Energy efficient thermal retrofit options for crude oil transport in pipelines

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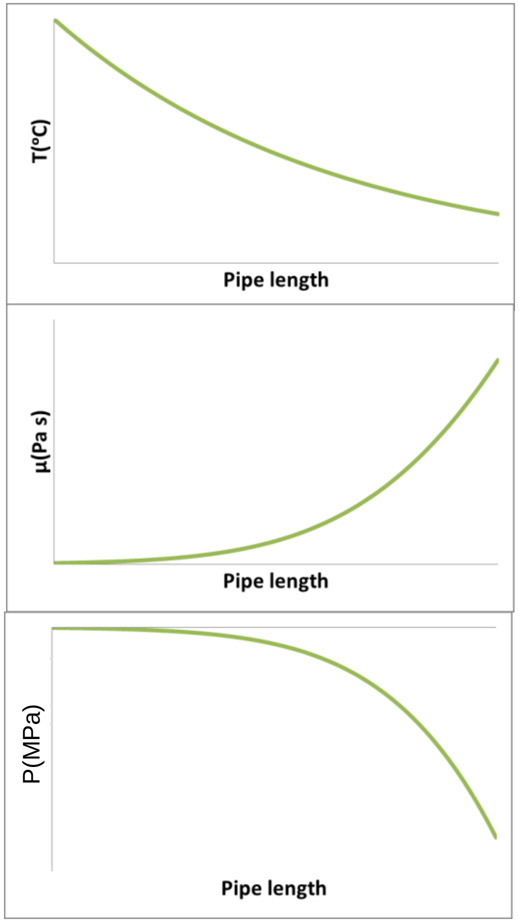
Oil transportation: Pipelines

- Most economic method for oil & gas transportation over land.
- Gradual depletion of conventional oil reservoir is leading to:
  - Remote locations
  - Unconventional oil (Heavy oil, tar sands…)

- Consequence:
  - Increased transport costs and technical difficulties

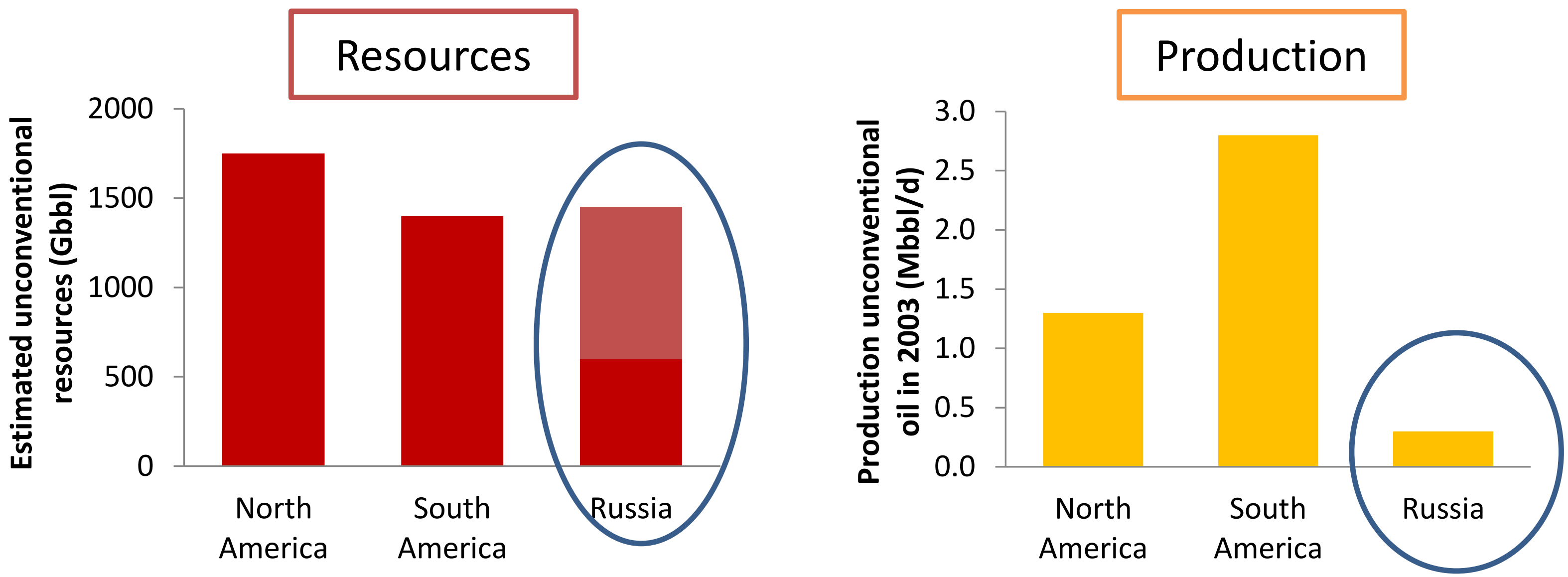
Pipeline design – Pressure Drop

- Pressure drop (ΔP) mainly depends on:
  - Friction
    - Viscosity: ↑μ→ ↑ ΔP
    - Throughput: ↑Flowrate→ ↑ ΔP
  - Ground elevation
- Thermal effects:
  - Viscosity increases exponentially with ↓T
  - Gradual cooling along pipelines:
    - ↑ΔP (& pumping cost)
    - ↓Flowrate; eventually flow inhibition
- Shift to <u>heavier oils</u> (↑μ)
  - Pipeline design/Drag Reduction Techniques
    - How likely is a shift to more viscous oils?



Unconventional Oil Resources

- ~ 50% of recoverable oil resources is unconventional (heavy oil, tar sands and bitumen) (IEA).
- ~ 87% of unconventional oil in Canada, Venezuela and Russia
- Russia has focused on production of conventional oil (1st World producer in 2011 (IEA)), but unconventional oil largely unexploited.



Ref. Saniere et al. Oil Gas Sci Technol. 2004

Russia Oil Pipeline Network

Huge pipeline network mainly developed for conventional oil.

China-Russia Pipeline

CRCOP	
Operation Mass flowrate Mtons/yr	15
Pressure (MPa)	8 to 10
Inner diameter (m)	0.7812
Depth buried (m)	1.5
Insulation (cm)	8
Heating	Unheated

Crude	ESPO
Origin	East Siberia
Type	light
API	34
μ (cP) @ 38°C	5.1
Pour point (°C)	-36

Conditions	
Winter T (°C)	-40
Inlet oil T (°C)	-6 to 10

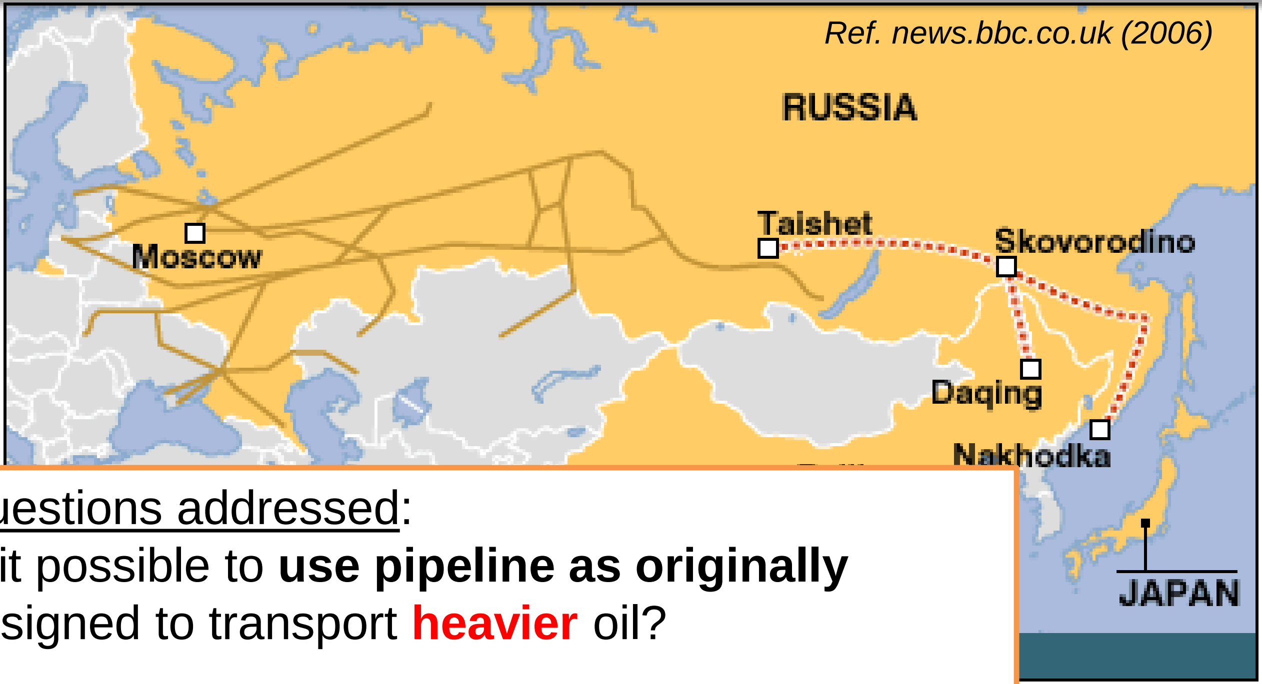
Eastern Siberia-Pacific Ocean (ESPO)

Ref. news.bbc.co.uk (2006)

http://www.rferl.org (2013)

Russia Oil Pipeline Network

Huge pipeline network mainly developed for conventional oil.
Challenge: Shift to heavier feedstock using existing infrastructure



<u>Questions addressed</u>:
Is it possible to **use pipeline as originally** designed to transport **heavier** oil?

What drag reduction strategy to use?

Drag Reduction Strategies

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Most widely used methods:

A. **Temperature conservation and heating**
  - Passive: insulation, burial
  - Active: heating (Continuous or Point Heating)

Pipe capacity fully used to transport oil

A. **Dilution with light hydrocarbons**
B. **O/W Emulsification**

Up to 30% of water or diluent: ↓ Throughput

C. **Others: drag reduction additive, low friction coatings, etc.**

Cost, Stability (under development)

Case study: Transport of Heavier Oils

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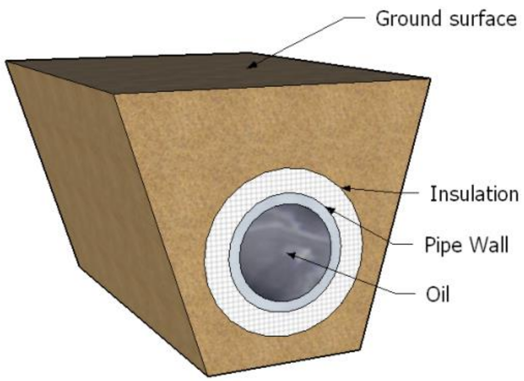
- Pipeline Section based on China-Russia Pipeline.
- Hypothesis: Shift to heavier feedstock
- To meet the max ΔP requirement:
  a) Reduction in throughput 🚫
  b) Drag reduction– enable transportation without ↓throughput

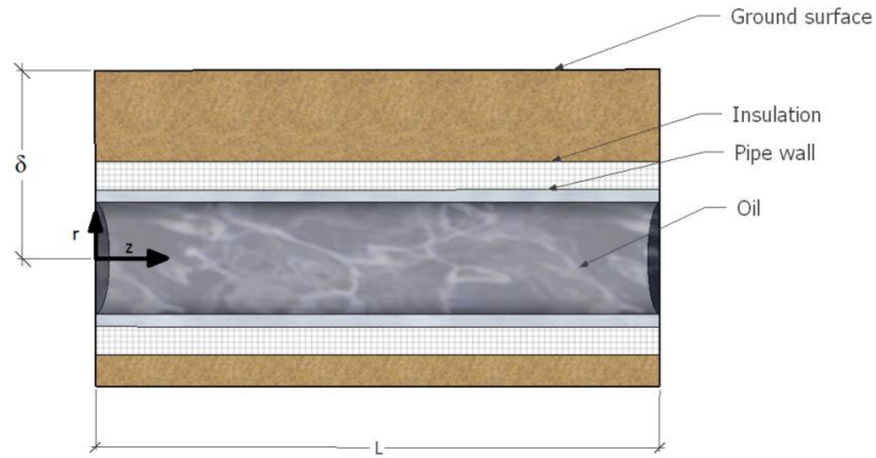
- Thermal strategy for drag reduction – Point heating:
  I. Passive (Insulation, burial)
  II. Heating at section inlet (processing terminal, pumping station – available resources)
  III. Point heating at intermediate locations between pumping stations
  – Constraint: Maximum allowable oil temperature: 90^{o}C

Modelling Approach

First-principles model for a buried, insulated pipeline

Evaluation of heat losses and ΔP along unheated pipeline sections





$-\frac{dP}{dz} = \frac{1}{2D_{w,i}} f\rho_{oil}{u_{oil}}^2 = \frac{4\tau_w}{D_{w,i}}$	$\pi\frac{{D_{w,i}}^2}{4}\rho_{oil}u_{oil}C_{p,oil}\frac{T_{oil}}{\partial z} = \pi D_{w,i}(-q''_{losses} + q''_{fricttion})$
$0 = \frac{1}{r}\frac{\partial}{\partial r}\left(r\lambda_{ins}\frac{\partial T_{ins}}{\partial r}\right)$	$q''_{env} = \frac{1}{R_{ins,o}\cosh^{-1}(\delta/R_{ins,o})}\lambda_{ground}\left(T_{ins}\Big\vert_{r=R_{ins,o}} - T_{env}\right)$
$\dot{m} = \pi R_{w,i}^2\rho u$	$Cp, \rho\mu, k\ f(\text{API}, \text{MeABP}, \nu_0, T)$

Case study: Transport of Heavier Oils

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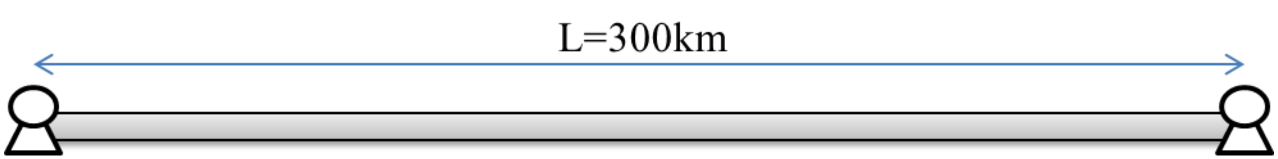
Definition of Pipeline Section

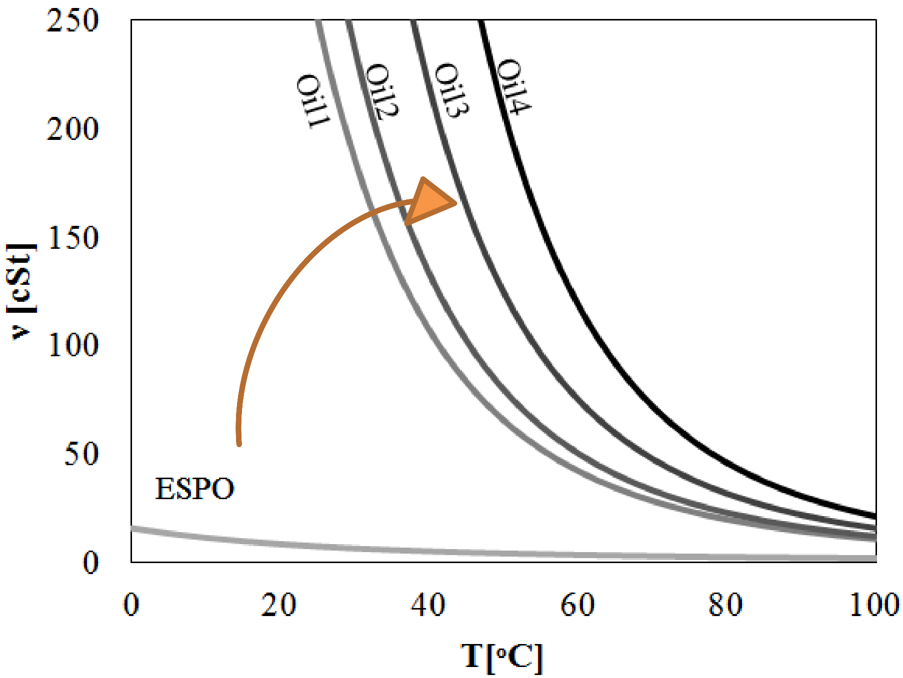
- Section of pipeline between two pumping stations
- Characteristics based on China-Russia Pipeline
- **Maximum ΔP** calculated based on:
  - ESPO crude oil (ν_{38^oC} = 5.11 cSt, very low viscosity)
  - Worst cooling conditions (T_{env} = -40^{o}C)
  - L = 300 km
  - Max. Flowrate = 15Mton/yr



ΔP_{max} = 4.8 MPa

Case study: Transport of Heavier Oils

Shift to heavier feedstock



Oil	API	ν_{38^oC} (cSt)
ESPO	34	5.1
1	24	120
2	22	150
3	20	250
4	18	450

Case study: Transport of Heavier Oils

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I. Insulation (√)

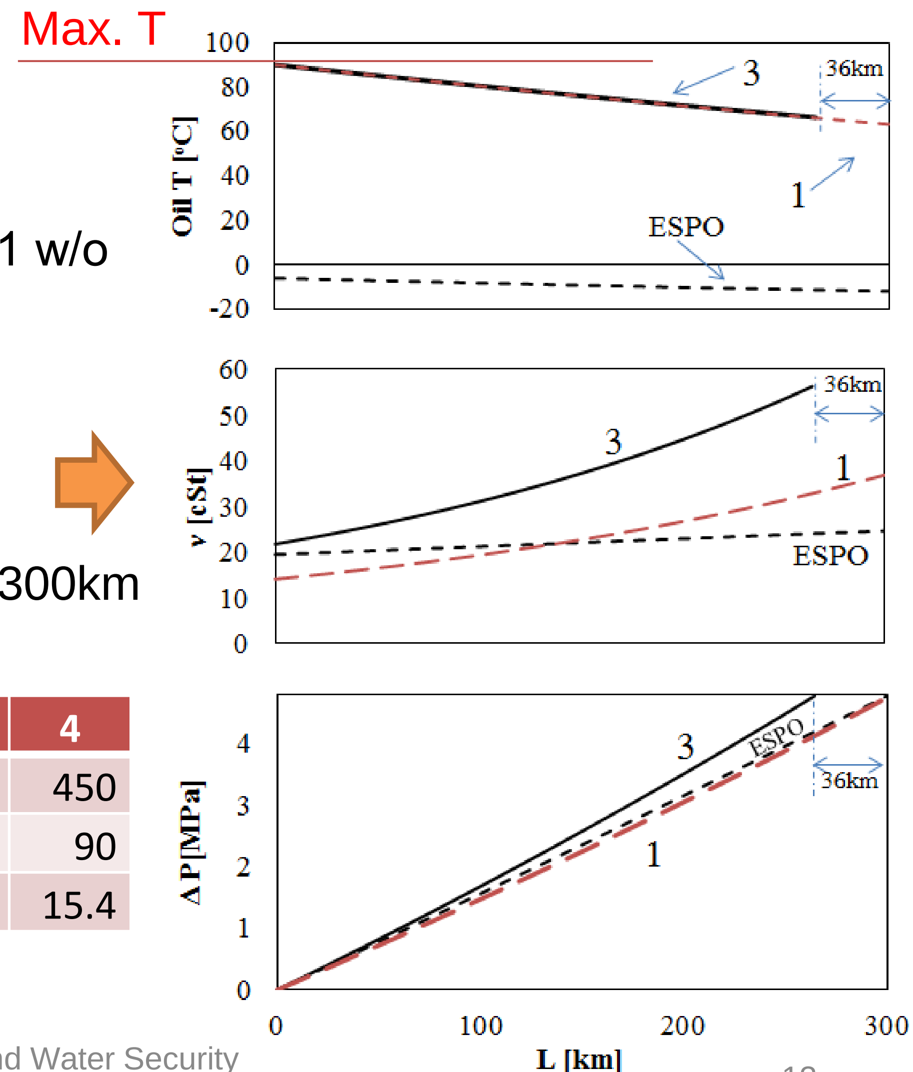
II. Inlet Heating (up to 90ºC)

- Enables transport for viscosity ≤ Oil 1 w/o ↓throughput.
- For more viscous oils: ↓throughput

E.g. Oil 3:

- ➢ 36 km short for full throughput
- ➢ 8.8% ↓throughput required to reach 300km

Oil	ESPO	1	2	3	4
$\nu_{38^\circ C}$ (cSt)	5.1	120	150	250	450
Inlet oil T [°C]	2	90	90	90	90
Throughput Loss [%]		0	2.7	8.8	15.4



Case study: Transport of Heavier Oils

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I. Insulation (√)

II. Inlet heating (√)

III. Intermediate heating

Decision variables:

- Number of heating stations
- Location
- Heat input in each station (ΔT)

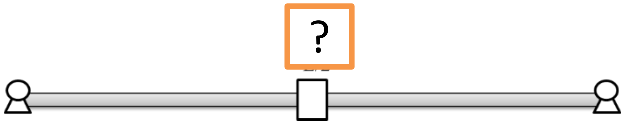
Constraints: Max Oil Temperature (90ºC)

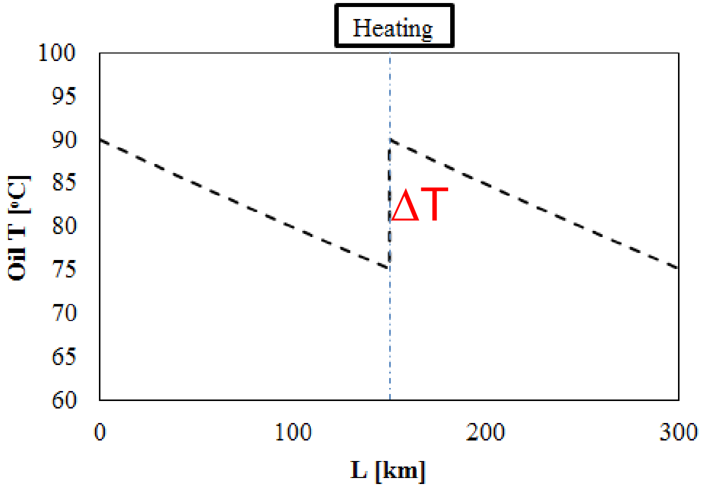
Objective:

- ➢ **Maximum throughput** ($)

whilst

- ➢ Minimum Heat Input (energy efficiency, $)
- ➢ Other considerations: Practicality, maintenance





Case study: Transport of Heavier Oils

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I. Insulation (√)
II. Inlet heating (√)

III. Intermediate heating

A. <u>Single Point Heating at Midpoint</u>

Example: Oil 3

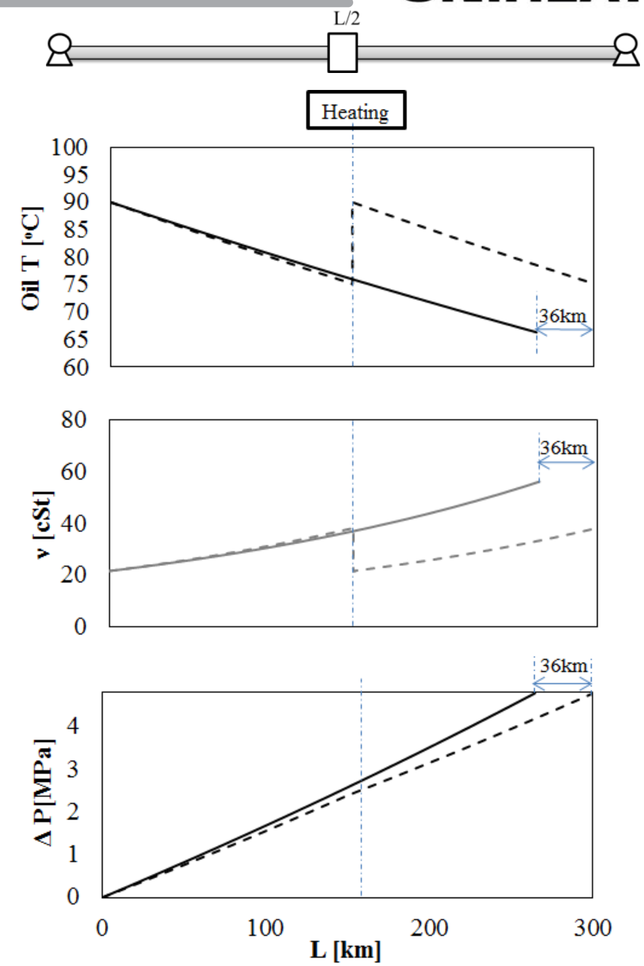
a) Inlet heating only:

8.8% throughput loss

b) Intermediate heating:

Oil re-heated to 90ºC (constraint)

4.5% reduction throughput loss



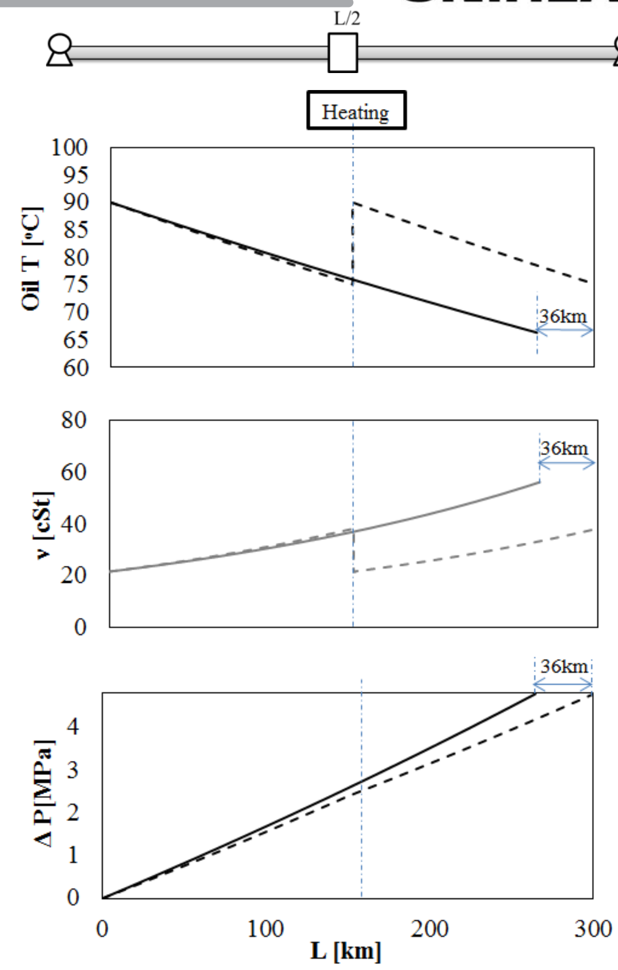
Case study: Transport of Heavier Oils

I. Insulation (√)
II. Inlet heating (√)

III. Intermediate heating

A. <u>Single Point Heating at Midpoint</u>

- Economic trade-off[1]
  + Savings in throughput
    Loss of 1% of throughput: $52.9MM/yr
  - Cost of heating
    Cost of increasing 10ºC: $2.7MM/yr (natural gas)
    + capital cost + maintenance



Subject to the cost of the heating technology, **cost of throughput generally dominant**

[1]IMF. Commodity Market Monthly; http://www.imf.org; February 12, 2015.

Case study: Transport of Heavier Oils

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I. Insulation (√)
II. Inlet heating (√)

III. Intermediate heating

A. Single Point Heating at Midpoint

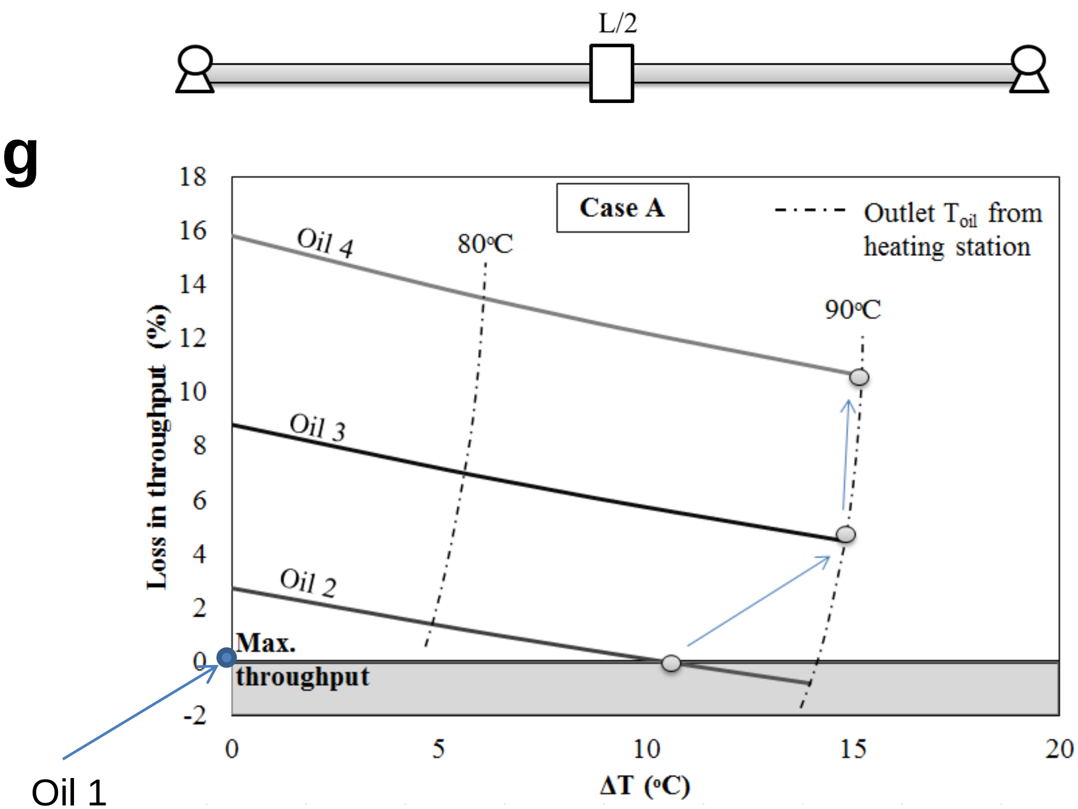
- Economic Trade-off:

  Throughput vs. Heat input

- Oil 2: Max Throughput by heating to ≈ 86ºC

  (room for further retrofit)

- More viscous oils:
  - Heat to 90ºC
  - Loss in throughput



-1% throughput = $52.9MM/yr
ΔT of 10ºC = $2.7MM/yr +

Case study: Transport of Heavier Oils

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I. Insulation (√)

II. Inlet heating (√)

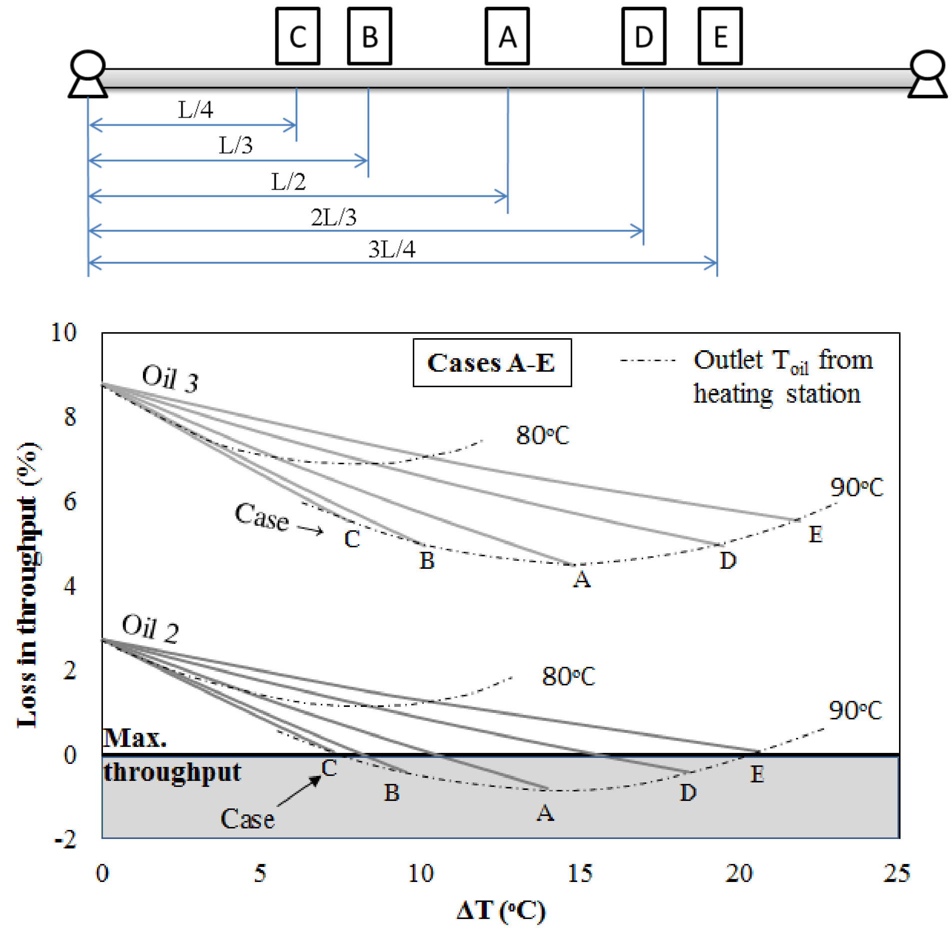
III. Intermediate heating

A. <u>Single Point Heating:</u>

<u>Optimal Location</u>

- Oil 2: Max Throughput and minimum ΔT
- More viscous oils:

  Optimal location for throughput near pipe midpoint



-1% throughput = $52.9MM/yr
ΔT of 10°C = $2.7MM/yr +

Case study: Transport of Heavier Oils

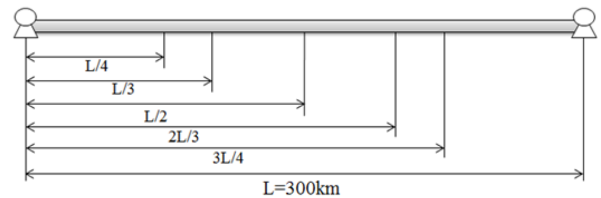
I. Insulation (√)
II. Inlet heating (√)

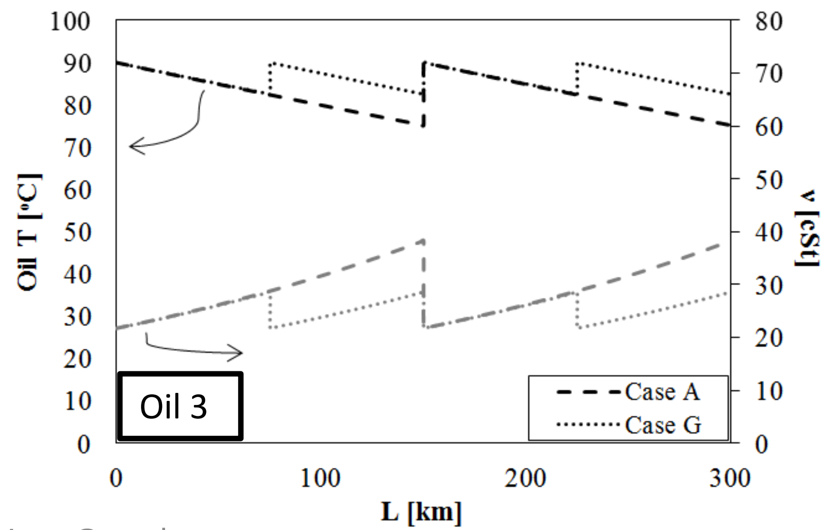
III. Intermediate heating

B. <u>Multiple Point heating</u>

- Uniform distribution along the pipeline (location and heat duty).
- Temperature maintained to higher values → ↓viscosity, ↓ ΔP

Case	L/4	L/3	L/2	2L/3	3L/4
A			ΔT		
B		ΔT			
C	ΔT				
D				ΔT	
E					ΔT
F		ΔT/2		ΔT/2	
G	ΔT/3		ΔT/3		ΔT/3





Case study: Transport of Heavier Oils

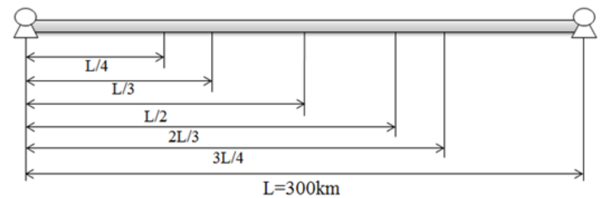
I. Insulation (√)
II. Inlet heating (√)

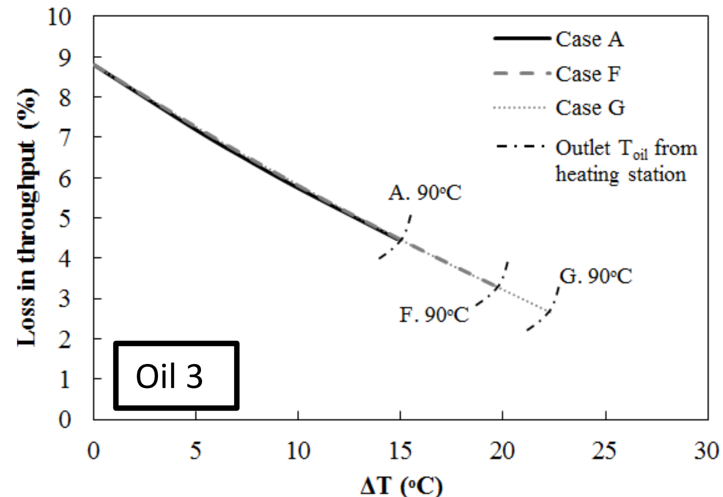
III. Intermediate heating

B. Multiple Point heating

- Same ΔT → same throughput as Case A (single heating, middle point)
- Permits greater heat input (ΔT) than single point heating (Max Oil T constraint).

Case	L/4	L/3	L/2	2L/3	3L/4
A			ΔT		
B		ΔT			
C	ΔT				
D				ΔT	
E					ΔT
F		ΔT/2		ΔT/2	
G	ΔT/3		ΔT/3		ΔT/3





Case study: Transport of Heavier Oils

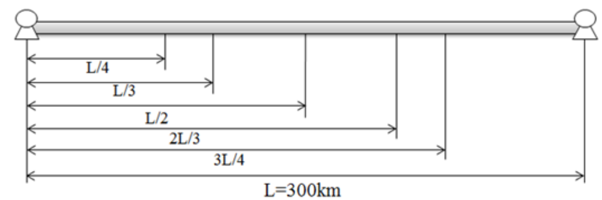
I. Insulation (√)

II. Inlet heating (√)

III. Intermediate heating

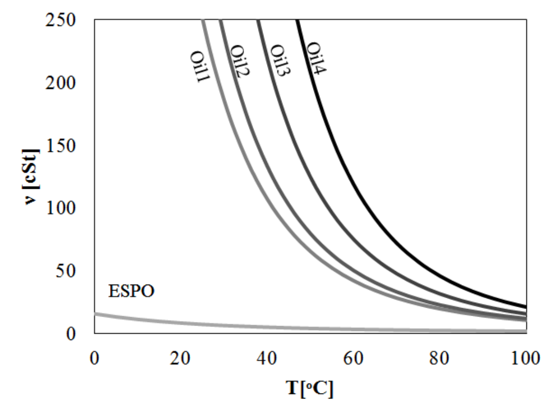
<u>Comparison</u>

Case	L/4	L/3	L/2	2L/3	3L/4
A			ΔT		
B		ΔT			
C	ΔT				
D				ΔT	
E					ΔT
F		ΔT/2		ΔT/2	
G	ΔT/3		ΔT/3		ΔT/3



Minimum throughput loss for various retrofit options:

Oil	1	2	3	4
No int. heating	0	2.7	8.8	15.8
1 int. Heating (A-E)	-	0	4.5	10.6
2 Int. heating (F)	-	-	3.3	9.2
3 Int. heating (G)	-	-	2.7	8.5

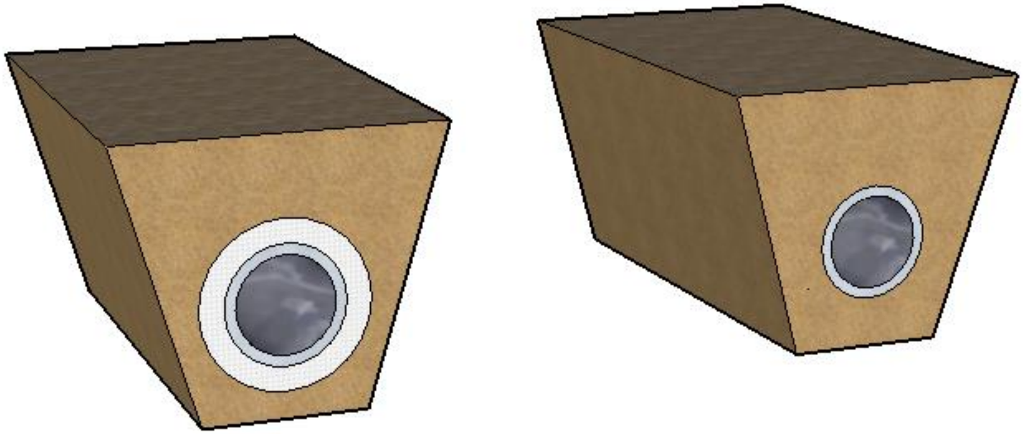


Case study: Transport of Heavier Oils

Importance of Insulation

<u>ESPO Oil, why insulation in actual design?</u>

- Insulated (actual) vs. non-insulated (still buried).



Case study: Transport of Heavier Oils

Importance of Insulation

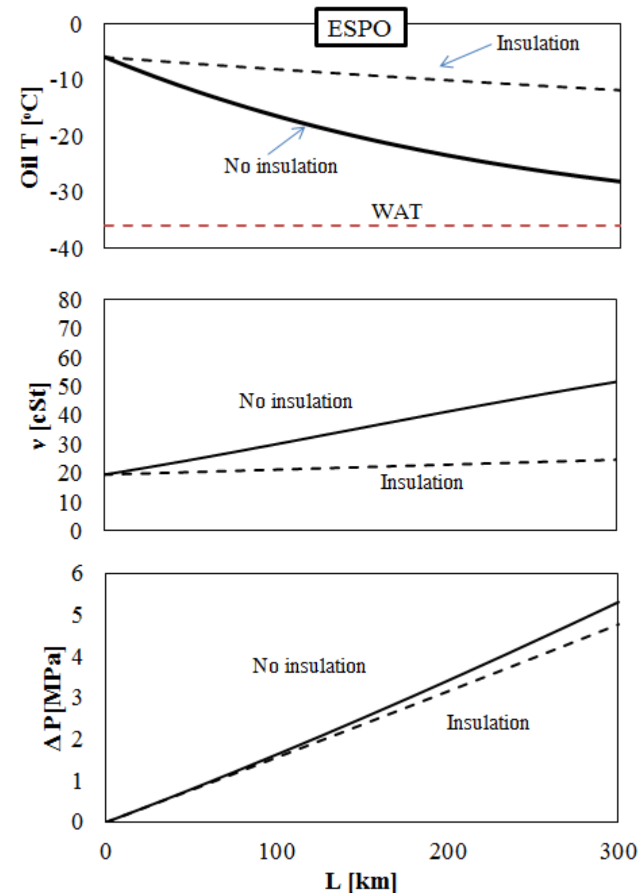
ESPO Oil, why insulation in actual design?

Non-insulated:

- Pressure drop is manageable (drag reduction not an issue)
- Oil T approaches wax appearance temperature (WAT)

Insulation ⇨ Flow Assurance (avoid deposition and blockage)

ESPO	
v_{38^oC} (cSt)	5.1
WAT	120

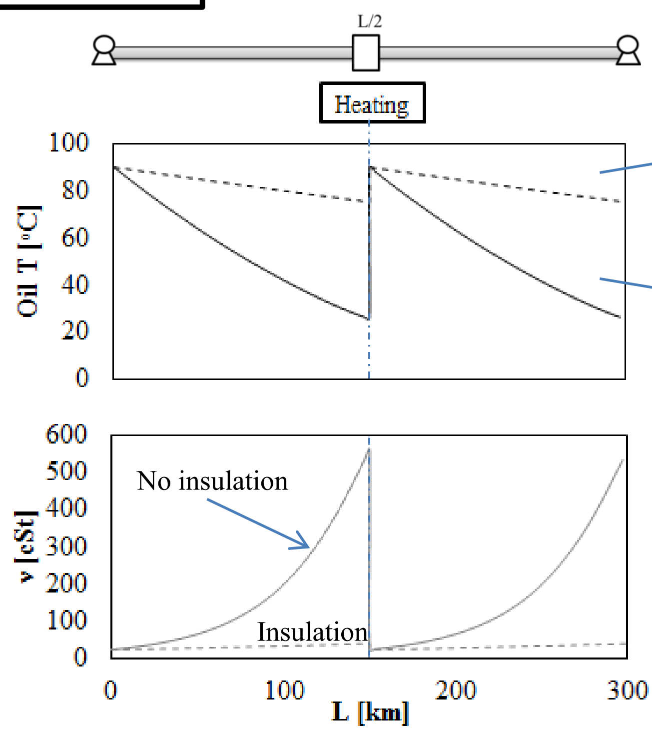


Case study: Transport of Heavier Oils

Importance of Insulation

<u>Retrofit for transportation of heavier oils</u>

Example: Oil 3



Insulation: 4.5% Throughput loss

No Insulation: **23.5%** Throughput loss

Non-insulated → Dramatic T drop:

↑↑ ΔT required

↓ Throughput

Case study: Transport of Heavier Oils

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Importance of Insulation

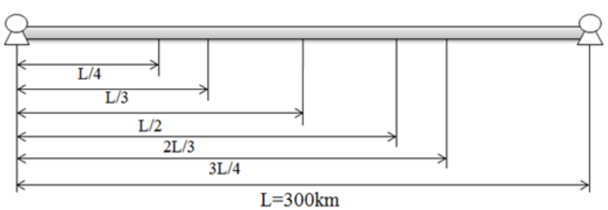
Thermal retrofits of heavier oils

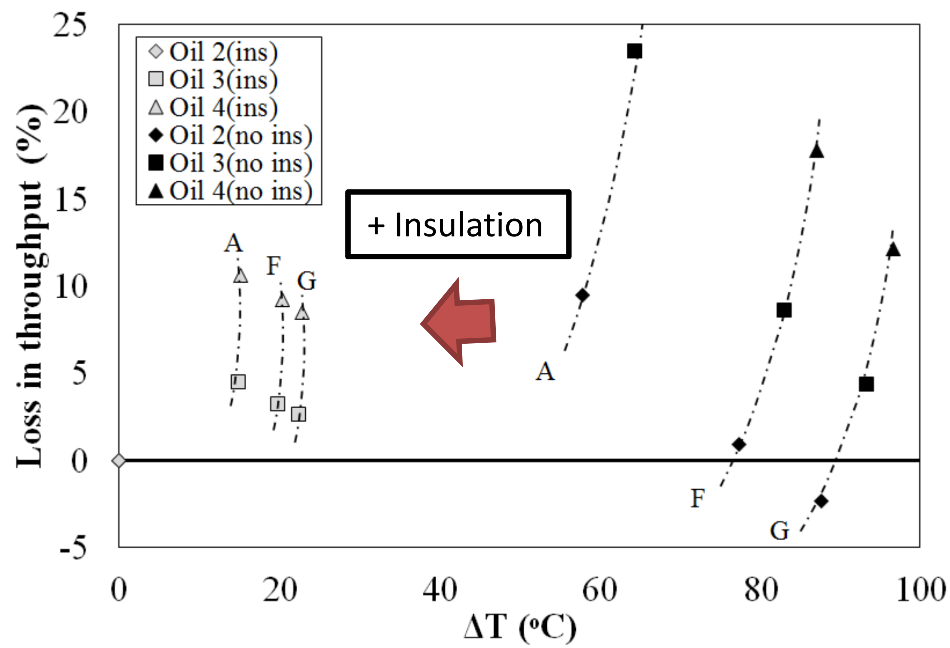
Non-insulated :

↑↑ ΔT required

↓ Throughput

Case	L/4	L/3	L/2	2L/3	3L/4
A			ΔT		
B		ΔT			
C	ΔT				
D				ΔT	
E					ΔT
F		ΔT/2		ΔT/2	
G	ΔT/3		ΔT/3		ΔT/3





Case study: Transport of Heavier Oils

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Importance of Insulation

Purpose of Insulation

ESPO → Flow Assurance

Heavier oils →
- Throughput savings
- Energy efficiency

Recommended in pipeline design for cold environments.

Conclusions

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- Point/Multipoint heating strategy can be used to retrofit existing pipelines, design for light oil, to transport heavy oil and minimize throughput losses.

- Best heating strategy depends on oil type.

  When carry out a retrofit:

  a) Look for optimal economic/energy design for the case on hand.

  b) Avoid bottlenecks that might limit application for heavier feedstock.

- Insulation recommended in initial design.

- For this method to be advantageous: Heating technology featuring:
  - Adaptable design (set-up, dismantling, retrofit).
  - Low capital cost.
  - Small impact on existing facilities.

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