Electrically Heated Flowlines – ANSYS FLUENT – Maxwell Coupled Solutions

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Outline

- Electrically Heated Flowlines: Overview
- Design Challenges
- Need for Simulation: ANSYS Approach
  - Electromagnetic Simulation
  - Computational Fluid Dynamic Simulation
- Results
Electrically Heated Flowlines: Overview

- Prevent hydrate and wax formation
  - Deepwater: Oil and gas exploration
  - Long tiebacks and operation shut down
- Reliable alternative to chemical injection: environmentally friendly

Hydrate Plug  
(courtesy: open literature)

Wax Deposition  
(http://pubs.acs.org/cen/coverstory/87/8738cover.html)
Design Challenges: Criteria

- Prevent hydrate plug or wax deposition by maintaining the flow lines at a design temperature
  - Deepwater production: May require continuous heating – Long lines
  - Maintain fluid temperature above design temperature – Short length
  - Raise the temperature of the fluid from ambient to above design temperature within specified time period
Electrically Heated Flowlines: Overview

- Electrical heating options (3 examples)
  - Pipe in Pipe: Closed current loop into one pipe return on the other
  - Open Loop (DEH): Current loop into cable, return in water and pipe
  - Induction: Three phase cable has no pipe return, induced currents only
Electrically Heated Flowlines: Overview

- Heating efficiency varies with each design
- Examples compared for 85W/m pipe heating
- Efficiency measures ratio of useful loss in pipe to total loss

593A flowline current
- 55% Efficient

1200A flowline current
- 49% Efficient

1014A flowline current
- 37% Efficient

Pipe in Pipe
- Open Loop (DEH)
- Induction
Design Challenges: Rating

- Knowledge of supply current and
  - Power Loss (heat generation) - Electromagnetic field simulation
- Knowledge of operating conditions and
  - Thermal Loss – Computational fluid dynamics simulation

Efficiently Design – Coupled Approach is Needed
ANSYS Approach: Coupled Simulation

ANSYS offers solutions for both electromagnetic field simulations and CFD simulations.
Electromagnetic Field Simulation

Simulation Goals

- Examine Field Distribution
- Determine Necessary Supply Current
- Parameterize Loss vs Geometry
- Compare Design Efficiencies
- Determine Circuit Lumped Parameters
Electromagnetics Field Simulation

Example: Field and loss distributions for open loop DEH

- 85 W/m heating target

Diagram showing the components:
- Copper Cable Core
- Cable Dielectric
- Cable Sheath
- Pipe insulation
- Steel Pipe
- Pipe Contents
- Seawater

10” dia. pipe
Field simulation input supply

- Unit current is applied to cable.
- Equal and opposite units of current are applied to the pipe and water for the return.
- 2D simulation of cross section is performed which does not include end effects at anodes.
Electromagnetics Field Simulation

Field simulation indicates how much current is needed to achieve desired power density.

- Simulation determines 59 $\mu$W/m/A$^2$ in pipe
- 1200A rms is required for 85 W/m

![Graph showing Loss vs. Current]

![Diagram of Magnetic Flux Lines]

![Diagram of Current Density]
Electromagnetics Field Simulation

Determine cable position effect on Loss

- Increased distance decreases impinging flux density, which decreases AC losses.
- Design cable position for performance, or characterize to understand non-ideal placement effects.

Pipe Loss vs Cable Position

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Power Electronics Circuit

Simulation Goals

- Determine necessary supply voltage
- Size and rate passive electrical components
- Build multiphase impedance balancing network
- Improve supply power factor
Determine necessary supply voltage

- Calculate system’s electrical impedance
- Inductance, Resistance, and Capacitance are measured per unit length

How much voltage is needed to achieve necessary current?
Power Electronics Circuit

Configure supply voltage connection

- Balance one-phase load across three-phase source
- Correct load power factor from 0.3 closer to 0.9

Power Source
Transformer
Load Balance Network*

Power Factor Correction
DEH representation

Power Electronics Circuit

Balance the load to distribute current among phases

Three Phase Balanced Load

No Load Balancing
Power Electronics Circuit

Add compensation capacitor to increase power factor

Power factor measures ratio of active power to active and reactive power

Current Supply with Compensation

PF=0.99

Less current needed from supply
Power Electronics Circuit

Verification: Track the active and reactive powers from the supply.

- Once energized little reactive power is needed from the supply due to the balanced power factor correction.

Once charged, reactive power is supplied by compensation capacitor.
CFD Simulation Studies: Thermal Loss

- Why CFD simulation?
  - Heat transfer in the flowline is due to Convection
  - External heat transfer – natural convection
  - Boussinesq model approximation
  - 2D Vs 3D modeling
The Boussinesq Approximation

- Boussinesq model assumes the fluid density is constant in all terms of the momentum equation except the body force term.

\[ \rho_0 \frac{D\bar{U}}{Dt} = \mu \nabla^2 \bar{U} - \nabla P + (\rho - \rho_0)\bar{g} \]

\[ \rho_0, \text{ Constant (operating) density} \]

- In the body force term, the fluid density is linearized.

\[ (\rho - \rho_0)g = -\rho_0 \beta (T - T_0)g \]

*The Boussinesq assumption is valid when density variations are small.*

*Cannot be used with species transport or reacting flows.*
2D Vs 3D Model

- 2D model assumptions
  - Deepwater operations – Long pipelines – No end effect influence
  - Calculate fluid steady state temperature – Given current and ambient conditions

- 3D model
  - Determine optimum power or length of the flow line – Given flow conditions, current and ambient conditions
  - Shut down or start-up operations
CFD Solution Domain: 2D Model

- Piggy back cable
- Thermal Insulation
- Sea at ambient temperature
- Pipe heat Source
- Flowing Fluid - Not modeled
CFD Flow Field: Velocity Field

Flow Due to Natural Convection - Boussinesq approximation
For a given current and ambient conditions, steady state temperature of the fluid can be predicted.
CFD Simulation Studies: 3D Modeling

- Determine safer operating maximum flow line length - Given flow conditions, current and ambient conditions
  - Considered a small segment of the flow line
- Used Multi-Fluid (VOF) approach to model the flow
  - The flowing fluid doesn’t use density based on Boussinesq approximation
- Fully developed flow profile is used @ the flow line inlet
- Turbulent modeling is limited to the flow line – zone based selection
CFD Simulation – 3D Domain

- Piggy back cable
- Pipe heat Source
- Flowing Fluid
- Sea
CFD Simulation – Velocity Vectors
Temperature Gradient Along Pipe

Hydrate formation temperature = 25°C

\[ y = -0.0019x + 30.002 \]
\[ R^2 = 0.9879 \]

\[ y = -0.0106x + 30.012 \]
\[ R^2 = 0.9885 \]
CFD Simulation Studies: 3D Modeling

- Without electrical heating, the current scenario would have restricted the flow line to 0.5 Km.
- By electrically heating the pipeline, the flow line could be extended to 3 Km for an optimum power.
  - Efficiently can limit the power for a given length.
- If power is not a restriction – the pipe could be maintained well above 25 °C and we could have design with no limit on the length.
Start-up and Shut-down Operations

Transient Simulation
Given Length, Power, and assumed all the lines are @ ambient conditions.
Transient Heating of Pipe

![Graph showing the transient heating of a pipe over time. The graph plots volume average temperature in Celsius (°C) against time in seconds. The temperature decreases rapidly initially and then increases more gradually as time progresses.]
Conclusion

- ANSYS coupled field solutions is useful for efficiently designing electrically heated flow lines
- Electromagnetic Field Simulations
  - Examine field distribution and determine the supply current
  - Compare design efficiencies
  - Configure power supply
- Computational Fluid Dynamic Simulations
  - Determine the required current to maintain a steady state temperature
  - Determine optimum power or length of the flow line – Given flow conditions, current and ambient conditions
  - Shut down or start-up operations
In natural convection, fluid motion is generated due to density difference (buoyancy) in the fluid caused by temperature gradients.

Body forces
- Typically gravitational
- Centrifugal (rotating machinery)
- Coriolis (atmospheric and oceanic vortical motion)

For this class of problems, flow and energy are strongly coupled.