rotating vortex

Magma Ascent Velocity: 1 m/s

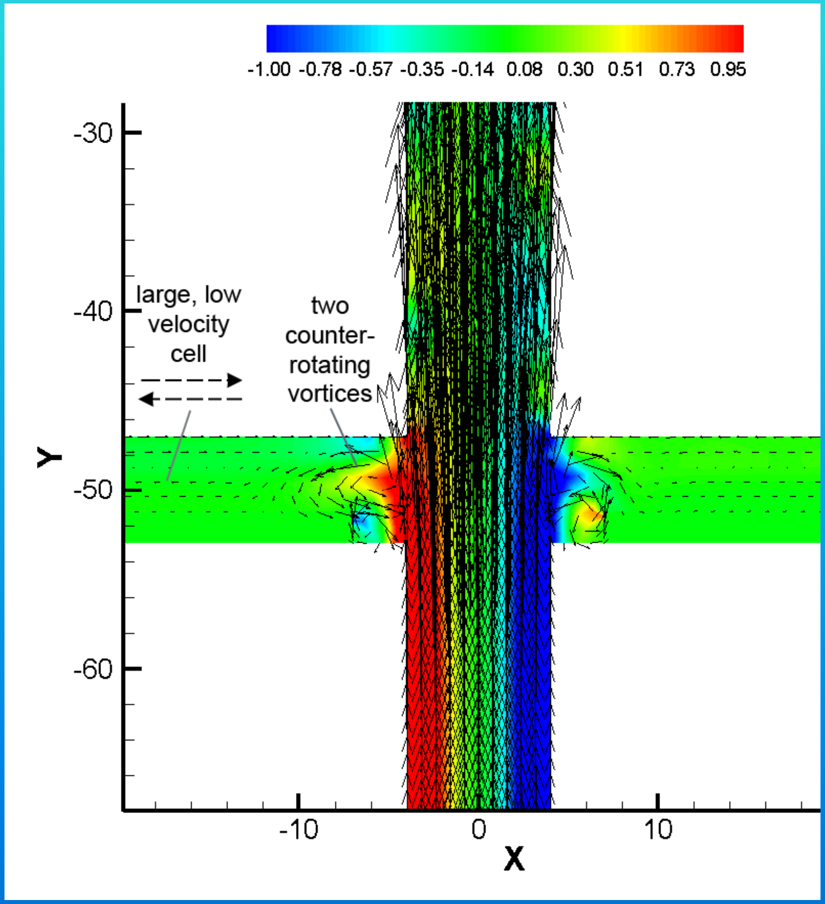


large, low velocity cell

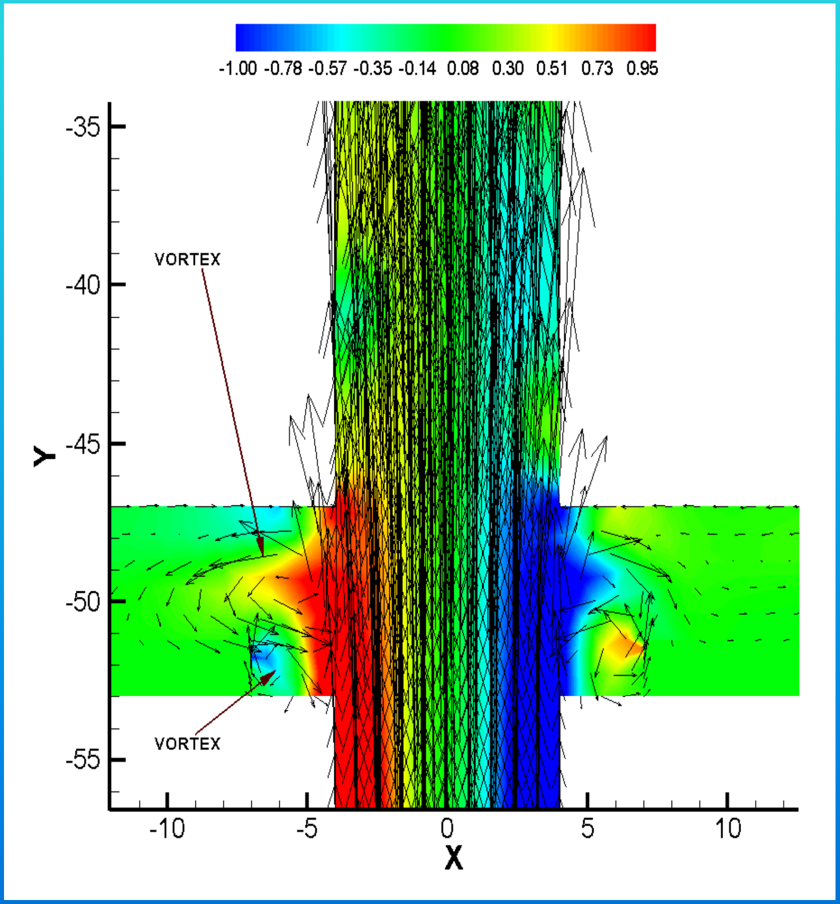
counter-rotating vortex

Magma Ascent Velocity: 2 m/s

EFFECT OF MAGMA ASCENT VELOCITY



Magma Ascent Velocity: 3 m/s



Magma Ascent Velocity: 4 m/s

CONCLUSIONS

- Magma Flow Patterns Within the Tunnel Are Affected by the Location of the Dike Intersection, Relative to Obstacles Present in the Tunnel
- Counterrotating Vortices in Magma Adjacent to the Dike Are Driven by Viscous Coupling Between the Magma Rising in the Connected Dike and the Magma in the Tunnel
- Magma Ascent Velocity Influences the Formation of a Vortex Inside the Tunnel
- At Higher Ascent Rates, Vertically Coupled Counterrotating Vortices Develop in the Space Between the Dike and the Obstacles
- In All Cases, Some Pattern of Circulation Developed in the Tunnel, and the Pattern Was Largely Influenced by the Interplay Between the Ascending Magma and Location of the Obstacles

ACKNOWLEDGEMENTS

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