Modeling Local and Advective Diffusion of Fuel Vapors to Understand Aqueous Foams in Fire Fighting

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Outline

- Background of Issue
- Past and Current Laboratory Experiments
- Model
  - Domain
  - Equations
  - Algorithms
- Verification of Model
- Future Tests
- Timeline

Background

- Fuel pool fire
  - Two dimensional fire (class B fire)
- Class B foams
  - Filming foams
    - Aqueous Film Forming Foams (AFFF)
- AFFF contains water and fluorinated surfactant
  - Lowers surface tension
    - Lays on less dense liquid hydrocarbon pool
- Two current issues

Background – Current Issues

- Application of AFFF
  - Formation of a film layer
- Film layer suppresses evaporation
  - Combustion of fuel vapors
- Vapor suppression not constant over time
  - Studied by Leonard and Williams
- “Burnback” experiments

Background – “Burnback” test importance

- Initial fire suppressed
  - Unseen flame or ember
- Portion of foam layer compromised away from flame
- Ability of foam layer to
  - maintain its integrity in presence of an open flame
  - suppress fuel vapors to prevent “ghosting”
- Failure will lead to re-ignition of previously contained fire

“Ghosting”

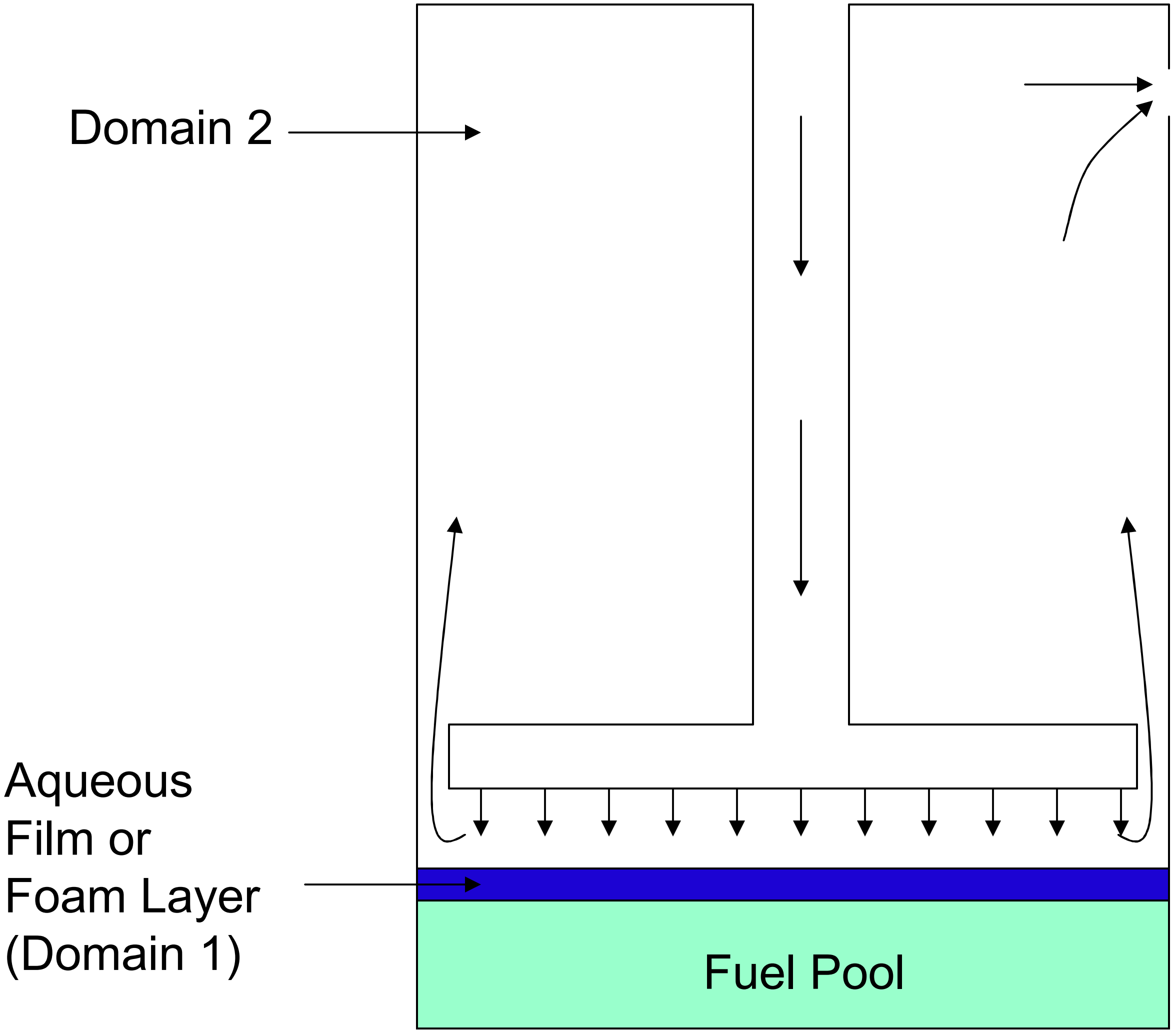
Background – Current Issues

- Fluorinated film forming foams
  - Environmentally unfriendly
  - Toxic
- Process of being replaced
  - Satisfactory replacement not found yet
- Vital to understand:
  - Performance of fluorinated product
  - Performance of new product

Laboratory Experiments

- Film layer studied by Leonard
- Foam and film layer studied by Williams
- Experimental design
- Vapor concentration measured over time
  - Initial suppression
  - Increase in vapor concentration
  - Steady state reached after certain time
- Suggested diffusion as a possible mechanism

The Domain



The Model

- Designed to match laboratory experiments of Leonard and Williams
- Variables needed: velocities and concentration of fuel vapors
- Separation into two domains
- Cylindrical coordinates
- Aqueous layer assumed to be stationary $\Rightarrow u = w = 0$
- Aqueous layer assumed to be a continuum
- Binary Diffusion coefficient assumed constant
  - Project Goal: Match diffusion coefficient in domain 1 to steady state results

Equations

$$r: \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial r} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial r^2} + \frac{\partial^2 u}{\partial z^2}\right) \qquad (1)$$

$$z: \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial r} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial z} + \frac{\mu}{\rho}\left(\frac{\partial^2 w}{\partial r^2} + \frac{\partial^2 w}{\partial z^2}\right) \qquad (2)$$

$$Y_{FV}: \frac{\partial Y_{FV}}{\partial t} + u\frac{\partial Y_{FV}}{\partial r} + w\frac{\partial Y_{FV}}{\partial z} = -D\left(\frac{\partial^2 Y_{FV}}{\partial r^2} + \frac{1}{r}\frac{\partial Y_{FV}}{\partial r} + \frac{\partial^2 Y_{FV}}{\partial z^2}\right) \qquad (3)$$

- Diffusion term different for the two domains

Algorithm – Species Fraction (3)

- Upwind Differencing from Pozrikidis for Convective – Diffusion Equation
- Upwind Difference for Convective Terms
- Centered Differencing for Diffusion Terms

$$\frac{\partial f}{\partial t} + U\frac{\partial f}{\partial x} = \kappa \frac{\partial^2 f}{\partial x^2}$$

$$\frac{f_i^{n+1} - f_i^n}{\Delta t} + U\frac{f_i^n - f_{i-1}^n}{\Delta x} = \kappa \frac{f_{i+1}^n - 2f_i^n + f_{i-1}^n}{\Delta x^2}$$

- To find D a bi-section method will be used

Algorithm – Stream Function and Vorticity

- Substitute $u = \frac{-1}{r}\frac{\partial \psi}{\partial z}, w = \frac{1}{r}\frac{\partial \psi}{\partial r}$ in (2) and (3)
- Obtain

$$\nabla^2 \psi = -\Omega \tag{4}$$

$$\frac{\partial \Omega}{\partial t} + u\frac{\partial \Omega}{\partial r} + w\frac{\partial \Omega}{\partial z} = \frac{\Omega u}{r} + \eta\left[\frac{1}{r}\frac{\partial \Omega}{\partial r} - \frac{\Omega}{r^2} + \frac{\partial^2 \Omega}{\partial r^2} + \frac{\partial^2 \Omega}{\partial z^2}\right] \tag{5}$$

Algorithm – Stream Function and Vorticity

- Algorithm from Pozrikidis to solve (4) and (5)
  - Find vorticity based on velocity fields
  - Update vorticity
    - Upwind Differencing Scheme
  - Solve for Poisson eq. for stream function
    - Explicit point–successive over–relaxation iterative scheme
  - Solve for velocity fields

The Model

- Validation
  - Diffusion constant for fuel vapors in air known
  - Comparison to a published result
  - Stagnation flow solution
- Application and Data
  - Fuel vapor concentration data from film lab experiments
  - Fuel vapor concentration data from foam and film lab experiments
  - Parametric tests

The Model

- Platform and Language
  - Fortran90
    - Intel compiler
  - MacBook Pro
    - 2.4 GHz Intel Core 2 Duo
    - 3 GB memory
- Deliverables
  - Software package that finds diffusion coefficient for a fuel based off of concentration data
  - Input data
  - Coefficient and visualization results

Timeline

- October – November
  - Code Upwind Differencing and Steam Function/ Vorticity Algorithms
  - Stagnation flow solution from Leonard
- December – February
  - Verify code against Fuel Vapor in Air data
- March – April
  - Apply code to Film and Foam data
- May
  - Prepare report and final presentation

References

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Questions?