Radiative heat transfer estimation in pipes with various wall emissivities

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Introduction
- Heat transfer through inclined pipes investigated deeply
  – focus on convection
- Radiative heat transfer mostly negligible since order of magnitude comparably small
- Fraction of radiative heat transfer hardly to be calculated except for demanding numerical simulations
- Aim is to provide easy-to-use model for radiative heat transfer estimation in pipes including pipe wall

Geometry, definitions and assumptions

![Diagram of pipe geometry and definitions for the calculation model.](image)

- Radiative properties – grey and diffusive surfaces with a constant emissivity \( \varepsilon \).
- \( Q_{\text{rad}} \) is the net radiation exchange between the warm and the cold end of pipe.

Available analytical approaches
Model of two plane-parallel surfaces (VDI HEAT ATLAS):

\[
\phi = 1 + \frac{2L}{\varepsilon} \left[ \sqrt{\frac{D^2 + L^2}{D^2}} \right]
\]

Theoretical minimum of radiative heat transfer:

Pipe wall neglected, arbitrary \( \varepsilon_{w,c} \):

\[
\dot{Q}_{\text{rad,Min}} = \frac{2 \times 6.67}{\varepsilon_{w,c}} \left( \frac{T_w^4 - T_c^4}{100^4} \right)
\]

Theoretical maximum of radiative heat transfer:

Pipe wall fully reflecting or \( L \to 0 \), arbitrary \( \varepsilon_{w,c} \):

\[
\dot{Q}_{\text{rad,Max}} = \frac{2 \times 6.67}{\varepsilon_{w,c}} \left( \frac{T_w^4 - T_c^4}{100^4} \right)
\]

Numerical investigation and model development
- Numerical simulations carried out with radiation module of ANSYS CFX
- Discrete Transfer Model (DTM) with surface-to-surface option
- Covered boundary conditions field:
  \[
  \frac{L}{D} = 1.50; \quad \varepsilon_{w,c} = 0.1; \quad \varepsilon_{p,w} = 0.1; \quad T_c = 4K; \quad T_w = 300K
  \]

Numerical model fitted by simulation results:

\[
\dot{Q}_{\text{rad,Mod}} = \dot{Q}_{\text{rad,Min}} + \left(1 - \frac{1}{\varepsilon_{w,c}}\right) \frac{\dot{Q}_{\text{rad,Max}} - \dot{Q}_{\text{rad,Min}}}{\varepsilon_{w,c}}
\]

Discussion of results and conclusions
- New model applicable to estimate radiative heat flux for different materials used in cryogenics
- Higher \( \varepsilon_{w,c} \) and \( \varepsilon_{p,w} \) involve higher maximum values for short pipes, but decrease of \( \dot{Q}_{\text{rad,Mod}} \) is larger with L/D
- Smaller \( \varepsilon_{w,c} \) and \( \varepsilon_{p,w} \) involve lower maximum values for short pipes, but decrease of \( \dot{Q}_{\text{rad,Mod}} \) is comparably small with L/D due to higher pipe wall reflection

Stainless steel pipes (L/D > 3) are more critical in terms of radiation in comparison to corroded copper.

However, no experimental investigation has been carried out, yet. Therefore, obtained results should be seen as an estimation of the expectable order of magnitude for \( \dot{Q}_{\text{rad}} \).