Methodology for Thermal and Dynamic Performance Comparison

Guy Harris CEO / CTO
June 2025

Executive Summary (Non-Technical)

This model compares two pipeline designs for transporting heated crude oil over long distances: one made of conventional steel, the other using lightweight composite pipe with GRP and PU foam insulation. The goal is to understand how much energy is lost as heat, and how much power is needed to keep the oil flowing. The model uses engineering principles to calculate temperature loss, pressure drop, and annual energy costs for pumping and reheating. Although some factors, like changing oil viscosity, are not yet included, the results show a dramatic reduction in energy use with the insulated GRP system. This document explains how the model works, what assumptions were made, and how the results compare to real-world pipeline systems.

	Steel System	HydroFoamer System	Delta	Saving
Diameter Pipe (m)	1.2	1.6		
Diameter Pipe (inch)	48	63		
Pipeline Length	50 km	31 miles		
Heating Costs (CAD)	CAD 93,600,000	CAD 72,000	-CAD 93,528,000	99.923%
Pumping Costs (CAD)	CAD 23,320,950	CAD 5,534,171	-CAD 17,786,779	76.270%
Total	CAD 116,920,950	CAD 5,606,171	-CAD 111,314,779	95.205%

1 Objectives of the Model

- Quantify and compare temperature loss over distance for both systems
- Quantify pressure drop due to friction
- Translate physical losses into annual energy demand and cost
- Explore how insulation affects energy needs in continuous operations

This model establishes a realistic baseline for decision-making. While precise viscosity behaviour is not yet modeled, thermal losses are calculated in full physical detail.

2 Key Assumptions

2.1 Flow Conditions:

- Volumetric Flow Rate (Q): 5.03 m³/s (from GRP DN1600 @ 2.5 m/s)
- Mass Flow Rate (ṁ): 4,146.9 kg/s (based on 825 kg/m³ crude density)

- Flow is assumed continuous, steady-state

2.2 Thermal Assumptions:

- Inlet temperature: 70°C
- Soil/ambient temperature: 20°C
- Segment length: 1 km (modeled as 50 segments)
- Heat loss is calculated per km, using local temperature for each segment

2.3 Thermal Conductivities:

- PU foam: 0.022 W/m·K
- GRP wall: 0.3 W/m·K
- Steel: 50 W/m·K
- External convective h (soil side): 10 W/m²·K
- Internal convective h (oil side): 300 W/m²·K (assumed turbulent)

3 Thermal Modeling Approach

Heat loss is calculated per segment using:

Step 1: Total Thermal Resistance (per metre)

- Steel System: R_total = R_oil-wall + R_steel + R_soil
- GRP + PU Foam System: R_total = R_oil-wall + R_grp + R_foam + R_soil
- Each resistance term is calculated using:

  R_convection = 1 / (h × A)

  R_conduction = ln(r_outer / r_inner) / (2πLk)

  Layer radii:

    Steel: r_in = 0.6 m, wall = 0.012 m

    GRP: r_in = 0.8 m, GRP wall = 0.018 m, PU foam = 0.1 m

Step 2: Heat Loss per Segment (1 km)

- q_i = (T_oil - T_soil) / R_total × 1000

Step 3: Temperature Drop per Segment

- $\Delta T_i = q_i / (\dot{m} \times c_p)$, where $\dot{m} = 4146.9$ kg/s, $c_p = 2100$ J/kg·K

4 Hydraulic Modeling (Pressure Drop)

Frictional pressure loss is modeled using Darcy-Weisbach:

- $\Delta P = f \times (L/D) \times (\rho v^2/2)$
- $f = 0.012$ (assumed turbulent)
- L = segment length (1000 m)
- D = internal pipe diameter (steel = 1.2 m, GRP = 1.6 m)
- ρ = crude oil density

Friction is calculated segment by segment, then accumulated across 50 km.

Note: Viscosity change with temperature is currently ignored. A fixed friction factor is used.1

5 Energy Calculations

5.1 Pumping Energy (continuous operation)

- Power = $\Delta P_{total} \times Q$
- Energy/year = Power × 8760 h
- Cost = Energy × $0.13 CAD/kWh

5.2 Reheat Energy (thermal losses)

- $\Delta T = T_{in} - T_{out}$
- $Q = \dot{m} \times c_p \times \Delta T$
- Energy/year = Q × 8760 h

6 Simplifications & Limitations

- The energy required to initially heat the crude and pipeline system from ambient to operating temperature ("cold start") is not included. While this energy can be significant—on the order of several GWh per full pipeline—this is a one-time cost per startup cycle. For continuous operations, its impact is negligible. For frequent shutdown scenarios, it should be included in future versions.
- Viscosity is fixed and does not respond to temperature changes
- Pumping efficiency not included (assumes ideal conversion)
- Always-on operation (no start/stop logic)

- Steel wall heat capacity is ignored
- No wax deposition or cold-flow assurance modeled

7 Why This Model is Valid

- Thermodynamic calculations follow engineering principles
- Radial heat transfer models are based on pipe geometry and material
- Energy and cost outputs match industry benchmarks

8 Caveats and Defence

- Viscosity and friction are simplified; more detailed models would increase pumping cost for steel
- Reheat logic assumes continuous heat loss without thermal buffering
- Electrical efficiency and pump mechanics are not included, but affect both systems equally
- Assumes standard soil contact; adjustment needed for sandy or waterlogged burial conditions
- Despite simplifications, all outputs match credible industrial systems in scale1

9 Sanity Check vs Industry Benchmarks

- Flow rate (~432,000 bbl/day) matches TransCanada/Enbridge trunk line scale
- Pumping power (~20.5 MW) matches 50–100 km segments in commercial lines
- Energy cost per barrel (~$0.73 CAD/bbl) is aligned with industry operating costs ($0.50–1.20)
- Thermal loss reduction with GRP+foam (~99.9%) matches district heating behavior (1–2°C loss over 50–100 km)
- All outputs are consistent with real-world designs for high-throughput buried pipelines

10 Next Steps

- Introduce temperature-sensitive viscosity for pumping energy
- Add CO_2 emissions and per-barrel energy metrics
- Model booster reheat/pump station strategies for 150–750 km extensions
- Build cost and capex/opex models for ROI and payback comparisons