NTNU

Department of Petroleum Engineering
and Applied Geophysics

Universal Temperature Profile in Pipe Flow

TPG 4515 Petroleum Production Specialization Course

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Identifying the problem

- The universal temperature profile encompasses temperature changes in pipe flow.
- Formation of solids in pipelines depends on temperature (and pressure).
- Knowledge about radial temperature change is extremely useful in order to know what to expect, taking appropriate measures to avoid formation of solids and awareness of pipeline conditions.

Agenda

- What is the Universal Temperature Profile
- Petroleum Production Case Examples
- Simple Sensitivity Analysis
- Discussion
- Comments on Used Method
- Conclusion

The Universal Temperature Profile

- Temperature profile from pipe wall, through viscous sub-layer, buffer layer to the turbulent core.
- Effect of outside cooling.
- Pipeline wall heat transfer.
- Effect of fluid and flow conditions.
- Where, and by how much, does the change happen?

Methods Used

1st Step:

- Obtain inner pipe wall temperature, Tvi, through modification of Fourier's Law.

2nd Step:

- Construct radial pipeline temperature profile.
- Converts temperature (and distance) to dimensionless terms.

Viscous sub-layer:

$$T^{+} = T_{v}^{+} + \Pr y^{+}$$

Buffer layer:

$$T^{+} = T_{v}^{+} + \left[5\Pr + 5\ln\left(0{,}2\Pr y^{+} + 1 - \Pr\right)\right]$$

Turbulent core:

$$T^{+} = T_{v}^{+} + \left[5\Pr + 5\ln\left(1 + 5\Pr\right)\right] + 2{,}5\ln\left(\frac{y^{+}}{30}\right)$$

(J.S. Gudmundsson, 2011)

Case Examples

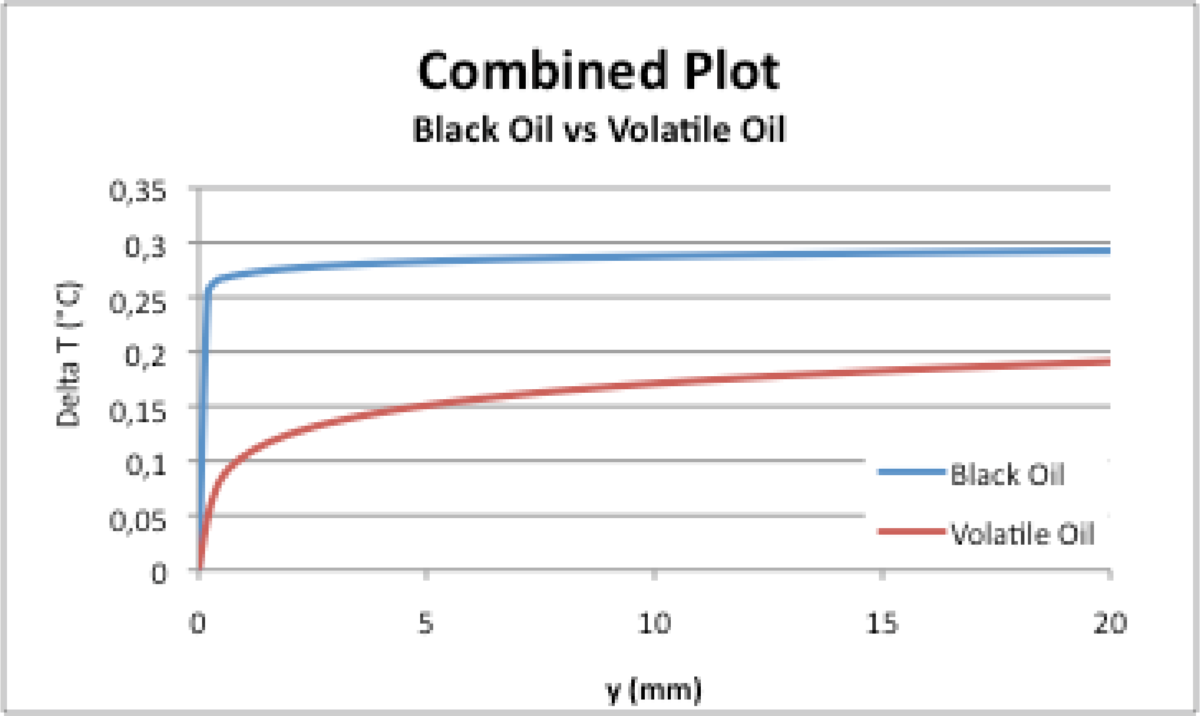
- FLUIDS:
  - Black Oil and Volatile Oil
    (HYSYS compositions, TPG 4135 Processing of Petroleum, 2011)
  - Shtokman Natural Gas
    (Translang Tech., year unknown)
  - Ormen Lange Natural Gas
    (Heskestad, 2004)

- Fluid properties are obtained from HYSYS under assumed reasonable pressure and temperature conditions.

General Assumptions

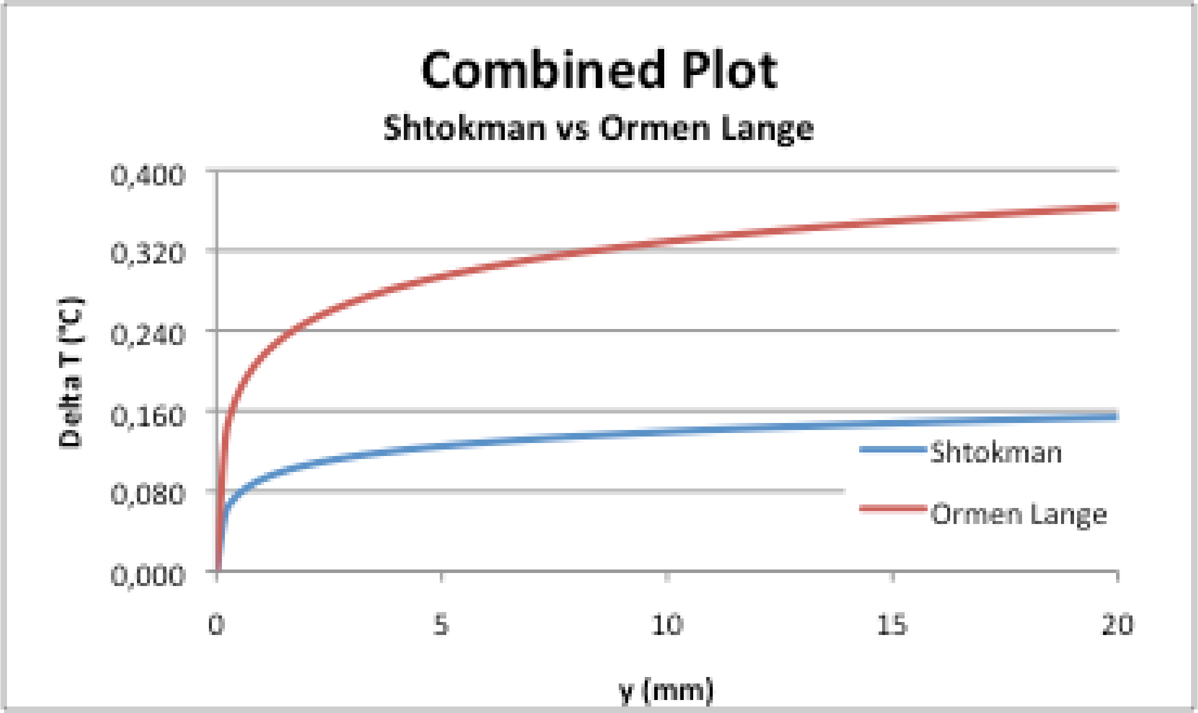
- STEADY STATE.
- PIPE:
  - Dimensions (12" ID)
  - Heat Transfer Coefficient, U (20 W/m^2 K)
  - Thermal Conductivity, kpipe (40 W/m K)
    - For not insulated carbon steel pipe.
  - Pipe Roughness (35,1 μm)
- CONDITIONS:
  - Ambient and Inlet Temperature (°C)
  - Pressure (Pa)
- BULK:
  - Velocity (2 m/s for oils, 30m/s for gas)

Black Oil vs. Volatile Oil



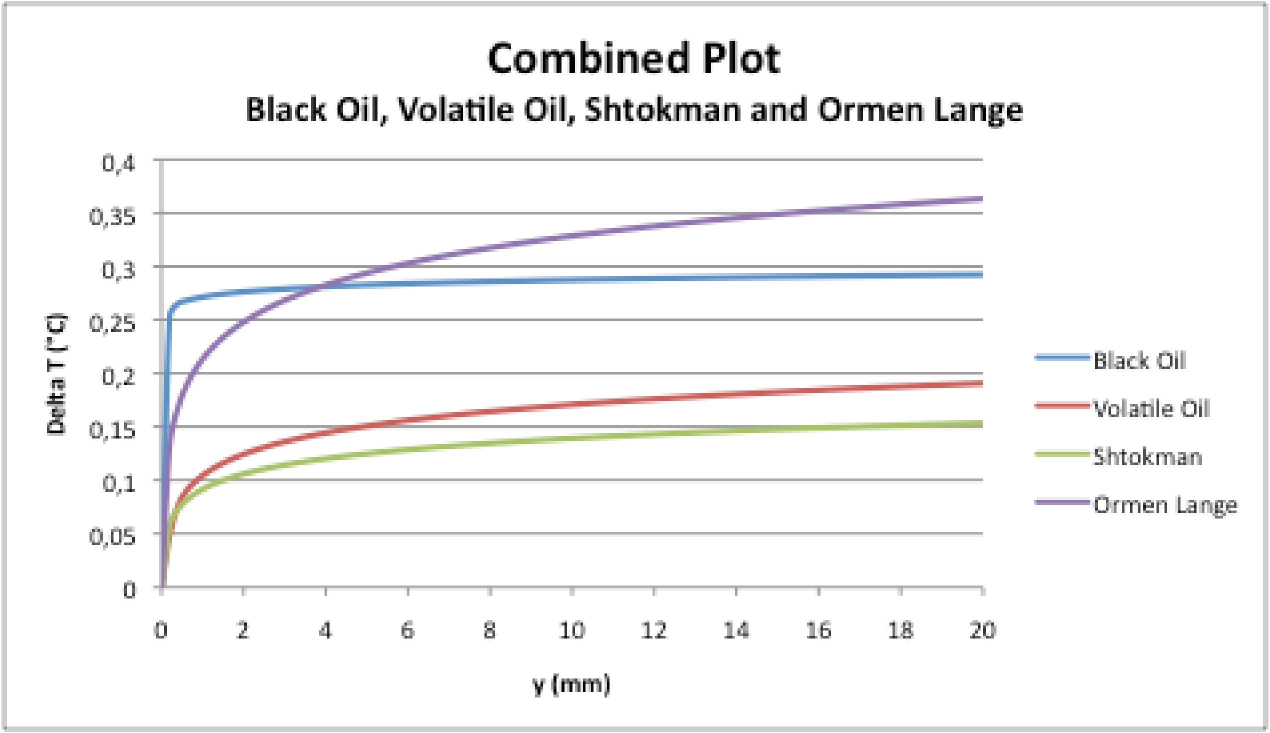
- Conditions: 20°C & 80 bara.
- Thicker boundary layer for black oil.
- Noticeable temperature change in turbulent core. Even more so for volatile oil.
  82% and 25% change in the viscous sub-layer for black- and volatile oil, respectively.

Shtokman vs. Ormen Lange



- Shtokman: 40°C & 100 bara.
  Ormen Lange: 80°C & 100 bara.
- Extremely thin sub- and buffer layer.
- Temperature change within these two layers is still 36% and 35% for Shtokman and Ormen Lange, respectively.

Oil vs. Natural Gas



- Shape of curve is very dependent on Pr number.
- Black oil has very high Pr number, giving it a distinct shape compared to the other fluids. $Pr_{BO} >> PR_{VO,G}$

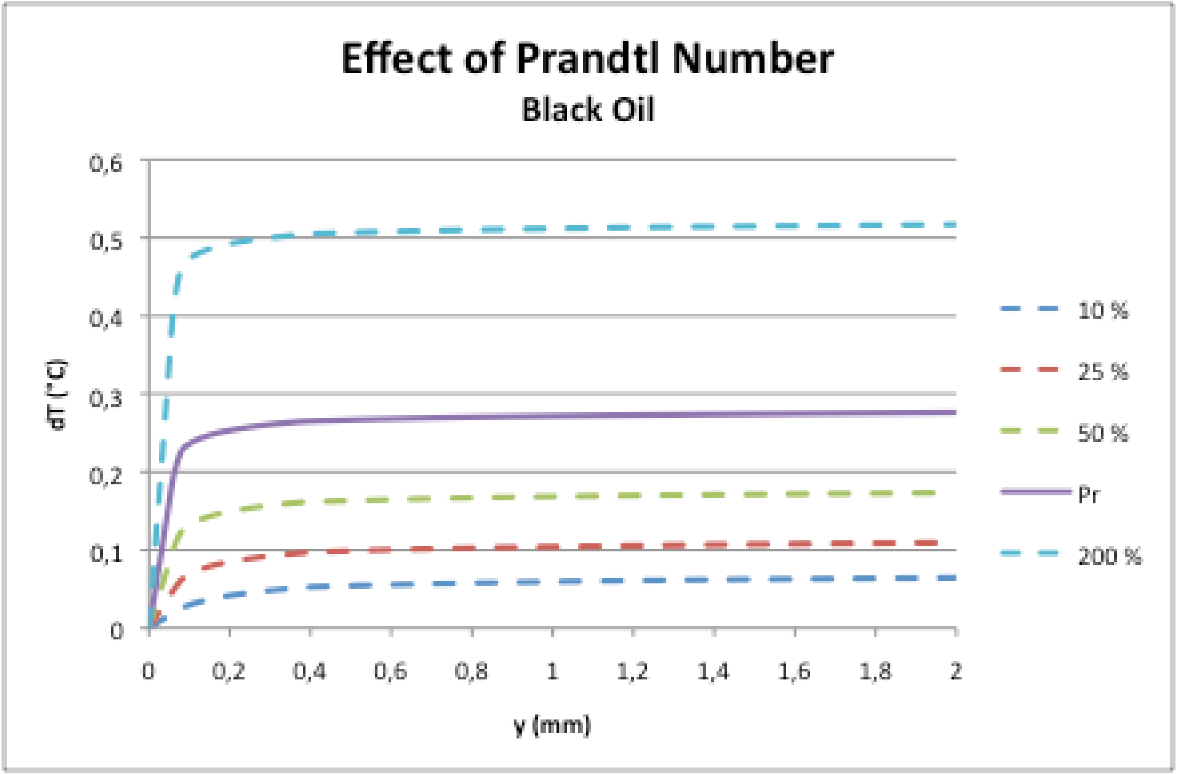
Simple Sensitivity Analysis

- Investigate the sensitivity of certain parameters and their effect on the radial temperature profile.
- Pr number shown to have significant effect.
  - Heat capacity and viscosity varies most between the fluids.
- Unchangeable parameters:
  - Heat Capacity
  - Viscosity
  - Thermal conductivity of fluid.

$$\Pr = \frac{C_p \mu}{k}$$

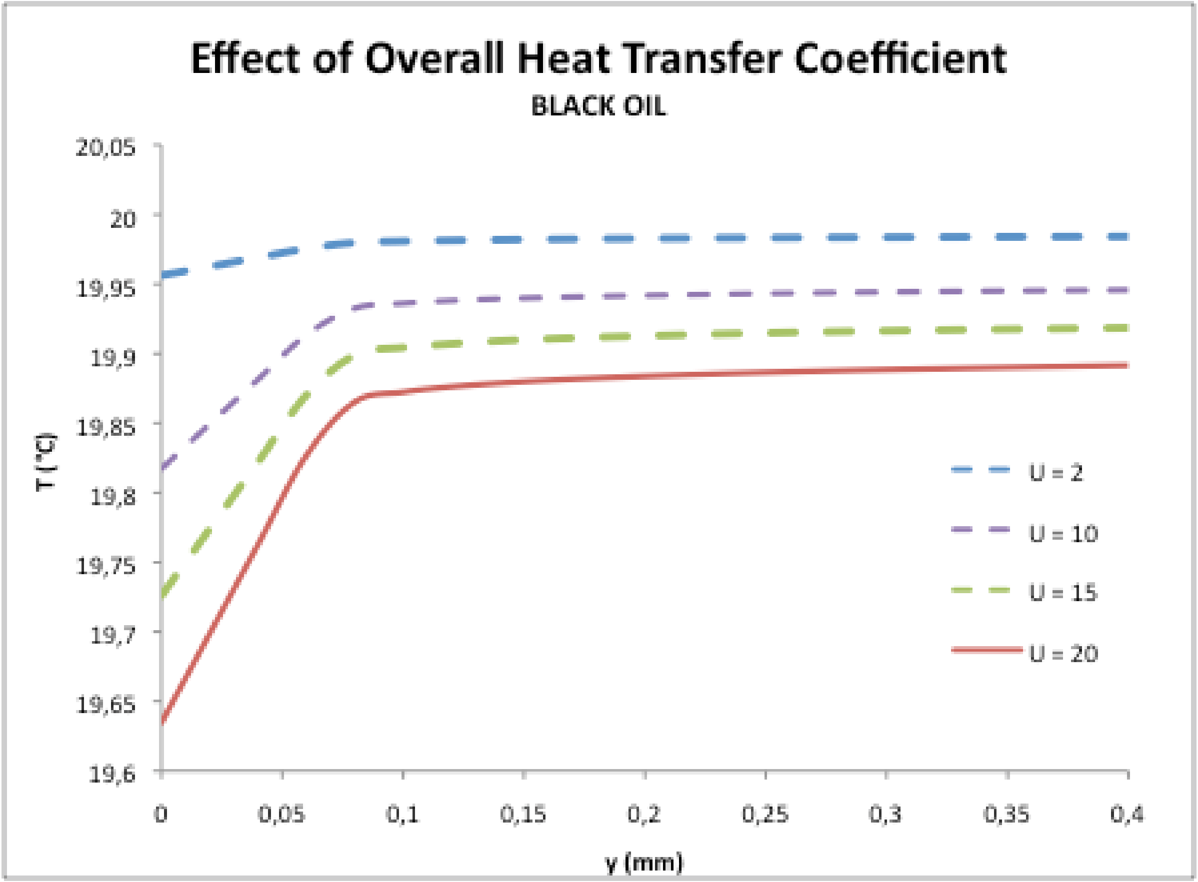
- Changeable parameters:
  - Heat Transfer Coefficient
  - Fluid Velocity

Simple Sensitivity Analysis



- Sharper transition into turbulent core. Higher dT as Pr decreases.

Simple Sensitivity Analysis



- The more insulation, the less temperature drop at the wall.
- Insulated pipelines have low heat transfer coefficients.

Discussion

- The calculations have been performed using a combination of real data, simulated data and assumed data.
  - Actual numbers may not be reliable because they are subject to a high degree of uncertainty.
  - Shape of profile, trends and the sensitive parameters is perhaps the most valuable and reliable information that can be extracted from this work.

- Helpful in identifying solid deposition “danger-zones”.
  - Wax, hydrates are more likely to start forming at the wall as the issues arise as temperature drops.

- Based on available data and model requirements the results are thought to be reasonable, keeping the uncertainties in mind.
  - Variations imposed by considering different fluids seem valid.

- Method used corresponds to what is described in “Fluid Mechanics & Transfer Processes” by Kay & Nedderman (1985), although from different reference points.
  - Kay & Nedderman → From turbulent core to pipe wall.
  - J.S. Gudmundsson → From pipe wall to turbulent core.
  - Model as described by Sippola is similar, but not closely considered in this work.

Conclusion

- Shape of temperature profile very much dependent on Prandtl number.
  - Heat Capacity
  - Viscosity
  - Fluid Thermal Conductivity

$$\Pr = \frac{C_p \mu}{k}$$

- Boundary layer is thicker for more viscous fluids.
- Relative radial temperature change is generally small.
- Most of the temperature change happens within the first few millimetres (oil) and centimetres (gas).
- Probability of solid formation is greater at the wall due to lower temperature.

References

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