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Two Dimensional Finite Element Heat Transfer Analysis of a Buried Refined Bitumen Pipeline During Initial Start-up, Shutdown Following Initial Start-Up, and Normal Operation

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Overview

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2. Model Description
3. Methodology
4. Results and Discussion
5. Future Work

Motivation

- Refined bitumen is a highly viscous oil formed from the distillation of heavy crude
- For pipeline distribution systems in cold weather areas the high viscosity can lead to:
  - Elevated pumping requirements and/or multiple intermediary pumping stations
  - Need for active thermal management methods such as heat tracing
  - Operationally intensive intervention methods such as fluid displacement
- A detailed description of the thermal behavior is thus needed for a reliable and cost effective design

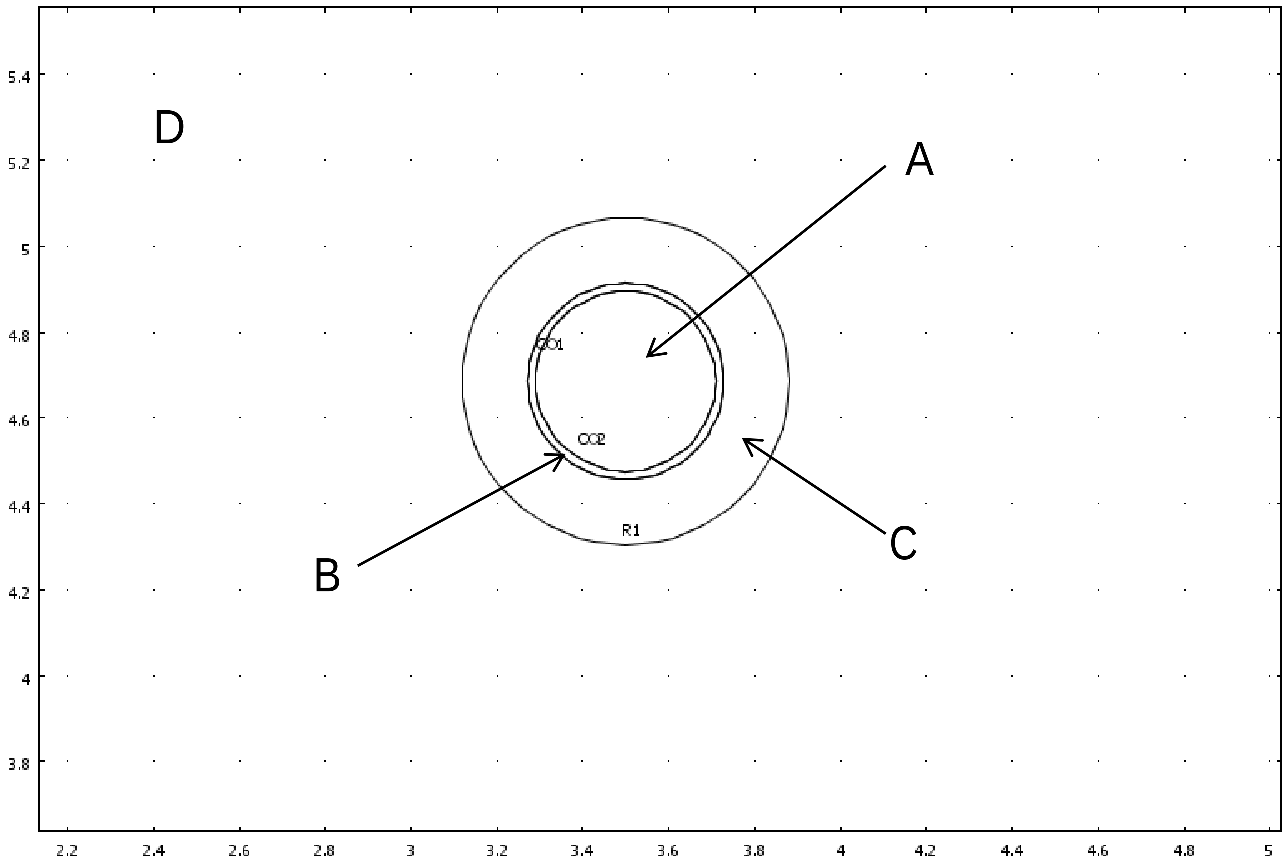
Methodology

- 3 operating scenarios were examined:
  - Steady State/Normal Operation
    - Dominates extent of thermal penetration into the environment (i.e. what radius of soil is heated by presence of the warm pipe)
  - Initial 14 days of Operation
    - Largest heat flux to the environment as surrounding soil acts as a heat sink
  - Shutdown following Initial 14 days of Operation
    - Large heat flux to the environment results in the least amount of cooldown time (i.e. time before operational intervention is required)
- Insulation sensitivity performed
  - 2 polyurethane foam insulation thickness were examined
    - 0.078 m
    - 0.235 m

Methodology – Use of COMSOL

- COMSOL V3.5a used for all simulations
- Conduction application mode used for modeling of the physics
- Free triangular meshing was used with default parameters
  - A single refinement of the mesh was made resulting in 28,800 elements
- UMFPACK direct solver used as the linear system solver
- Time integration was performed using the backwards differencing scheme

Model Description



Model Description - Geometry

Region	Description	Outer Radius (m)
A	Refined Bitumen	0.679
B	Steel	0.709
C	Polyurethane Foam Insulation	0.787 (Case 1) 0.944 (Case 2)
D	Soil	7 x 7 square

Model Description – B.C.’s and I.C.’s

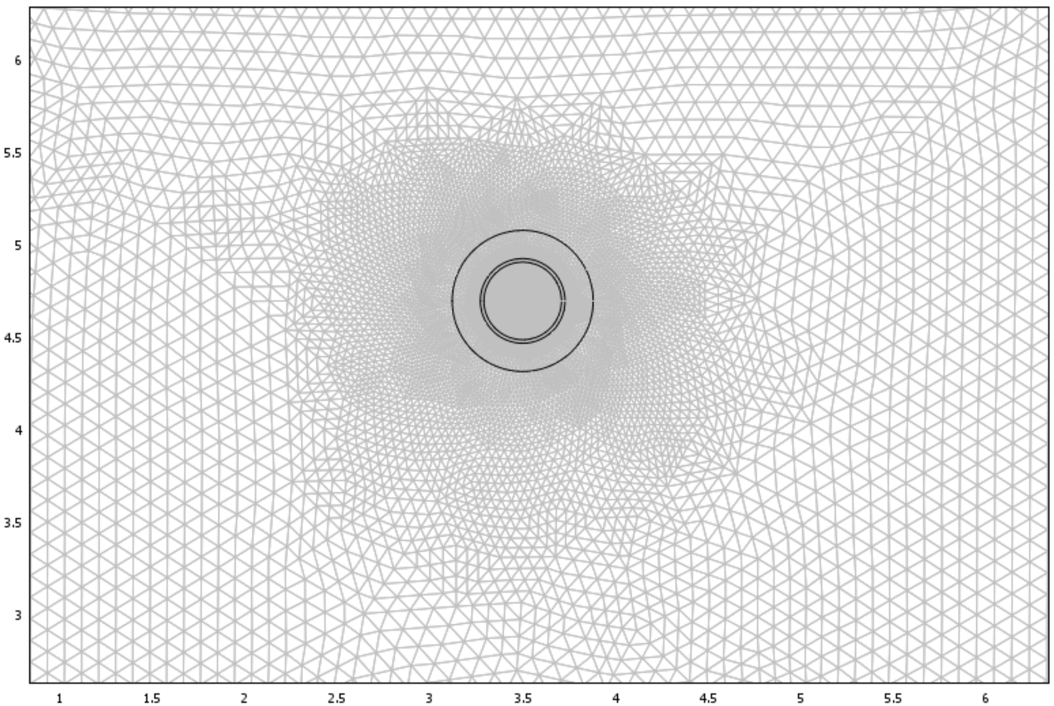
Region	Normal Operation	Initial Start-Up	Shutdown
A	110°C	110°C	Continuity
B	Continuity	Continuity	Continuity
C	Continuity	Continuity	Continuity
D	5°C	5°C	5°C

Model Description –I.C.'s

- For the initial start-up simulation:
  - Soil, insulation, and pipe wall assumed to be at ambient temperature of 5°C
  - Bitumen assumed to be at temperature of 110°C

- The results of the initial start-up simulations acted as the I.C.'s for the shutdown simulation

Model Mesh



Mesh Statistics

Global | Subdomain | Boundary | Point

Extended mesh:

Number of degrees of freedom:	57841

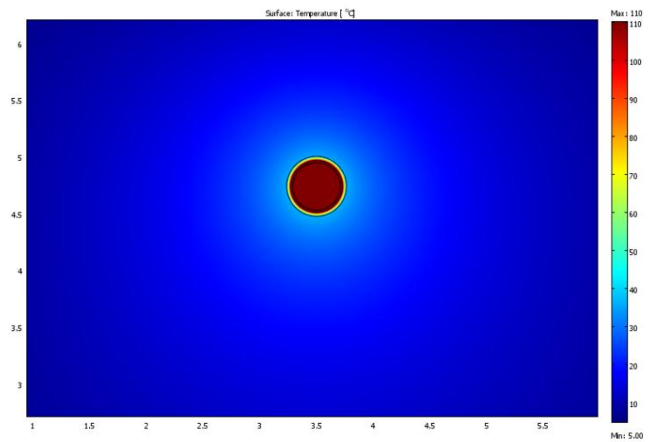
Base mesh:

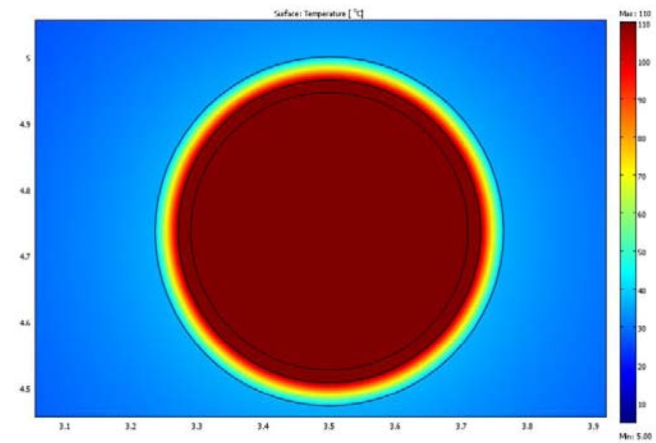
Number of mesh points:	14521
Number of elements:	28800
Triangular:	28800
Quadrilateral:	0
Number of boundary elements:	768
Number of vertex elements:	16
Minimum element quality:	0.7604
Element area ratio:	0.0018

OK | Help

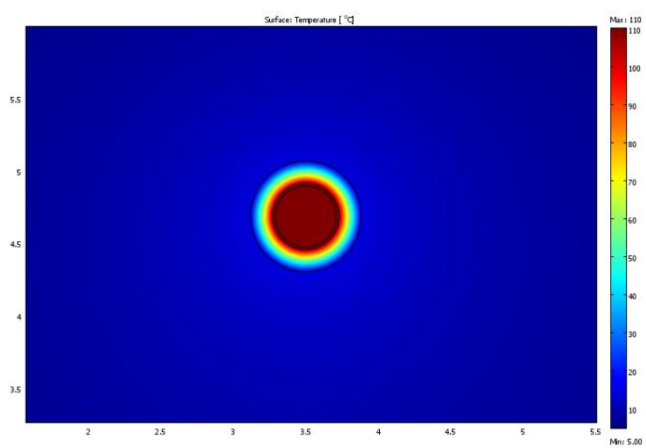
Results- Normal Operation

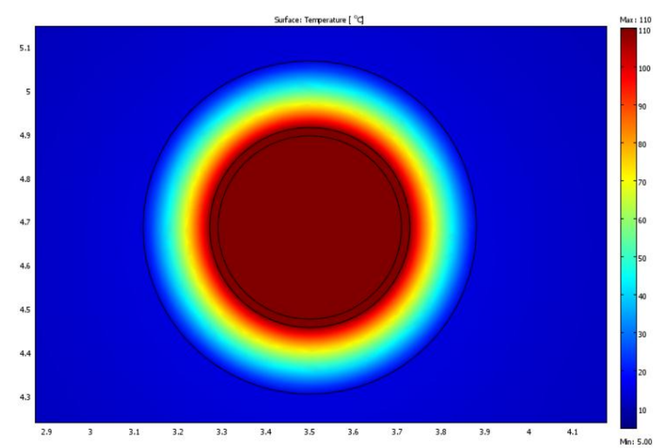
0.078 m PUF





0.235 m PUF

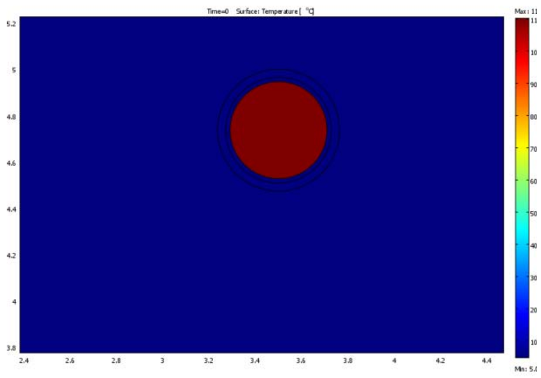


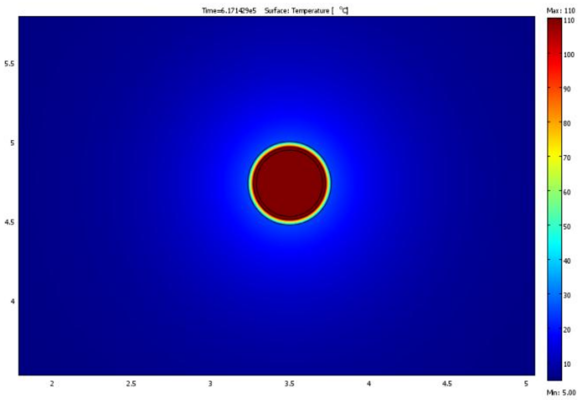


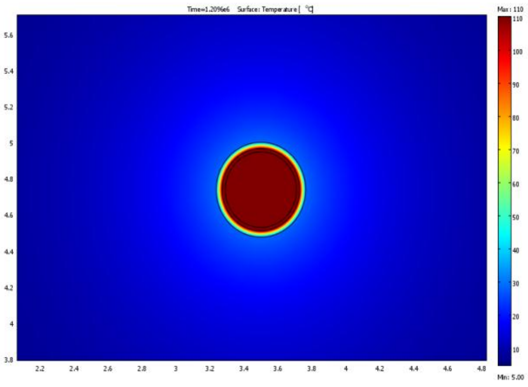
Results- Initial Start-Up

0 days | 7 days | 14 days

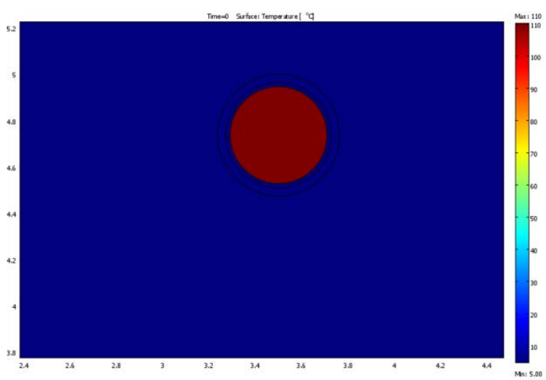
0.078 m PUF

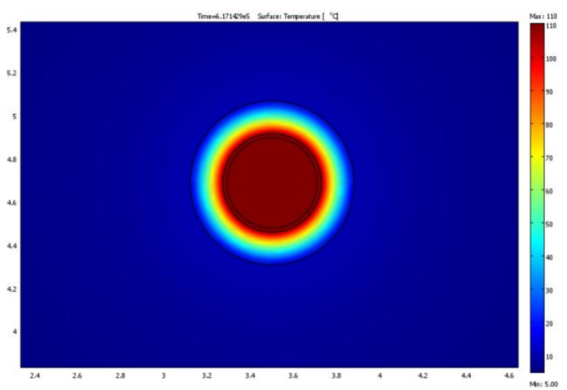


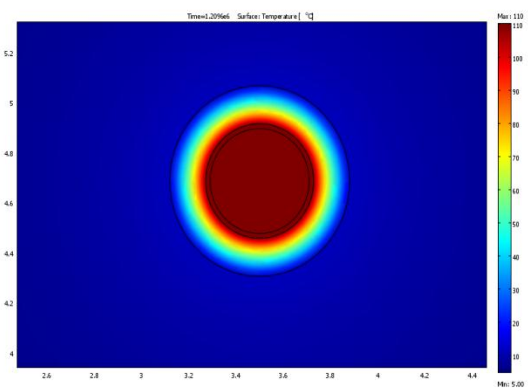




0.235 m PUF



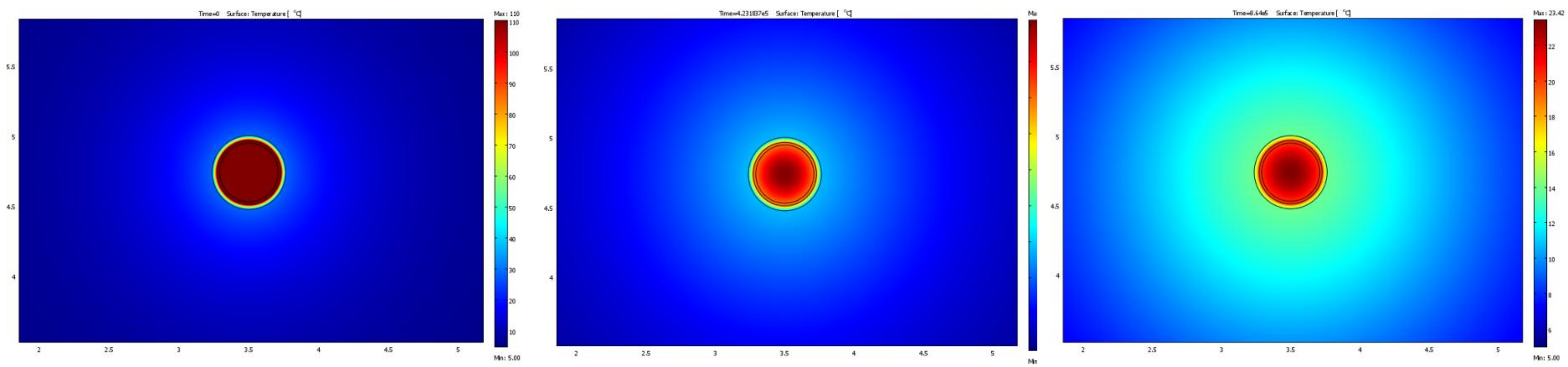




Results- Shutdown after Initial Start-Up

0 days | 5 days | 10 days

0.078 m PUF



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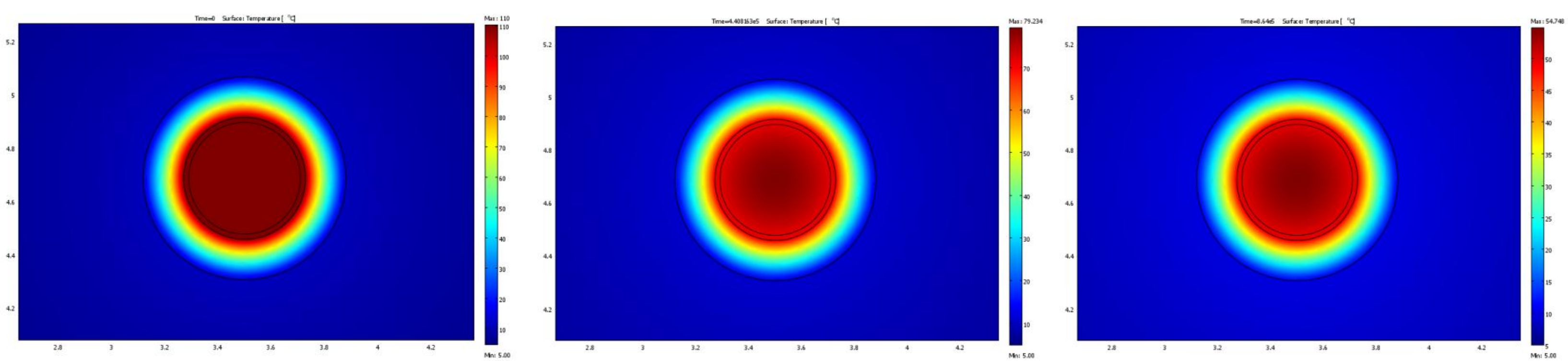

Future Work

- Extend model to three dimensions
- Incorporate multiphysics analysis
  - Coupled fluid flow/heat transfer analysis
    - Capture effects of internal convection
    - More realistic portrayal of pipeline restart pressures versus typical 1D approach
      - Warm less viscous flow heating and shearing off outer more viscous core
  - Use results from coupled analysis as boundary conditions in stress analysis
- Incorporate functions in heat transfer properties to account for permafrost (i.e. latent heat of fusion)

Thank you

and

Questions?

Back-Up

Theory

- Heat transfer by conduction is governed by the heat equation

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \bullet (k \nabla T) = Q$$

- If temperature is assumed to be time independent (i.e. steady state behavior), the heat equation reducec to Fourier's Law of Heat Conduction

$$\mathbf{q} = k$$

Model Description – Physical Props.

Region	Density (kg/m3)	Thermal Conductivity (W/(m*K))	Heat Capacity (J/(kg*K))
A	949	0.16	1,670
B	7,850	44.50	475
C	220	0.03	1,590
D	2,200	1.30	880