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Research Paper

Enhancing the flexibility of pipeline infrastructure to cope with heavy oils: Incremental thermal retrofit

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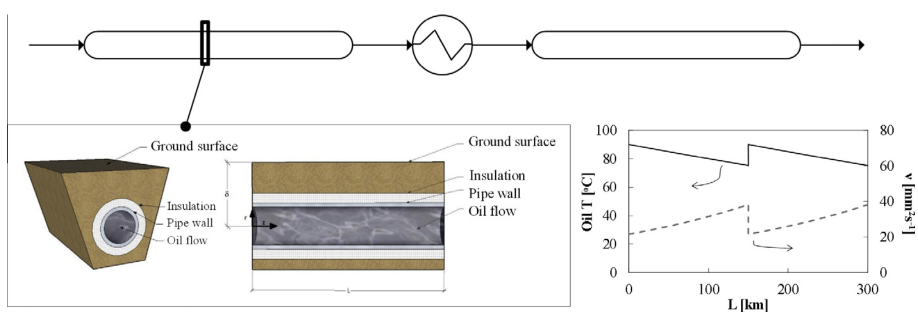
HIGHLIGHTS

- Intermediate heating proposed to adapt pipelines for transport of heavier oils.
- Viscosity is reduced and significant savings in throughput can be achieved.
- A flexible modelling framework to simulate oil pipelines is presented.
- Concept illustrated in a case study of a 300 km section of the Russia-China pipeline.
- Incremental addition and relocation of the heat duty using modular heating stations.

GRAPHICAL ABSTRACT



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ABSTRACT

Pipelines that were well designed for conventional oils may not be able to cope with a transition to heavy oils without some retrofit adaptation, as the increased pressure drop may exceed constraints and force some reduction in throughput. In this paper, ways of enhancing the utilization of existing, capital intensive infrastructure by small, incremental additions are explored. A thermo-hydraulic pipeline model for a buried pipeline is presented. The model is then applied to a case study involving a section of the important, recently built Russia-China ESPO pipeline, for which a gradual shift from the current (design) light oil to heavier oils is considered. A number of thermal retrofit scenarios are proposed and assessed which involve the incremental supply of additional heat at selected points. These scenarios go from pre-heating of the oil at entrance to use of single and multiple intermediate heating stations. The heating duty requirements for each case are calculated. The results show that a careful use of such thermal management techniques can significantly mitigate the reduction in throughput that would otherwise be required, leading to significant economic savings in operations. It is highlighted that the development of adaptable, modular low-cost heating technologies would make this approach significantly advantageous over other alternatives.

1. Introduction

Oil pipelines represent the most economical option to transport large amounts of oil over long continental distances. The hydraulic design of pipelines mainly takes into account pressure drop (ΔP)

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Nomenclature

API	API gravity
C_p	specific heat capacity, J kg^{-1} K^{-1}
e	specific enthalpy, J kg^{-1}
ESPO	Eastern Siberia-Pacific Ocean
f	friction factor, –
h	convective heat transfer coefficient, W m^{-2} K^{-1}
HS	heating station
L	pipeline length, m
MeABP	mean average boiling point, °C
$\dot{m}$	mass flowrate, kg s^{-1}
P	pressure, Pa
Q	heat duty, W
q''	heat flux, W m^{-2}
R	radius, m
r	radial coordinate, m
T	temperature, K
t	time, s
u	linear velocity, m s^{-1}
z	axial coordinate, m

Subscripts

env	environment
fr	friction
gr	ground surrounding the pipeline
i	inner
in	inlet
ins	insulation
j	pipeline module number
losses	losses through pipe inner surface
max	maximum
o	outer
out	outlet
vol	volume
w	pipeline wall

Greek letters

ΔP	pressure drop, MPa
ΔT	temperature increase between pipeline modules, °C
δ	distance ground surface to pipe centre, m
ρ	density, kg m^{-3}
λ	thermal conductivity, W m^{-1} K^{-1}
ν	kinematic viscosity, mm^2 s^{-1}
$\nu_{38\,°C}$	kinematic viscosity at 38 °C, mm^2 s^{-1}
τ_w	wall shear stress, N m^{-2}

due to friction and ground elevation. Relevant design variables include throughput, operating temperature, environmental conditions and fluid properties expected in the foreseeable future [1]. Viscosity, which varies inversely with temperature, is the key physical property for design, determining line size, pumping stations spacing and required pumping capacity (hence capital and operating costs). The pressure drop by friction increases with decreasing temperature (due to increase in viscosity), and decreases with flowrate (except for very low throughputs, as in the case of very viscous oils [2]). Therefore, the maximum distance between pumping stations heavily depends on the flowrate and the viscosity (hence on temperature) of the fluid being transported and heat losses along the pipeline.

Depletion of conventional oil reservoirs is gradually leading to extraction of heavier oils. These oils are generally characterized by higher viscosity, density and content of heavy metals, nitrogen and sulfur [3,4]. It is estimated that more than half of the recoverable oil resources are unconventional, with about 57% of those being some type of heavy or viscous oil [5]. In addition, the depletion of conventional sources is also leading to extraction in remote locations, many of them in cold regions (Alaska, Canada, Russia, deep oceanic waters) and even Arctic locations, where pipelines are seasonally or permanently exposed to extreme cold conditions. Under those conditions, viscosity increases due to gradual cooling along the line and application of drag reduction methods may be required for very viscous oils.

The main techniques for drag reduction involve viscosity reduction [2–4]: thermal (heating), dilution, and water emulsion. Emulsion and dilution reduce viscosity by adding up to 30 vol% of water or other diluent, which lead to reduced oil throughput and require additional auxiliary facilities. Other alternatives, such as core annular flow, internal coatings, and drag reduction agents, represent promising technologies for cold flow transportation, but are still costly, and may present stability issues or limited applicability depending on the oil composition. Further development is required for most of those alternative technologies [4].

Thermal methods, on the other hand, are widely proven and permit fully using the pipeline capacity to transport oil, but require local or continuous heating. A typical heating strategy consists of maintaining the high temperature at which oil is produced and introduced into the pipeline by applying insulation (passive strategy, e.g. insulation layer, burial) and, in most cases, reheating at later locations. Examples of existing heated pipelines are Alyeska in Alaska [3], Chad-Cameroon [6,7] (both with heating at pumping stations) and Mangala in India (with continuous heating along the entire length of the pipeline) [8].

Most drag reduction methods are conceived to be installed in new facilities. However, not many are suitable to retrofit existing infrastructures. In fact, although thermal strategies are generally considered viable for long, insulated pipelines with heating provided at pumping stations, recent works indicate that the development of new technologies applicable at intermediate locations can lead to significant increase of the length between pumping stations [7], reducing the high capital cost of pipeline infrastructures. In this paper, intermediate point heating is considered as the means to adapt existing pipelines to transportation of heavier feedstock, with the objective of minimizing the loss in throughput.

About 87% of all unconventional oil resources, including tar sands, bitumen, heavy and extra-heavy oil, are located in Canada, Venezuela and Russia. The exploitation of these hydrocarbons is commercially well advanced in Canada and Venezuela. On the other hand, oil production in Russia in the past decades has been focused on light oils, and heavy oil and bitumen reserves remain almost unexploited [3]. As conventional sources deplete, this is inevitably leading to a shift in oil quality, with viscous oils becoming more important in the coming years. Russia has developed a huge pipeline network to export crude oil from Siberia and the Urals to Europe and to the Far East [9]. Export to the Far East has been recently achieved with the finalization of the Eastern Siberia–Pacific Ocean (ESPO) pipeline, providing an alternative exportation route with great economic and geopolitical importance [10,11]. This pipeline allows transportation to Japan, Korea and especially to China, where oil can now be massively exported through the 953 km pipeline branch recently constructed between Skovorodino (Russia) and Daqin (China) [12]. This is an example of a new costly and long unheated pipeline through remote locations,